Pulsars and GLAST: Observational Perspective

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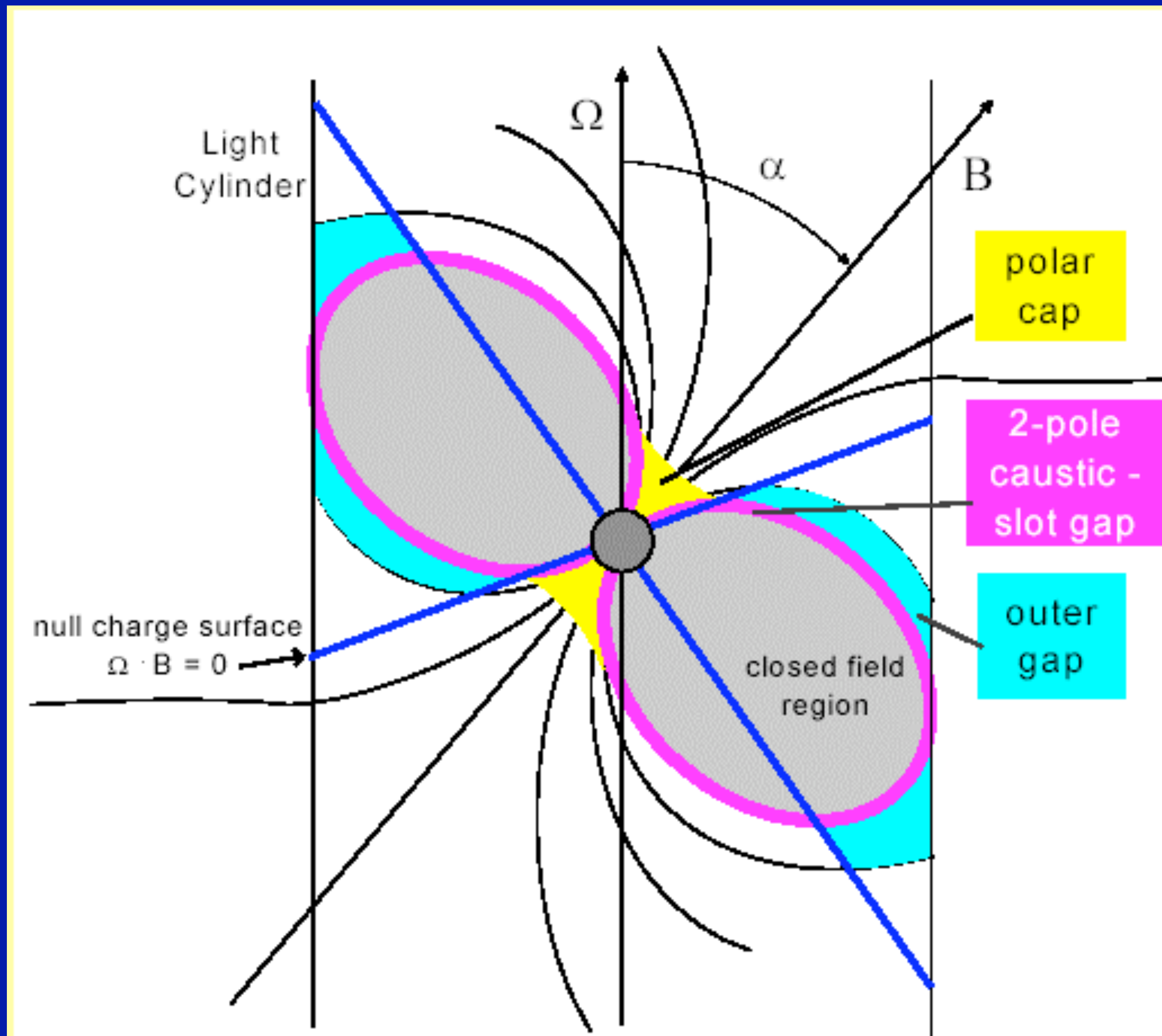
Overview

- Why pulsars?
- What did we know in 1995, post EGRET ?
- What do we know today ?
  - And what we still don't know
- Expectations from GLAST
  - What will we see and what will we learn ?
- Radio timing for the GLAST mission
  - Why radio timing is crucial for GLAST success

Pulsar Science

- Huge electric fields, capable of accelerating charges up to TeV energies are present in pulsar magnetic fields
- The radio emission is highly coherent (T_b up to 10^{40} K) but is only a tiny fraction (10^{-5}) of the energy budget
  - It is rich in phenomenology
  - But still very poorly understood
- Gamma-ray pulsations do not require a coherent mechanism; accounts for 50% of the spin down energy
  - Physics is more tractable
  - Location of the γ-rays not yet understood
- GLAST will detect many more pulsars, have better pulse profiles, and better spectral resolution.
  - Should answer some of these fundamental questions

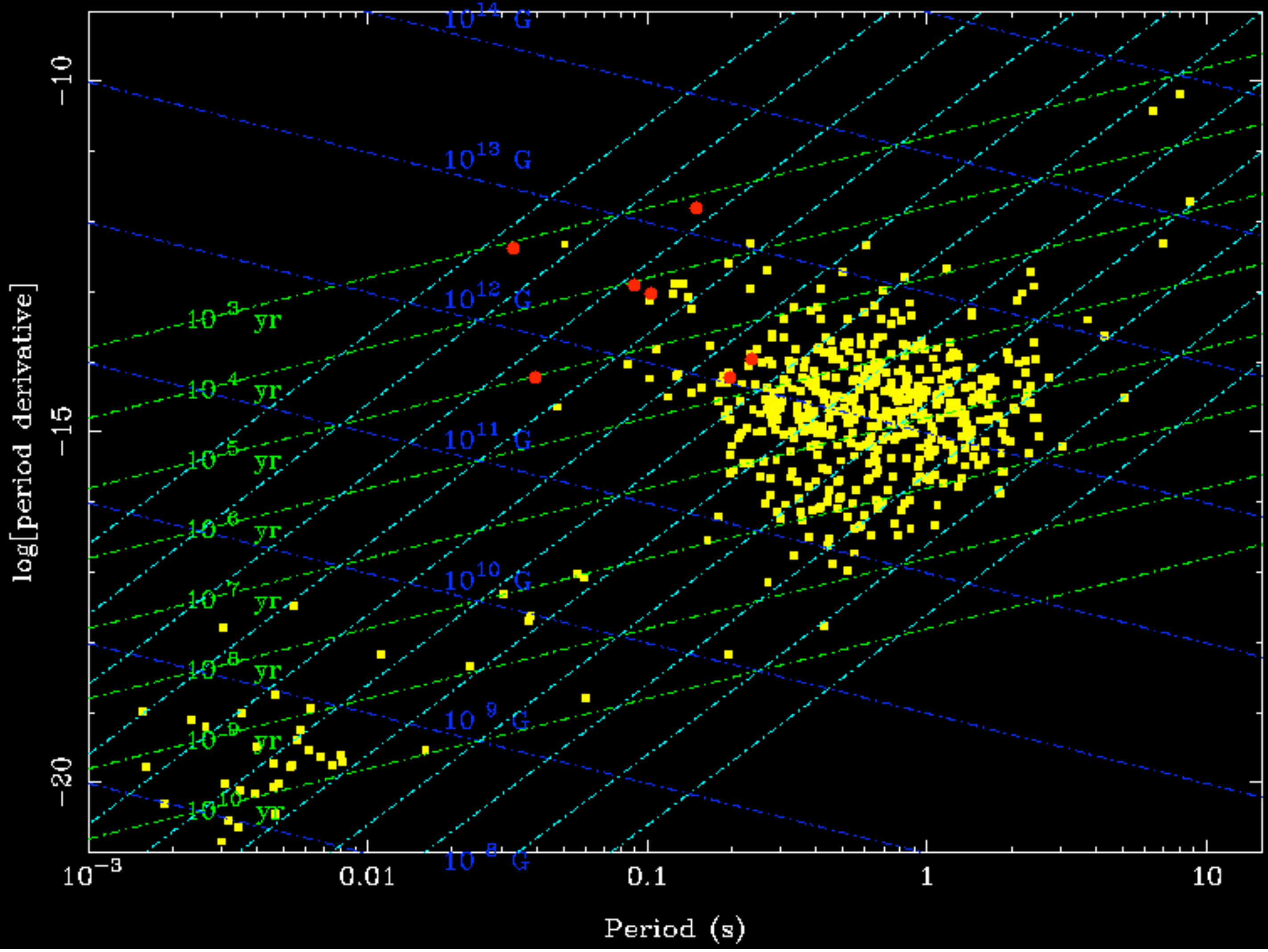


Light
Cylinder
Ω
α
B
polar
cap
2-pole
caustic -
slot gap
outer
gap
null charge surface
Ω · B = 0
closed field
region

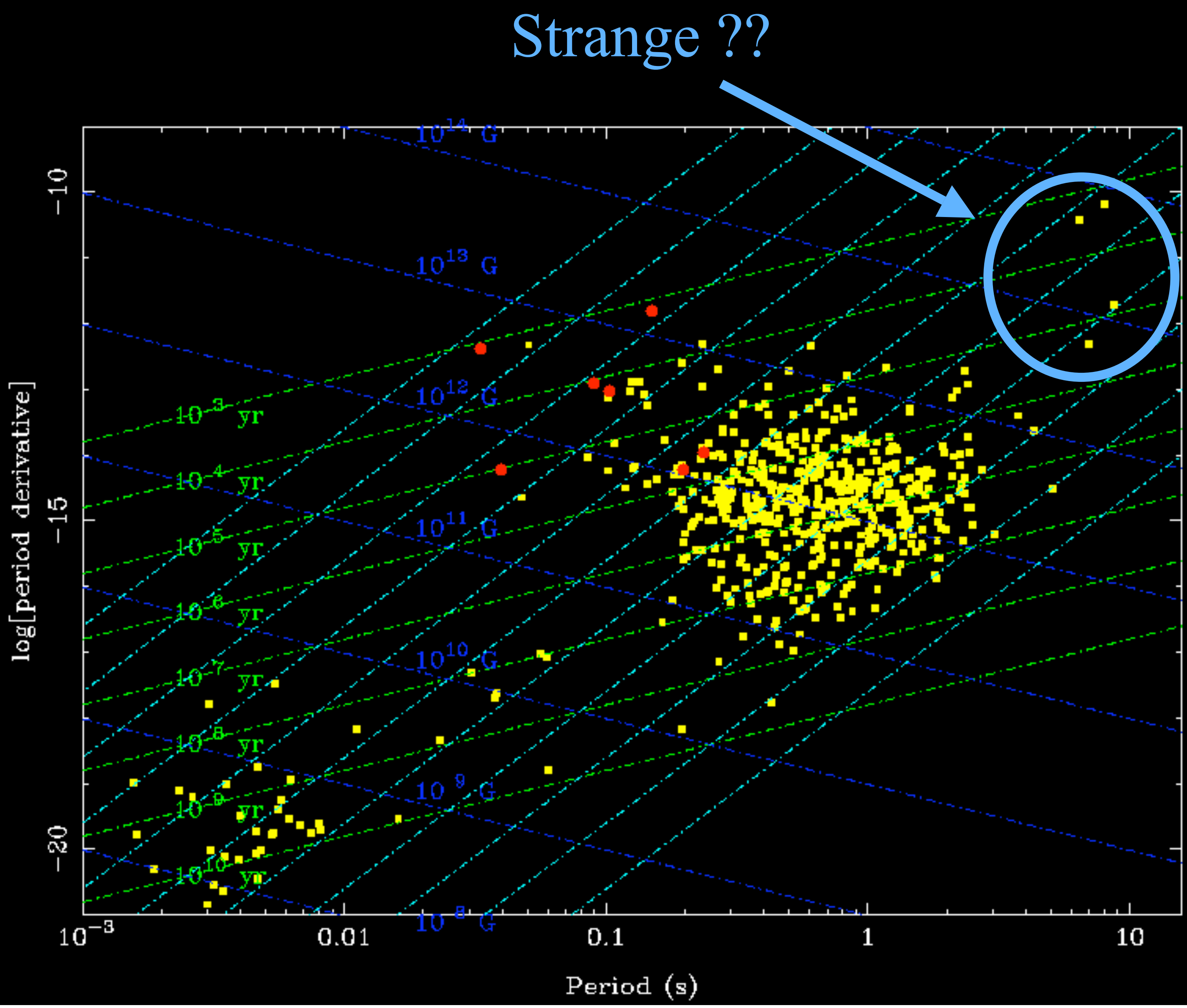
State of play in 1995

- 600 radio pulsars known
- 20 pulsars with periods less than 10 ms
- 7 rotation powered pulsars at high energy
- Handful of pulsar wind nebulae
- ~~Most/all neutron stars at birth had B~10^{12} G and P~20ms~~
- ~~Young pulsars = radio luminous~~
- ~~Crab only pulsar with giant pulses~~

