Fermi LAT observations of gamma-ray pulsars

Lucas Guillemot

guillemo@mpifr-bonn.mpg.de

on behalf of the Fermi LAT Collaboration, the Fermi Pulsar Timing Consortium, and the Fermi Pulsar Search Consortium

Pulsars @ Munich meeting

The Fermi Gamma-ray Space Telescope

Fermi = Large Area Telescope (LAT)
+ Gamma-ray Burst Monitor (GBM)

Expected lifetime of at least 5-10 years.

Observations of the gamma-ray sky from 20 MeV to more than 300 GeV.

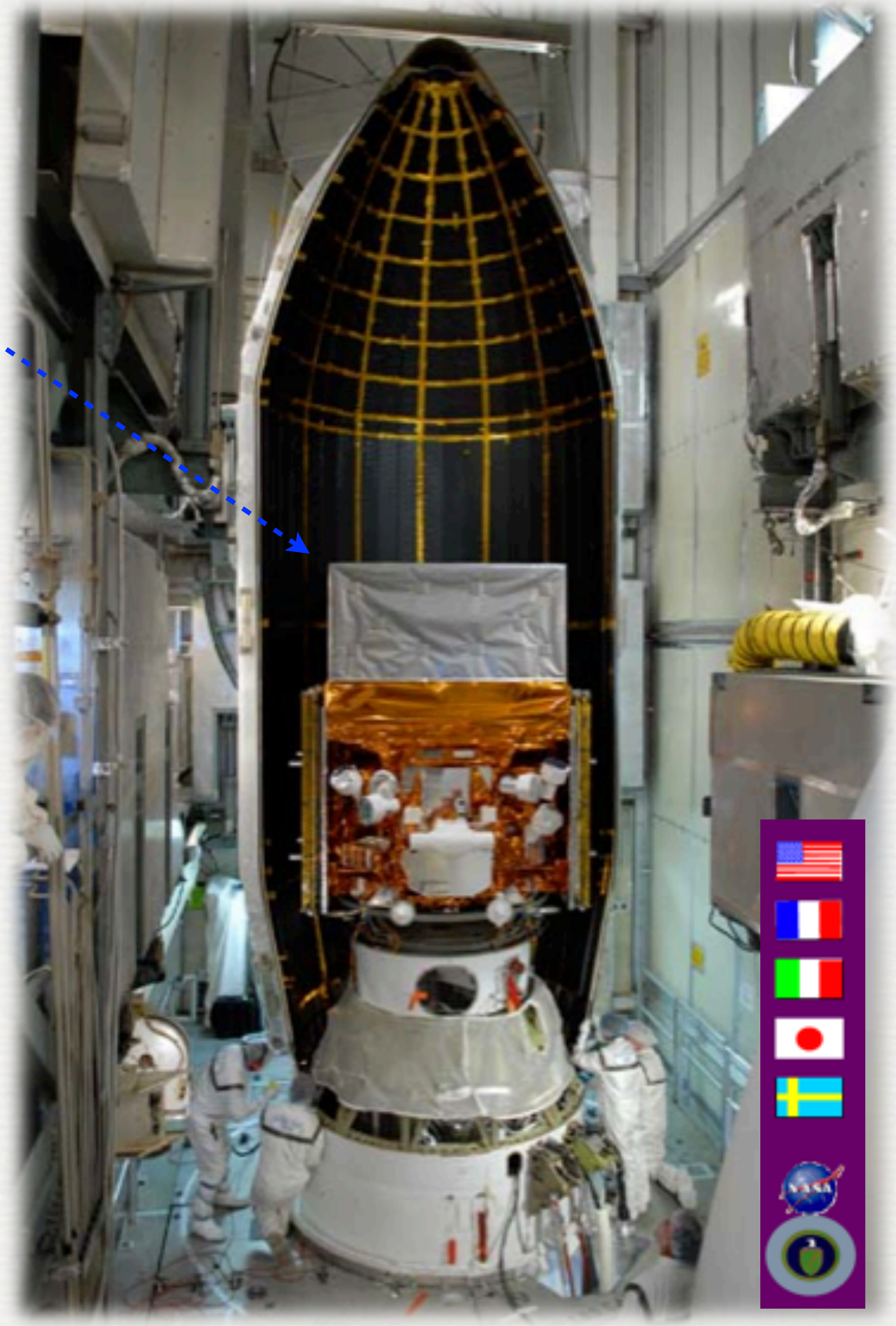
Area of 8000 cm^2, PSF of ~0.6° at 1 GeV, viewing angle of 2.4 sr (1/5 of the sky).

Survey strategy. Whole sky seen in two orbits (8 times per day).