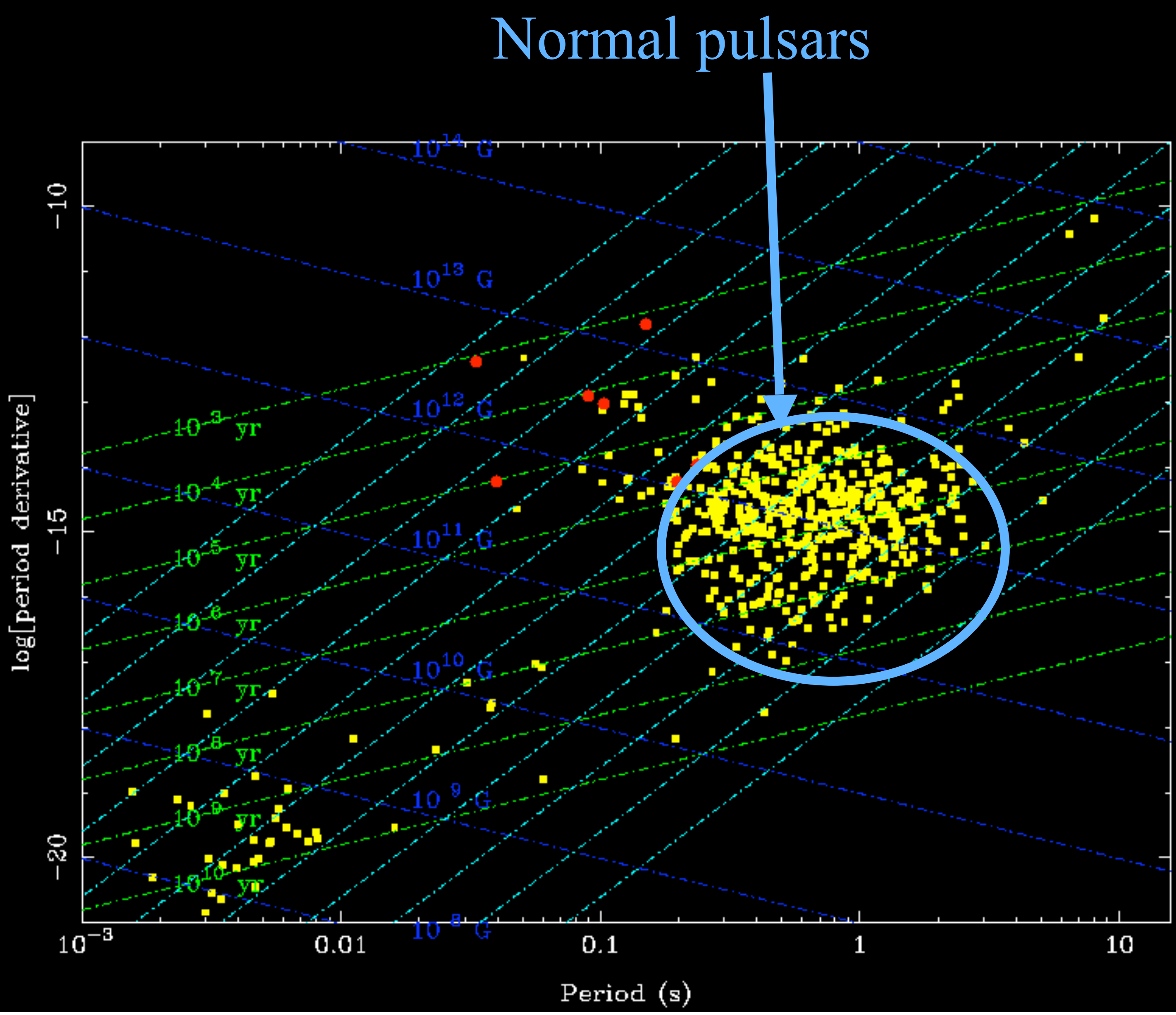
The Pulsar P-Pdot Diagram - 1995



The Pulsar P-Pdot Diagram - 1995

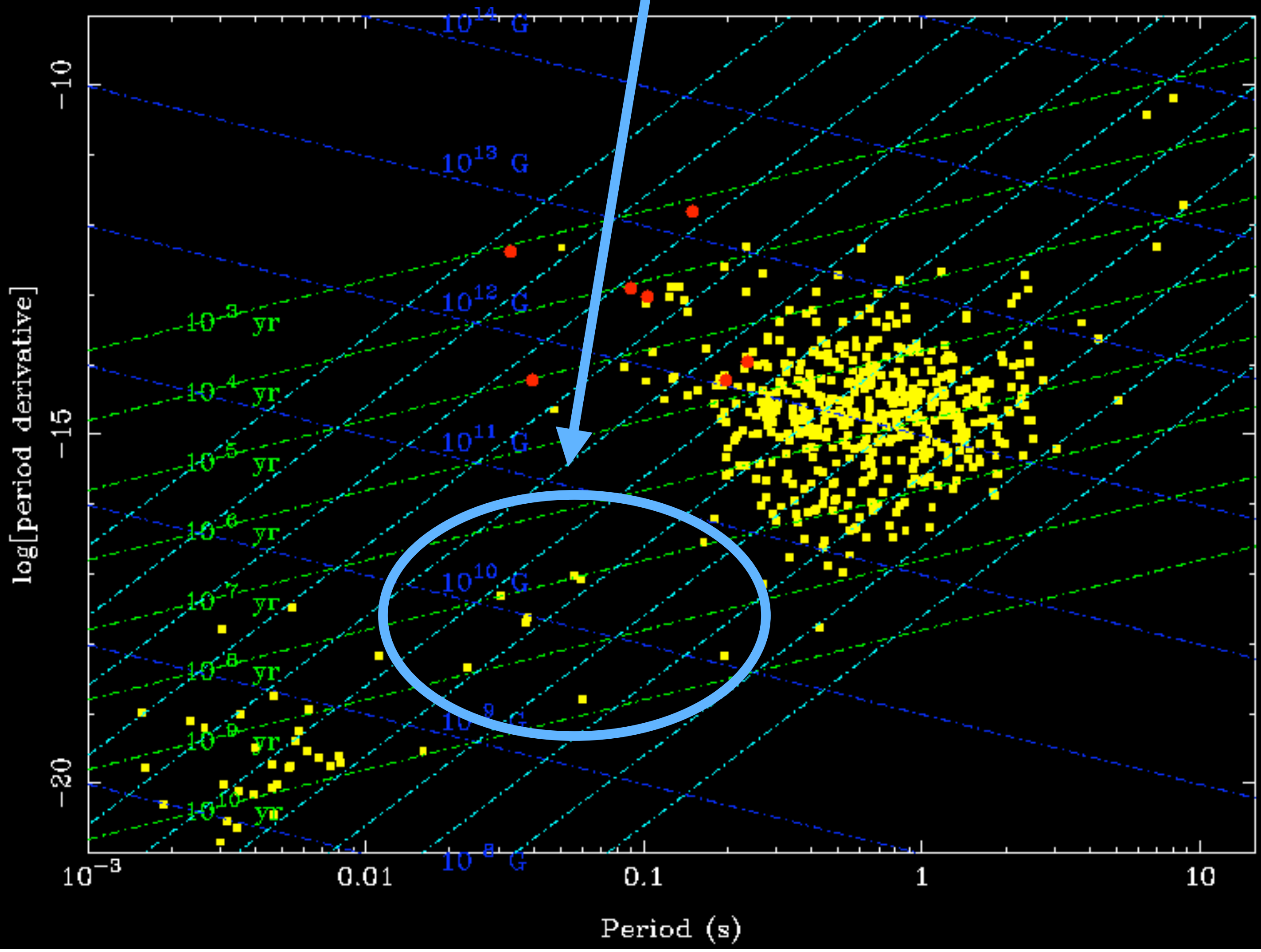


The Pulsar P-Pdot Diagram - 1995

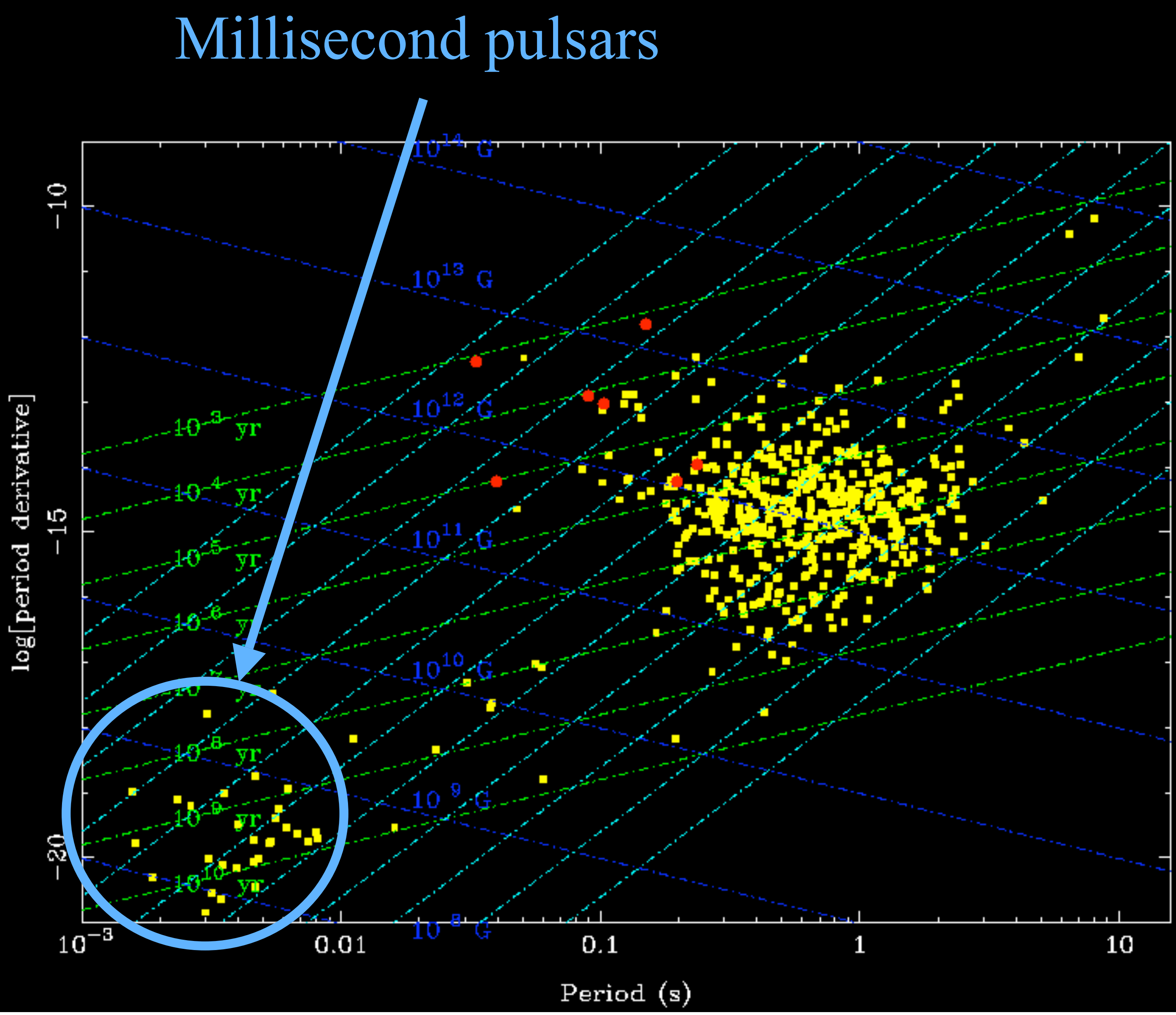


The Pulsar P-Pdot Diagram - 1995

Binary NS-NS systems

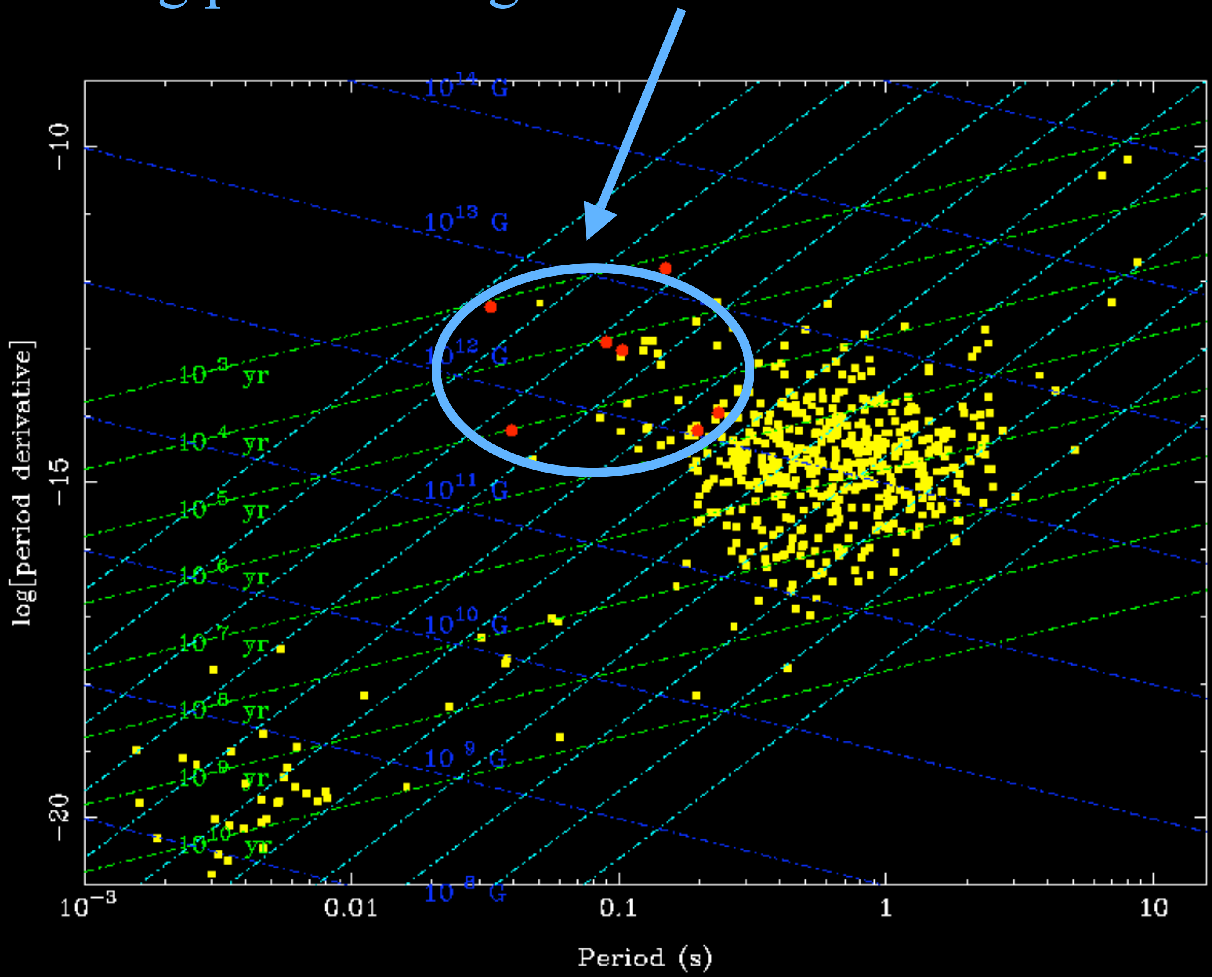


The Pulsar P-Pdot Diagram - 1995

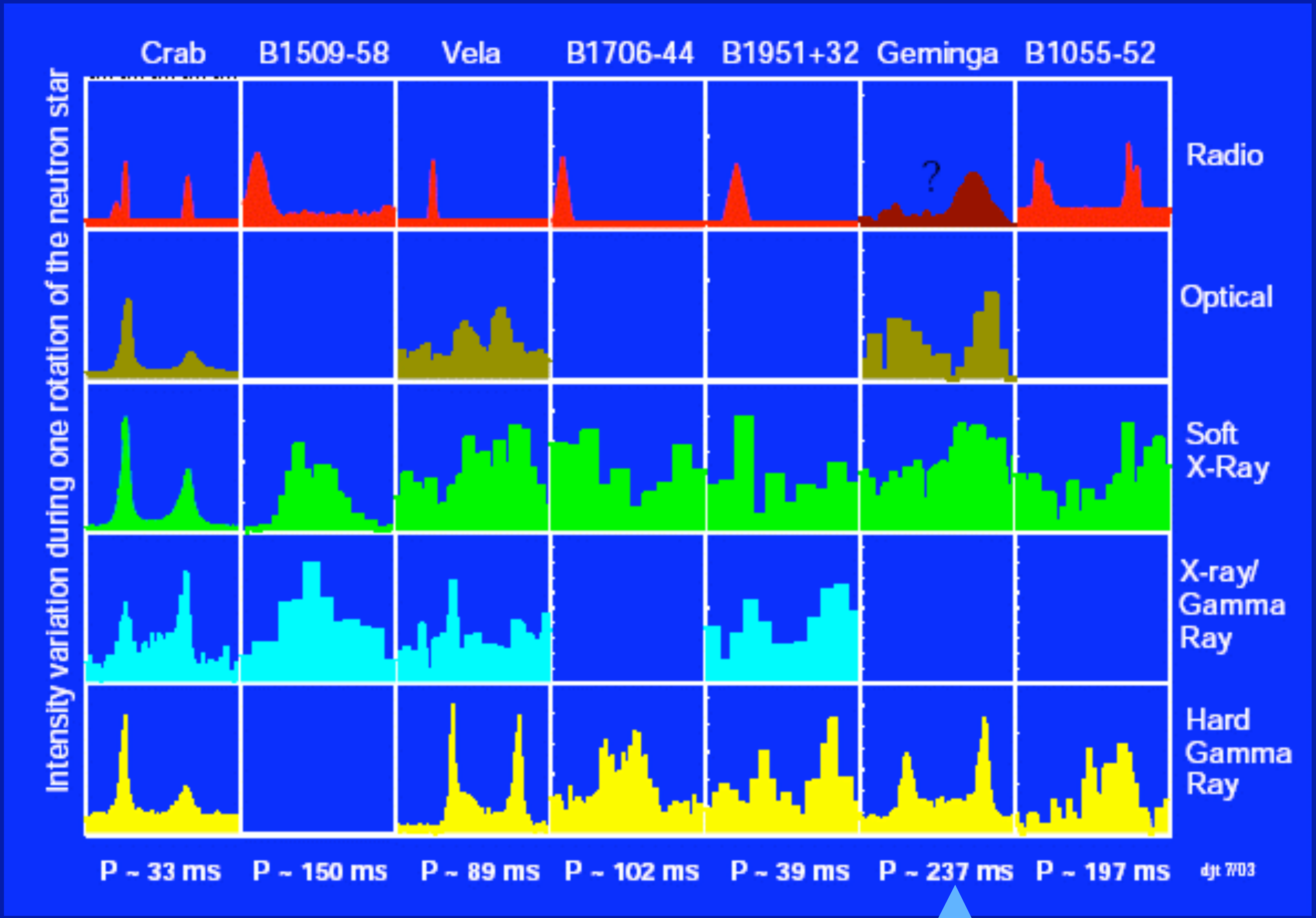


The Pulsar P-Pdot Diagram - 1995

Young pulsars - high Edot - EGRET detected



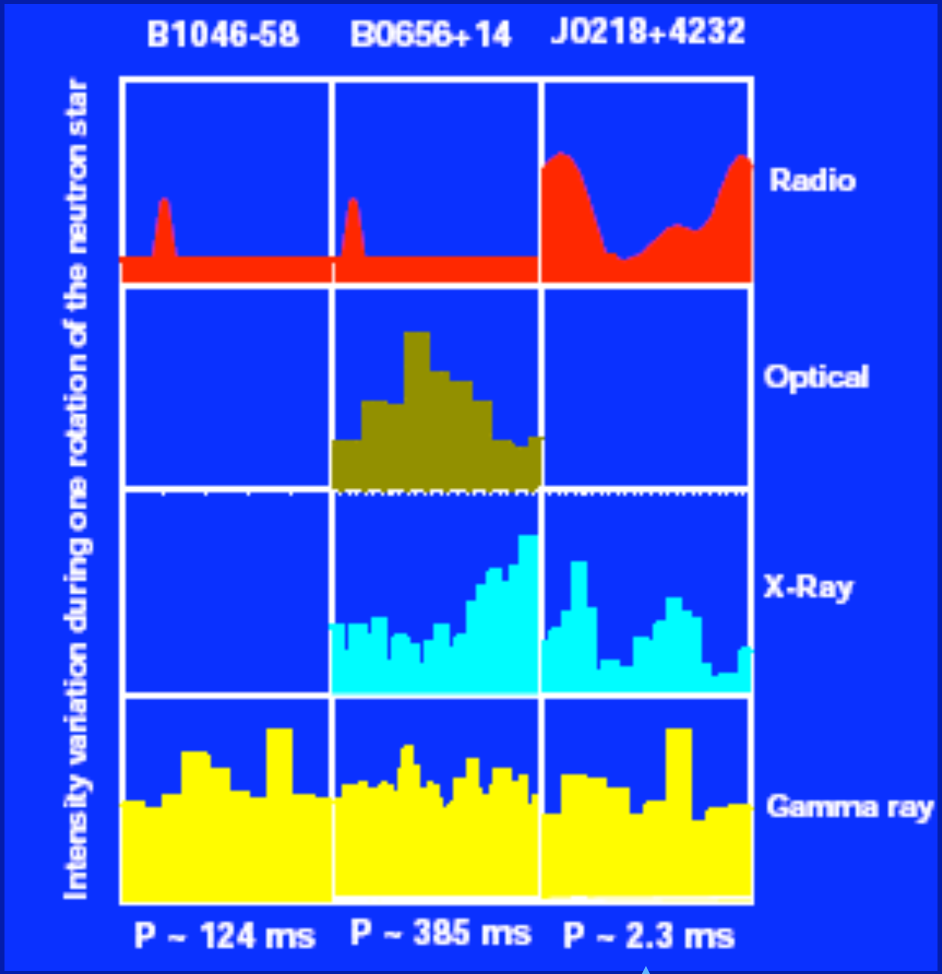
The EGRET detections



Dave Thompson's famous plot

Geminga

The EGRET candidates



MSP

EGRET UIDs

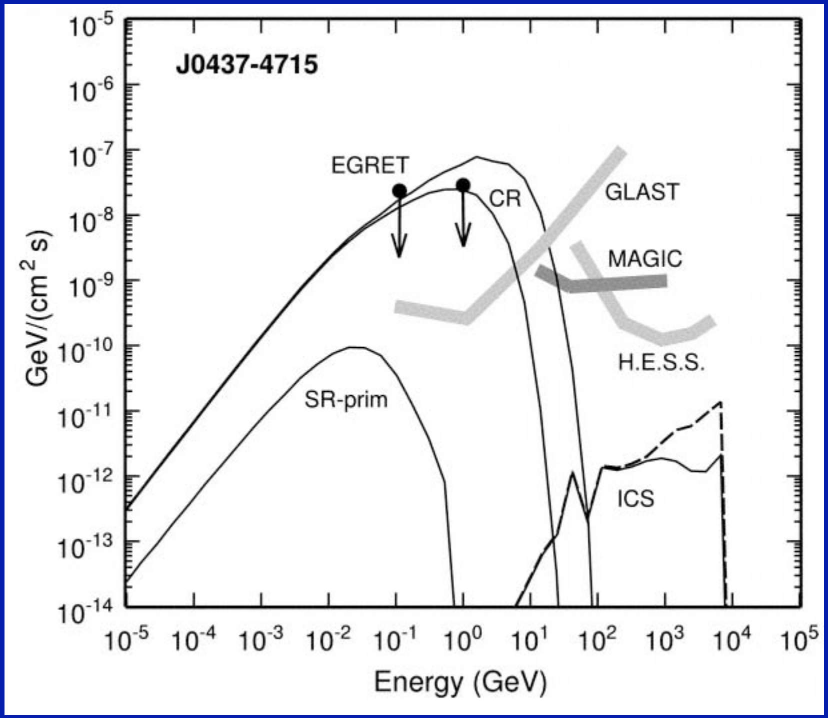
56 mid latitude boxes searched - no good pulsars (Crawford et al. 2006).

Low latitude pulsars: 6-8 very good candidates since EGRET (Roberts 2003).

Cannot extrapolate ephemeris backwards to check for pulsations so it is still unclear whether the EGRET source is the pulsar or the associated wind nebula / SNR.

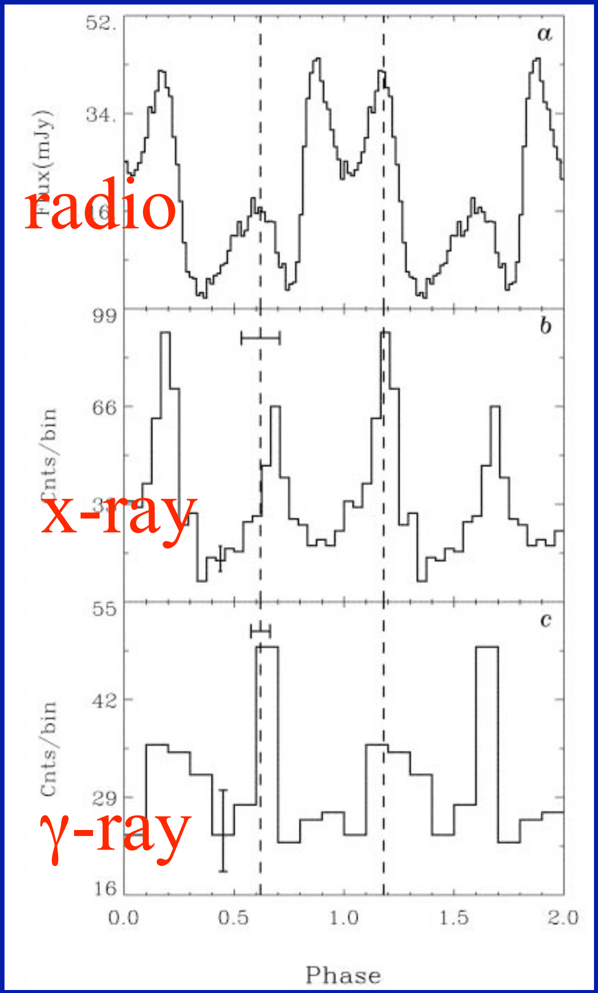