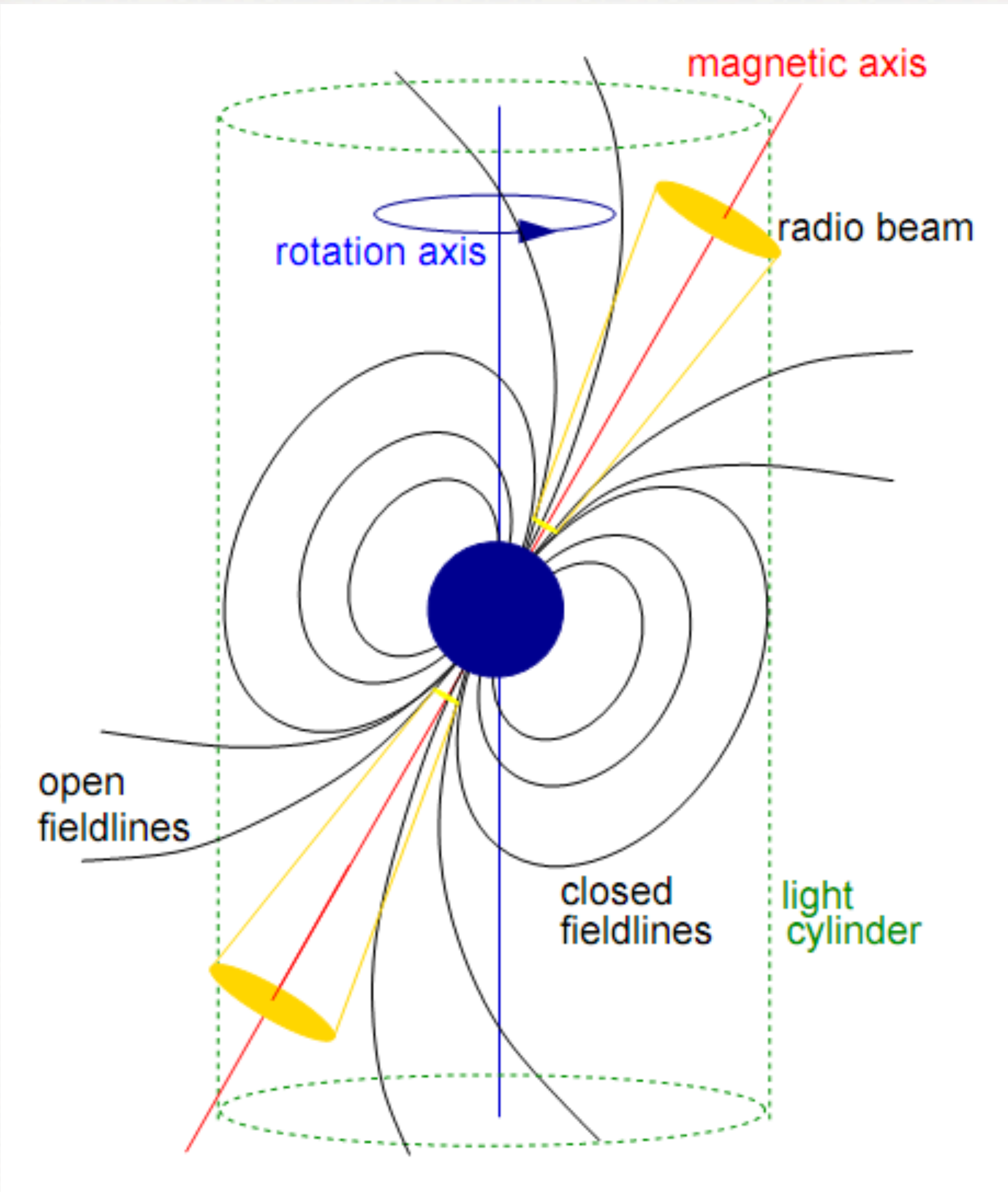
Launched on 11 June 2008.

Approx. 30 times more sensitive than EGRET.

(see Atwood et al., ApJ 697, 1071, 2009)



Pulsars



Pulsars are rapidly rotating, highly magnetized neutrons stars, born in supernova explosions of massive stars.

Typically, M ~ 1.4 M_{sun} and R ~ 10 km

A dense plasma is co-rotating with the star. The magnetosphere extends to the "light cylinder", where the rotation reaches the speed of light.

Emission (radio, optical, X-ray …) can be produced in beams around the pulsar, which acts like a cosmic light-house.

~ 1900 pulsars known today. Vast majority in radio!

Some pre-launch open questions

- What mechanisms produce the emission, from radio to gamma rays?
- Where do these phenomena take place?
- Are there gamma-ray millisecond pulsars?
- What is the fraction of radio-loud and radio-quiet pulsars?
- What is the contribution of gamma-ray pulsars to the diffuse Galactic emission?

Observing pulsars with the Fermi LAT

Folding gamma-ray photons using astrometric, rotational and binary parameters measured in radio or X-rays (known pulsars)

Large pulsar timing campaign, allowing pulsations searches for >700 pulsars!