The first γ-ray millisecond pulsar?

In spite of their age, some MSPs have spin down energies comparable to that of young pulsars and are predicted to be γ-ray emitters in many models.

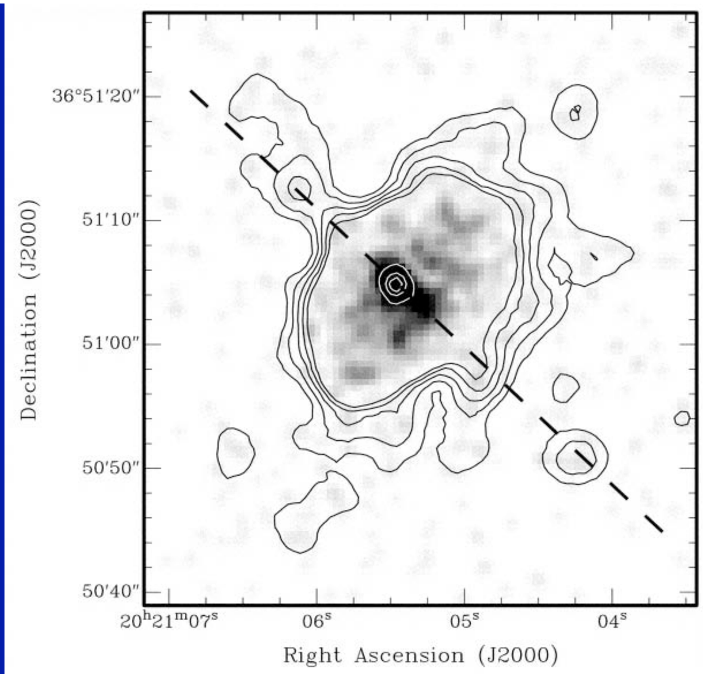


Harding et al. 2005

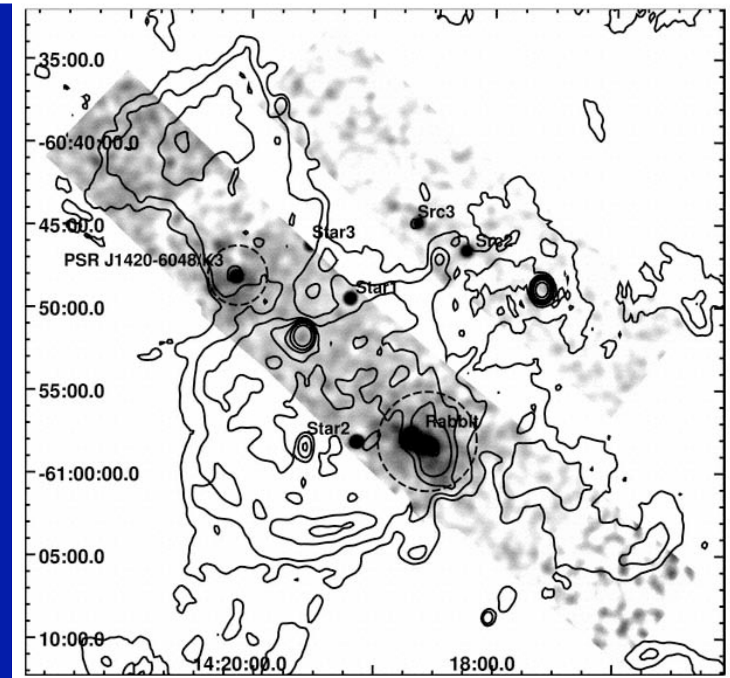
J0218+4232



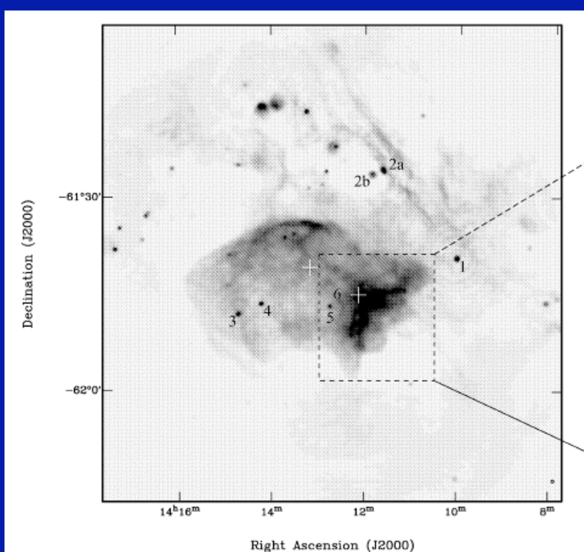
Kuiper et al. 2002



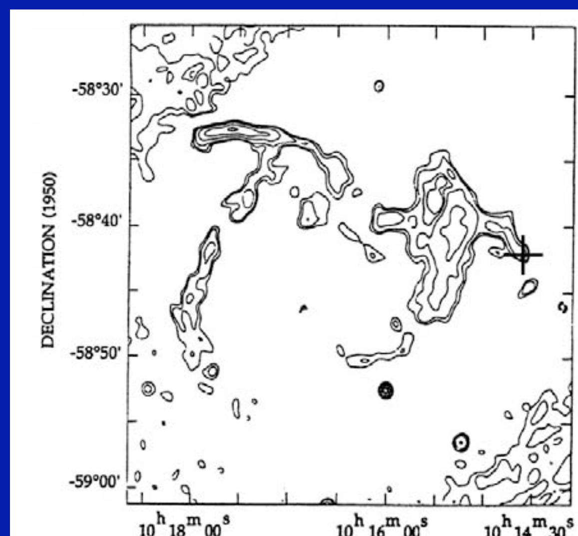
2021+3651 (Hessels et al.)



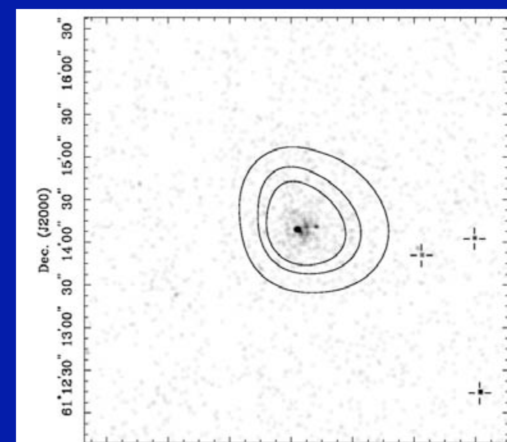
1420-6048 (Roberts et al.)



1412-6145 (Doherty et al.)

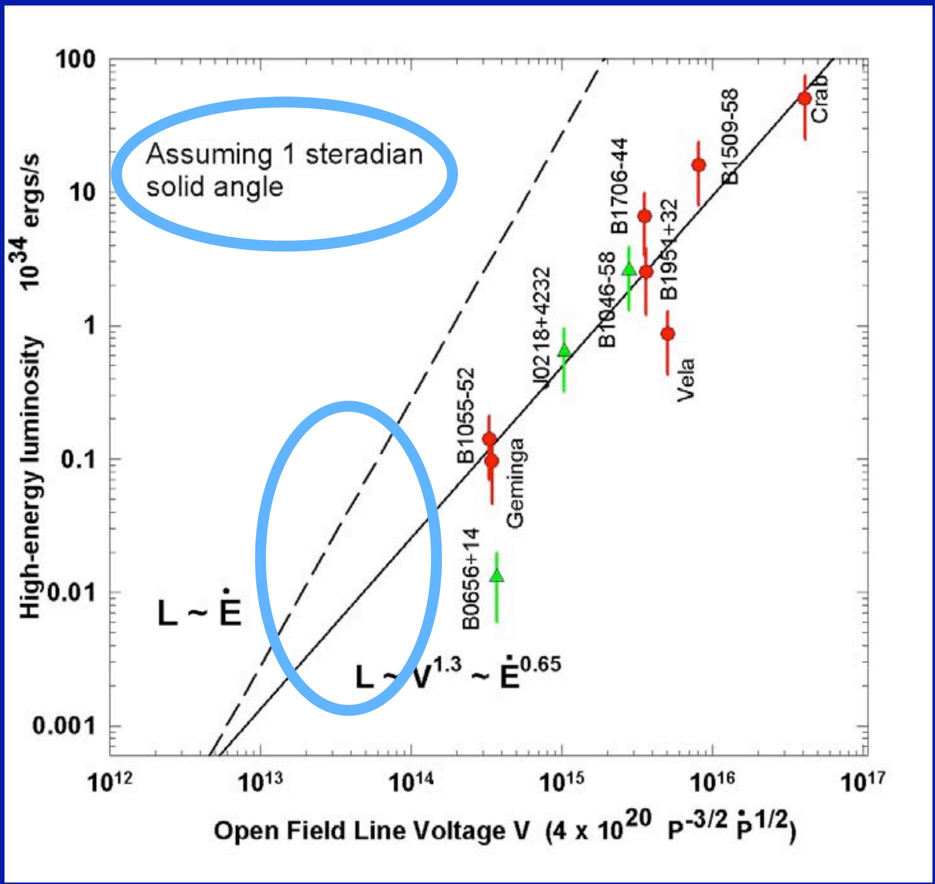


1016-5857 (Camilo et al.)



2229+6114(Halpern et al.)

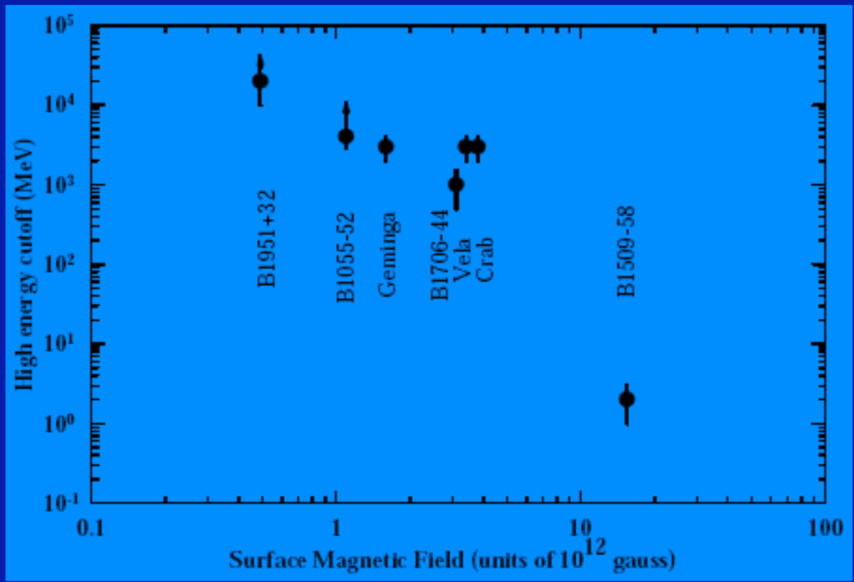
Results from EGRET



γ-ray luminosity proportional to sqrt(spin down energy [Edot]).

But what happens as lines converge?

And what about the assumption about the beaming angle?



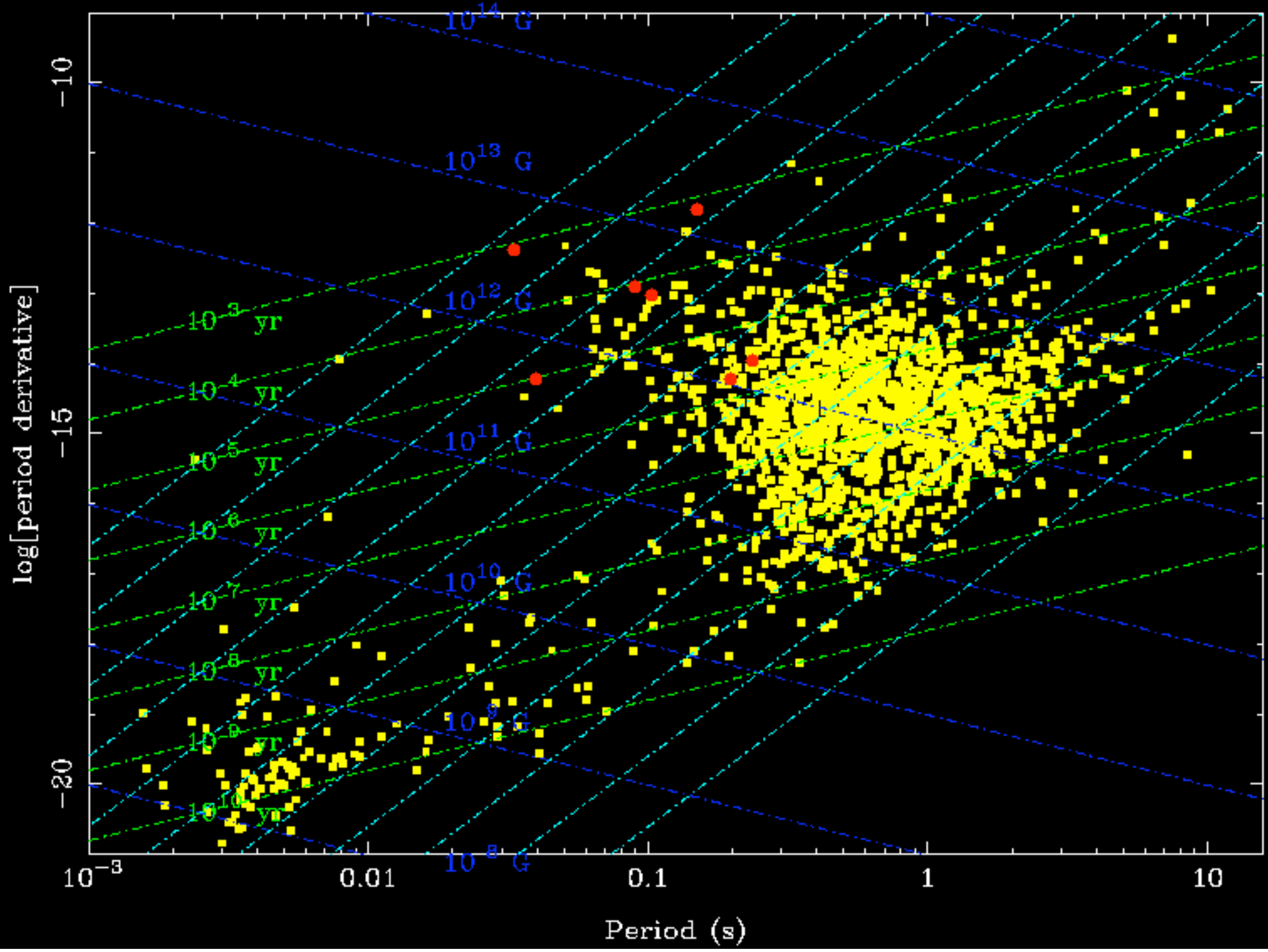
High energy cutoff depends on magnetic field - what is the high energy pulse cutoff?

No pulsations seen by HESS

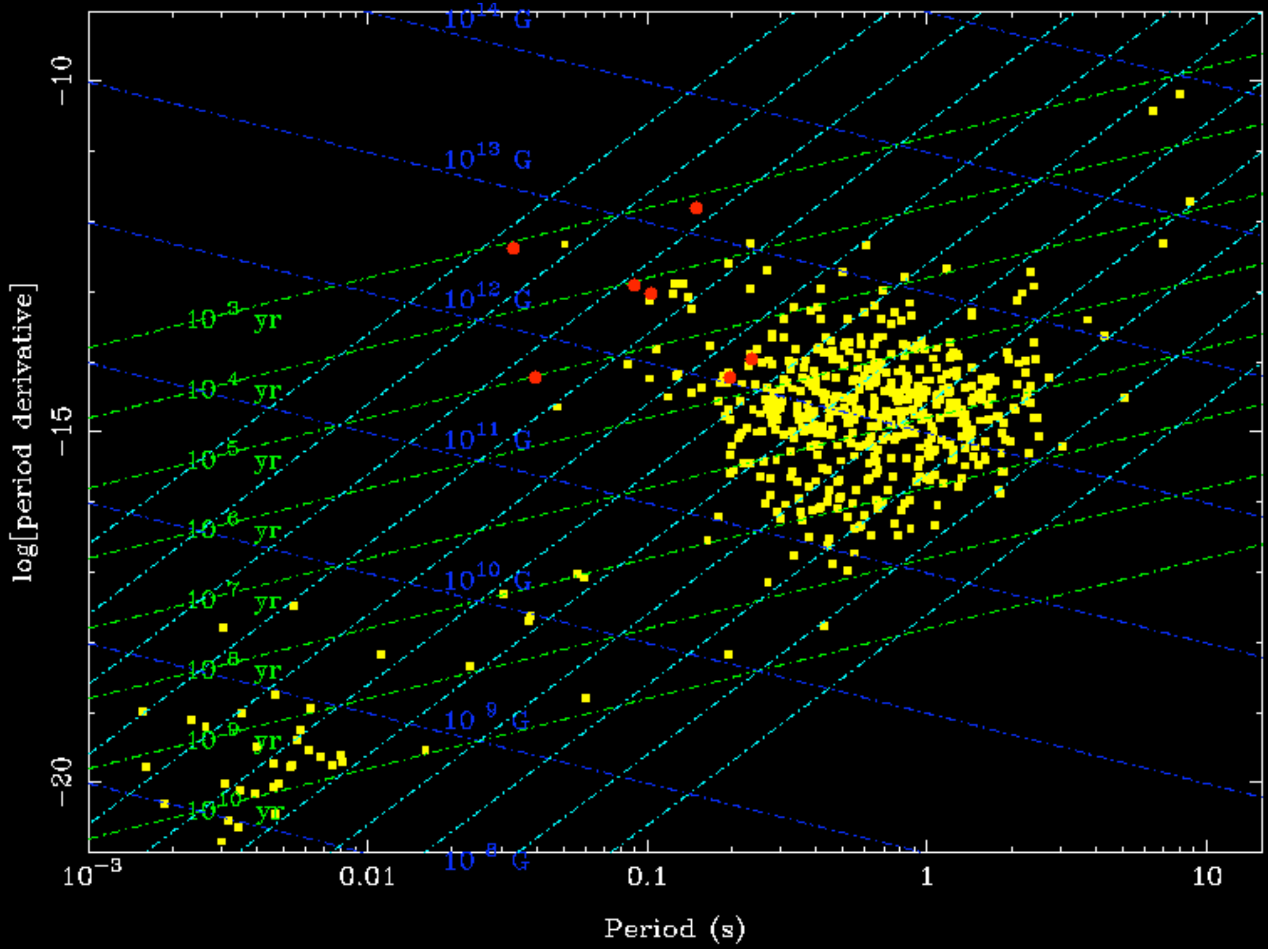
State of play in 2007

- 2000 radio pulsars known
- 81 pulsars with periods less than 10 ms
- 7 (+3?) rotation powered pulsars at high energy
  - A few (7?) new plausible EGRET associations
- A whole zoo of new and interesting objects
  - Magnetars } high B, long P objects
  - AXPs / SGRs
  - CCOs central to SNRs
  - INS isolated X-ray objects
  - Occasional pulsars RRATs, long term nullers
- Many pulsar wind nebula
  - Radio, X-ray, TeV wavelengths: rich science
- Many young pulsars are weak / low luminosity
- Many pulsars with giant pulses - link to high energies?

The Pulsar P-Pdot Diagram - 2007



The Pulsar P-Pdot Diagram - 1995



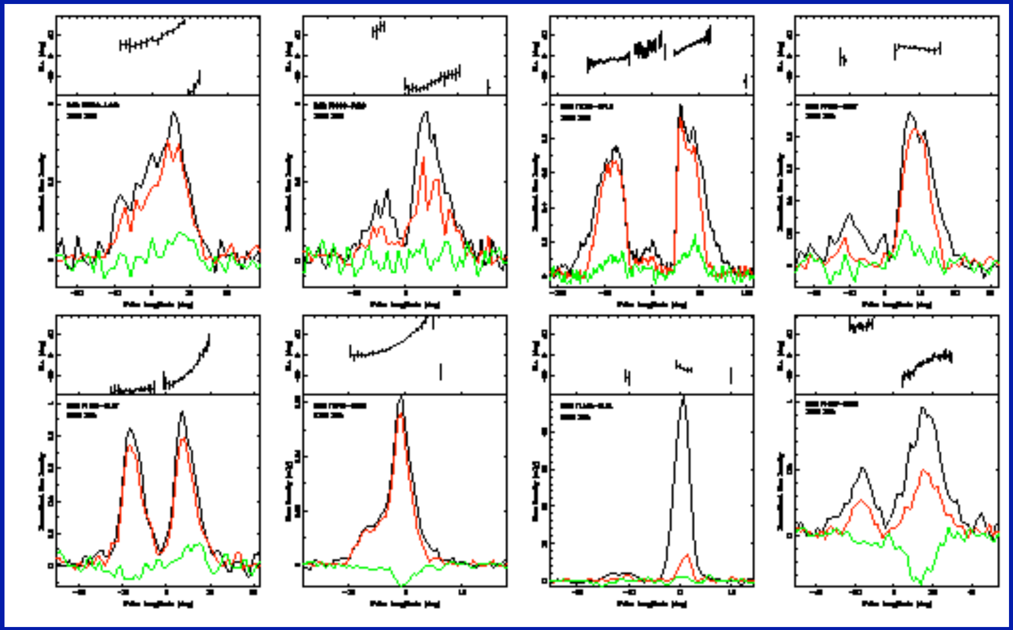
Expectations from GLAST

- 50-100 young, energetic pulsars
- 10+ millisecond pulsars
- 50-100 γ-ray loud, radio quiet pulsars (cf Geminga)
  – Model dependent and difficult to detect pulsations
- High energy pulsations (to at least 100 GeV)
- More photons
  – Better resolved pulse profiles
  – Better resolved spectra
- Pulsars at the Galactic Centre?
- Giant radio pulses and γ-ray emission?

→ Understand the acceleration processes in pulsars

More Pulsars from GLAST

We know that young pulsars have relatively wide radio beams with emission heights at least 10% of the light cylinder radius



Johnston & Weisberg 2006

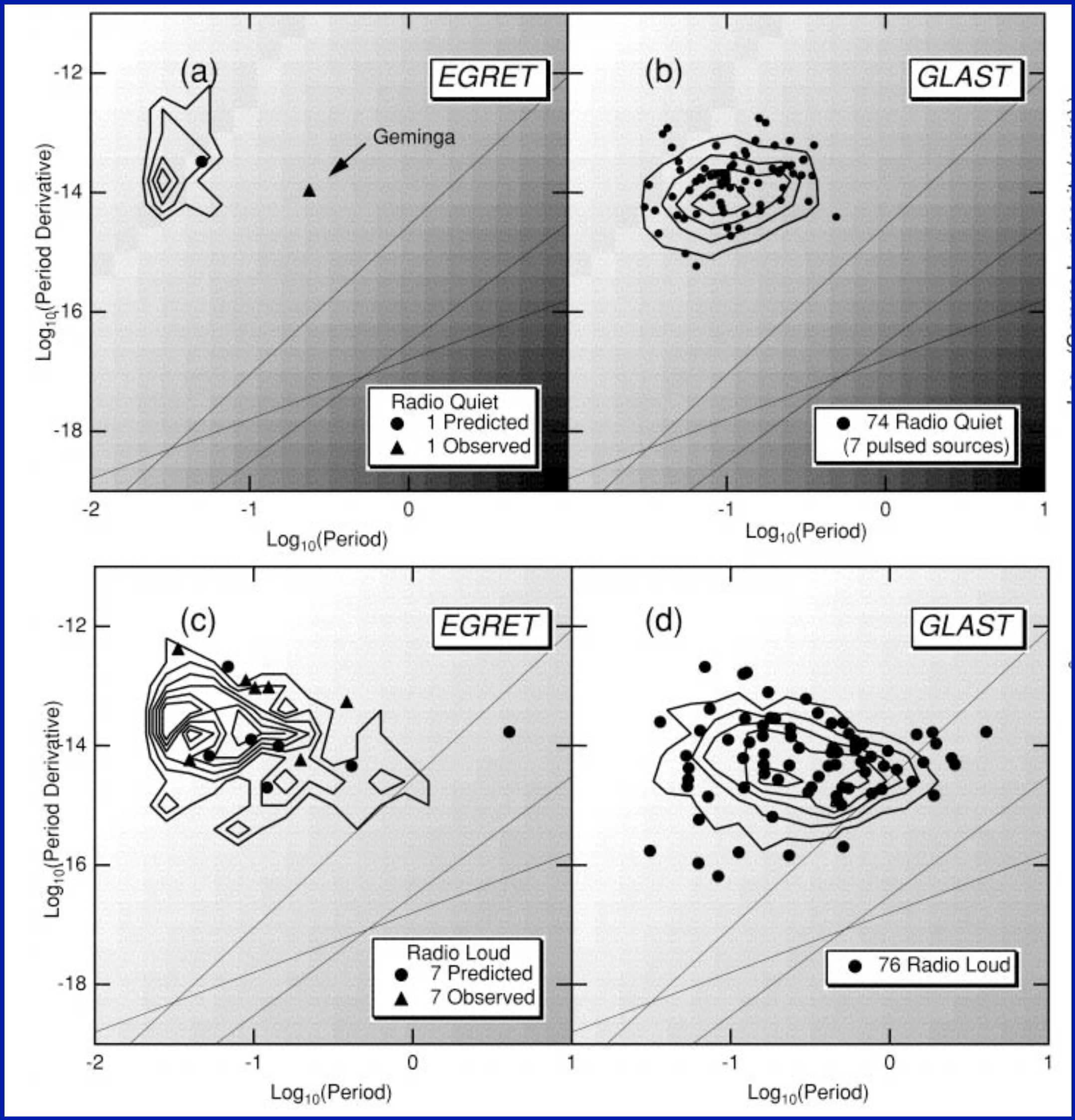
The radio beaming fraction of young pulsars is therefore ~50%

The beaming fraction in γ-rays is very model dependent

But to first order one might expect the radio loud to radio quiet ratio to be ~1 roughly consistent with EGRET numbers.

More Pulsars from GLAST

Population synthesis by Gonthier et al. (2002) assuming the polar gap model for γ-ray emission predict about equal populations of radio loud and radio quiet objects.

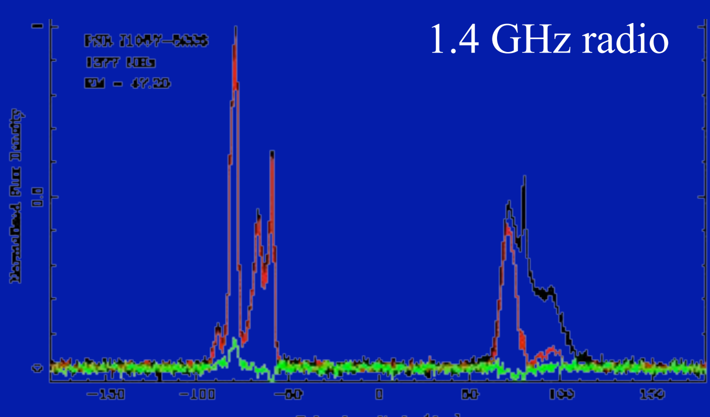


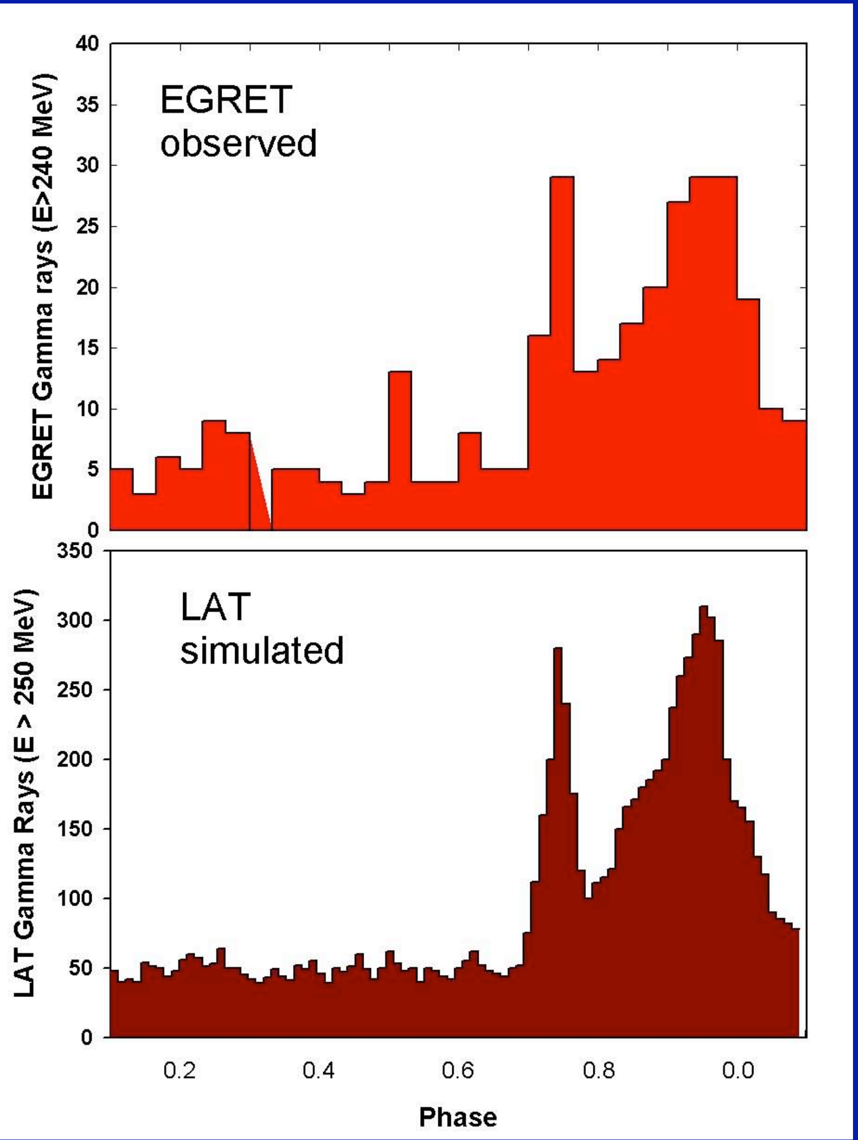
Better Pulse Profiles from GLAST

PSR B1055-52 light curve with EGRET. Not really enough photons.

With GLAST things improve substantially.

How are the pulse shapes, separation, and relationship to pulses seen at other wavelengths explained in different models? What is the source of the off-pulse emission?





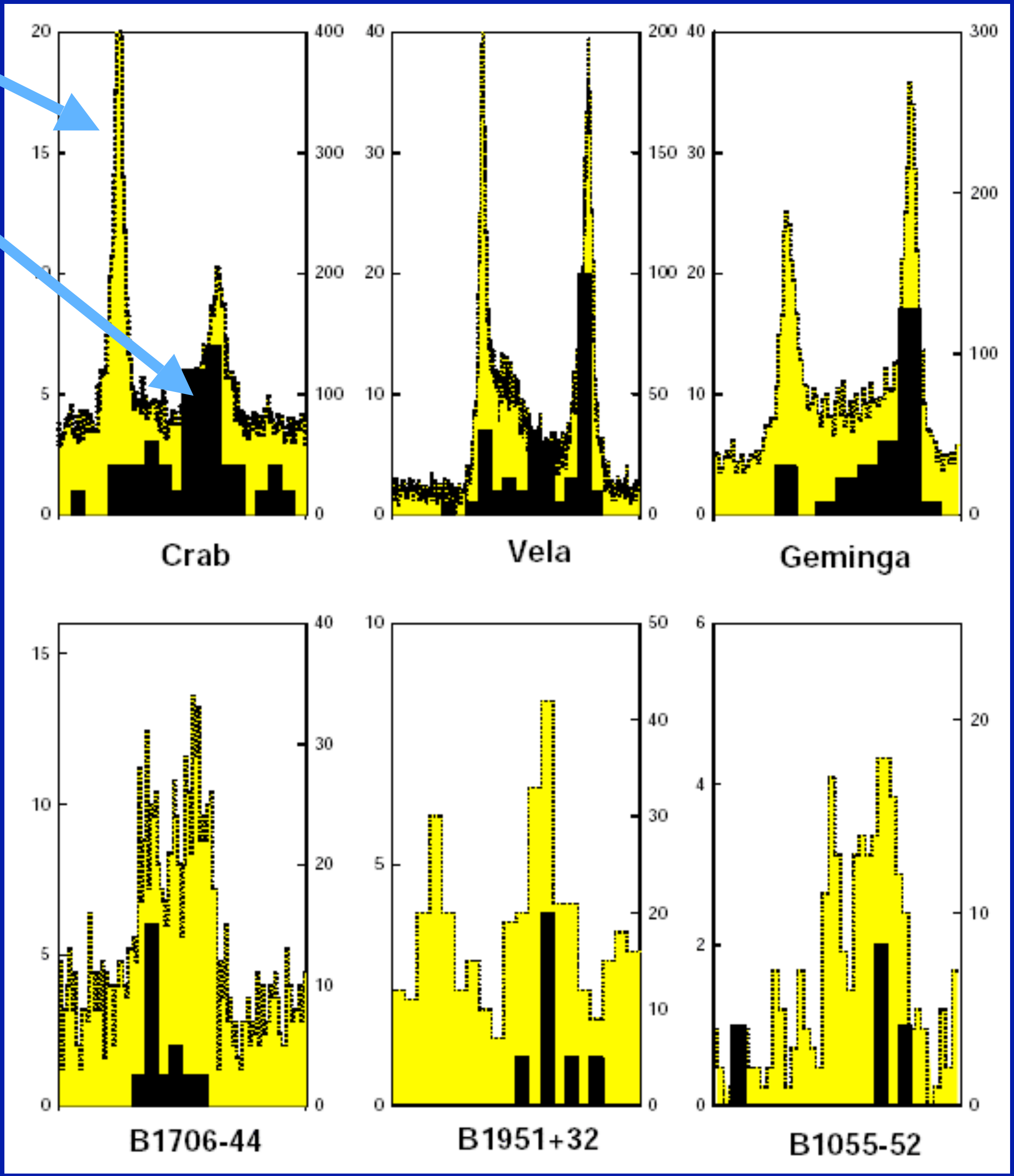
Higher Energies from GLAST

100 MeV

5 GeV

EGRET struggled to detect photons above 5 GeV but good evidence for detections and only single component?

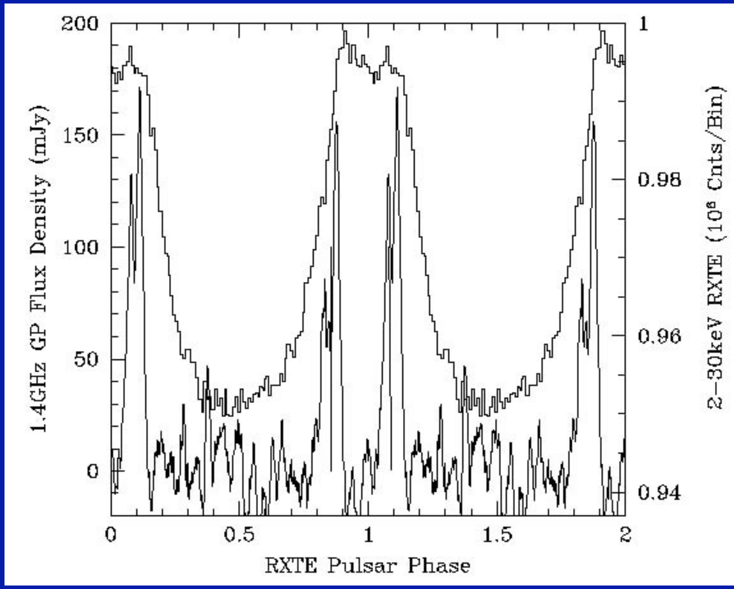
GLAST will clean up and test models



From Thompson 2003

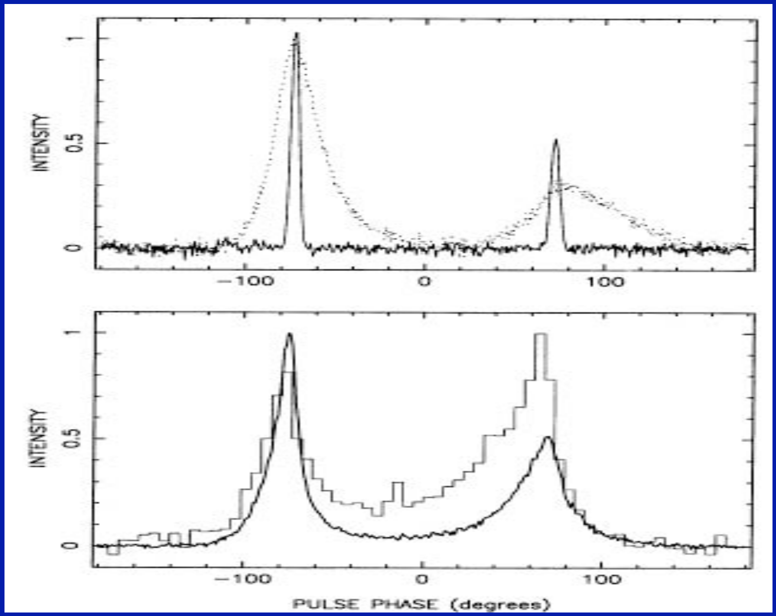
Giant pulses?

Giant radio pulses are seen in phase with high energy pulses in the Crab, 1937+21, 0540-69 and 1821-24 and generally offset from the main radio emission.



0540-69 (Johnston & Romani)
Crab (Lundgren et al.)

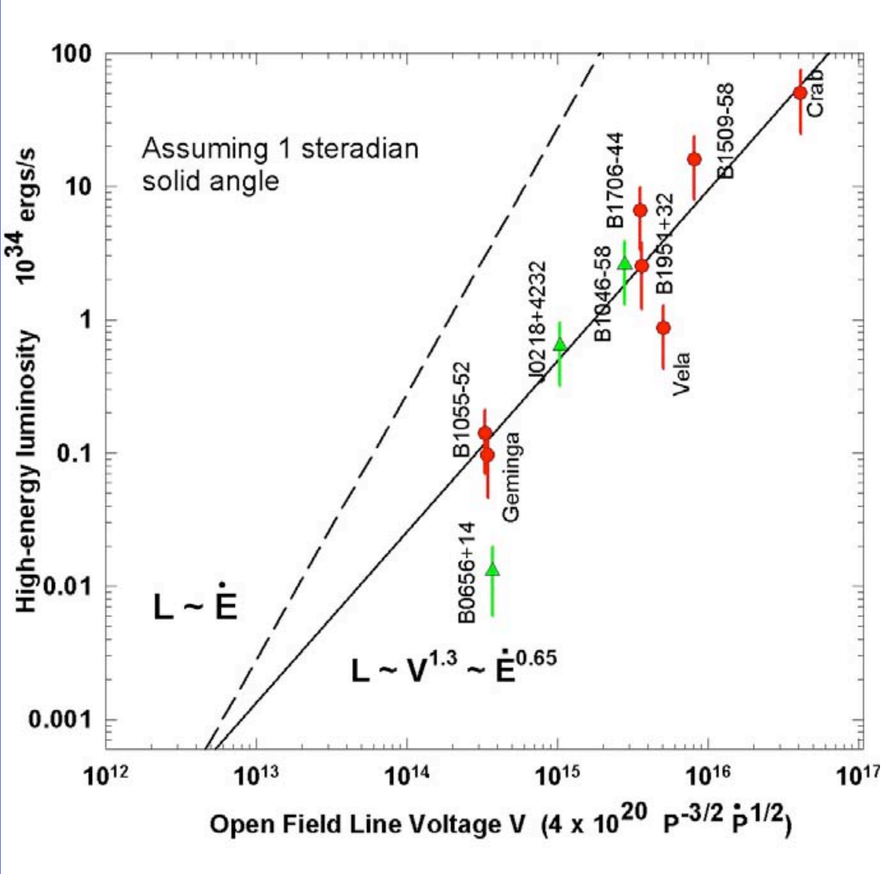
Does the giant pulse emission originate from the same region of the magnetosphere?



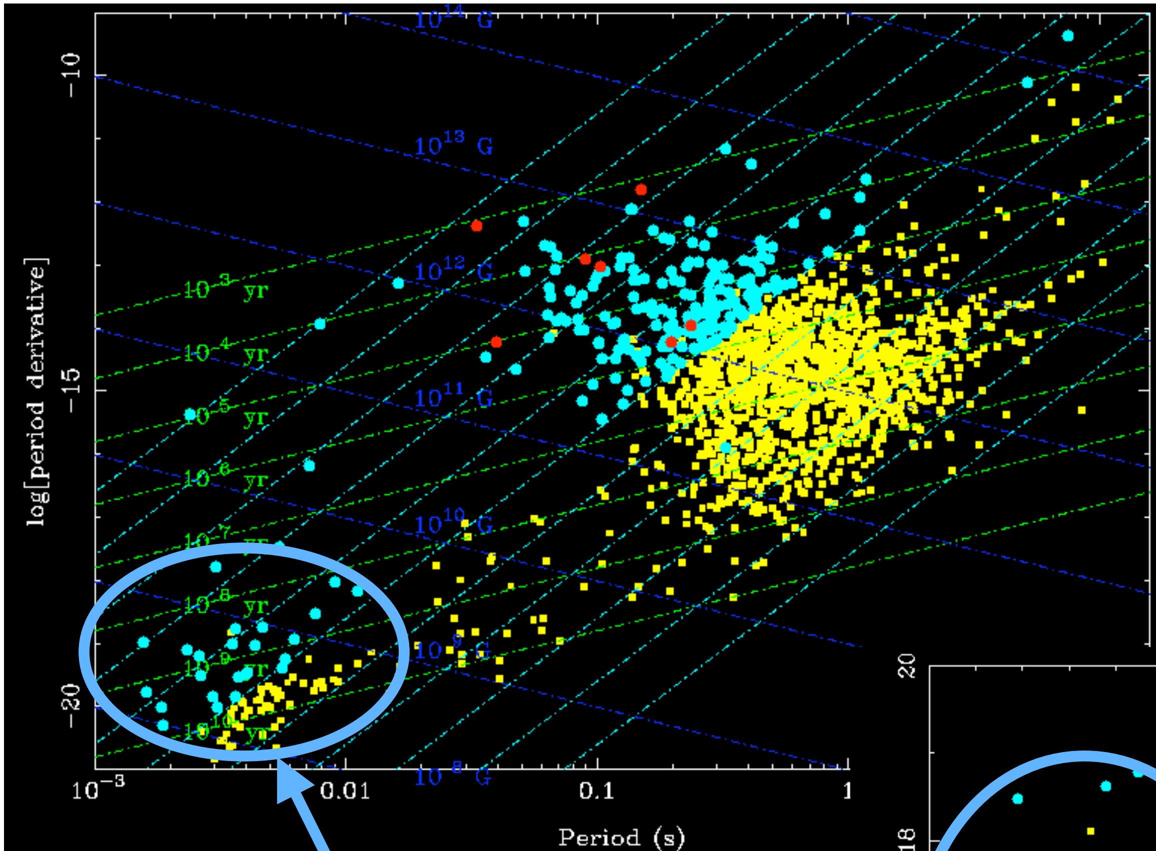
BUT - Strong variability seen in the radio is not seen at high energies (although possibly in the optical)

Which pulsars to target?

- $L\gamma \propto$ sqrt(Edot)
- Cutoff at 3×10^{34} erg/s (?)
- Use 10^{34} erg/s
- Gives **225** pulsars
- At Earth : $L\gamma \propto \text{dist}^{-2}$
- Figure of merit then is $L\gamma \sim \text{Edot}/\text{dist}^2$

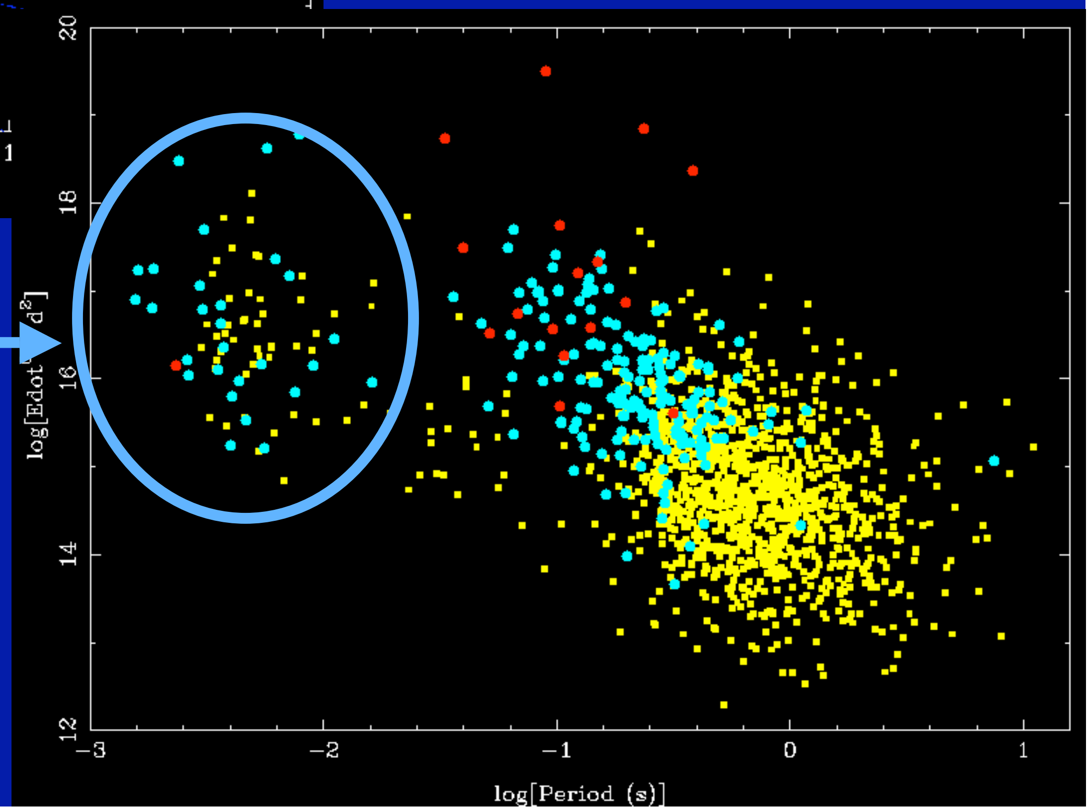


Note that all-sky survey sees all pulsars every few hours but these cannot all be monitored in the radio!



P-Pdot plane

MSP population

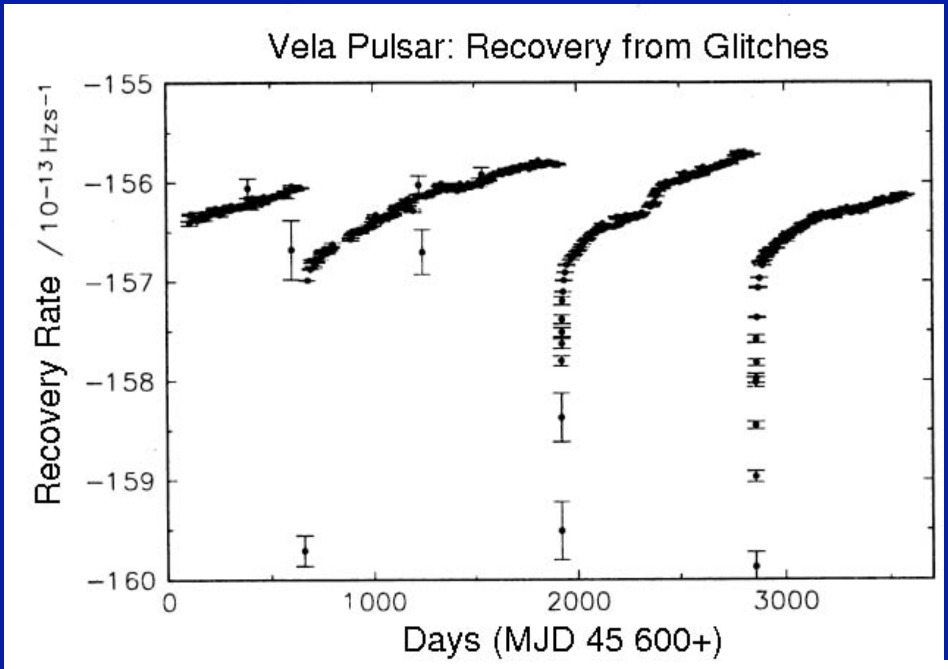


Edot$^{0.5}$/d^{2} - P plane

Why radio telescopes?

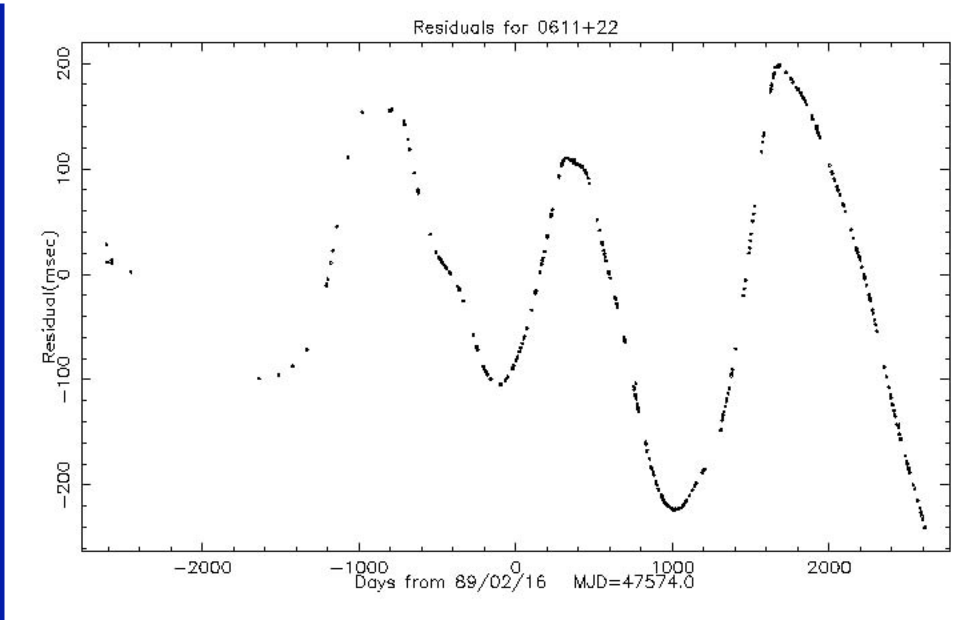
- Not photon starved!
- γ-ray observations would like 1-10 milli-period accuracy on photon arrival times
- Regular radio observations can provide ephemerides accurate enough to do this
- BUT
  - Young pulsars are noisy!
  - Young pulsars glitch!
  - Young pulsars are weak!
- Intensive observations necessary
  - Large campaigns planned or underway at major radio telescopes (Parkes, Lovell, GBT, Nancay)

Image: Claire Flanagan



Example of multiple glitches (`starquakes') in the Vela pulsar

Example of pulsar `timing noise' causing phase wander by +/- 0.5 period in PSR B0611+22



Without constant monitoring phase cannot be accurately predicted !!

Image: George Hobbs

Summary

- GLAST will
  - Detect many more γ-ray pulsars
  - Provide much better γ-ray pulse profiles
  - Provide much better spectra
  - Lead to a better understanding of the acceleration process and origin in pulsars
- Will require support from the radio pulsar community - 100 days/yr observing
- Fruitful collaboration between the observers and the theorists … feedback loop

Looking forward to launch and the next few years!