(See Smith, Guillemot, Camilo et al., A&A 492, 923, 2008)

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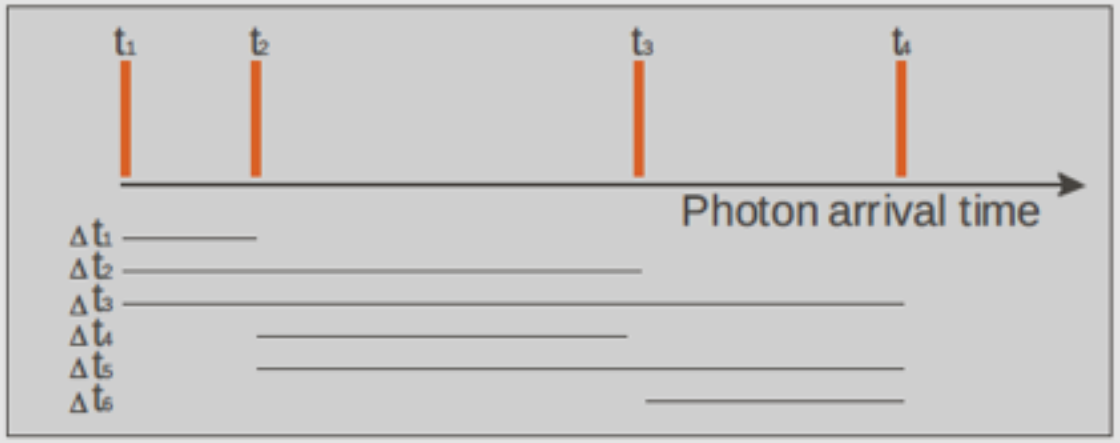
Blind searching for pulsations directly in the gamma-ray data, at the positions of compact objects, supernova remnants, Fermi unidentified sources.

(See Atwood et al., ApJL 652, 49, 2006)



Credit: M. Ziegler

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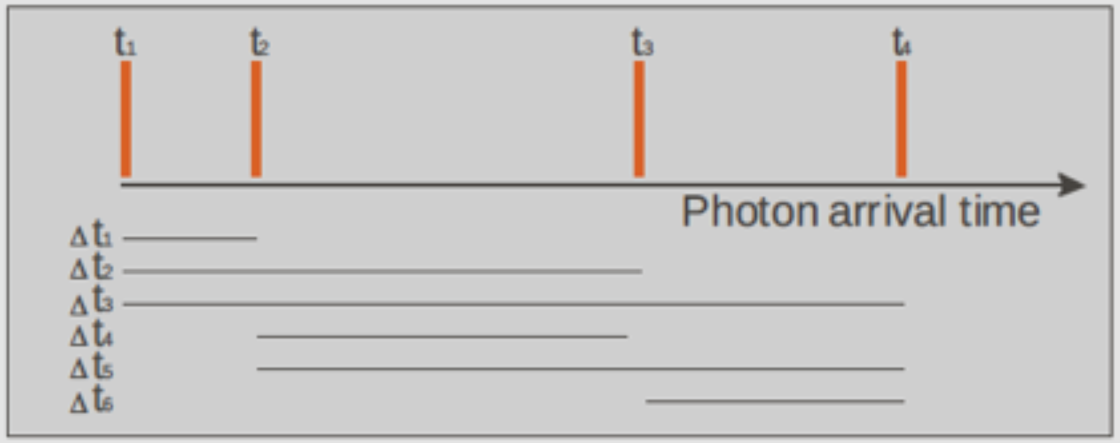

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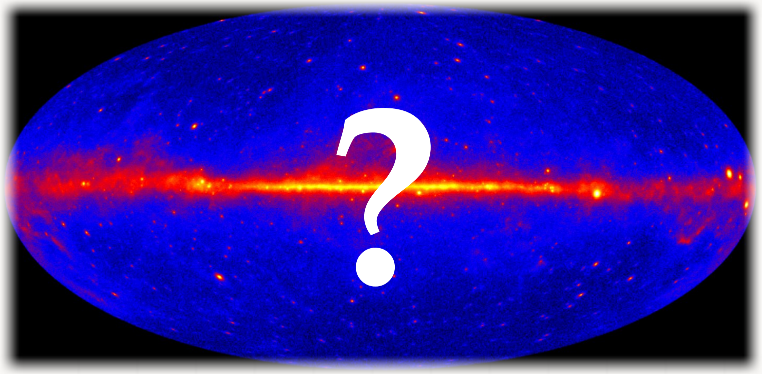


Blind searching for radio pulsars at the positions of Fermi unidentified sources, likely to be pulsars (from their spectra and lack of variability).

Large campaign involving radio telescopes around the world:

GBT, Parkes, Nançay, Effelsberg, Arecibo, GMRT.

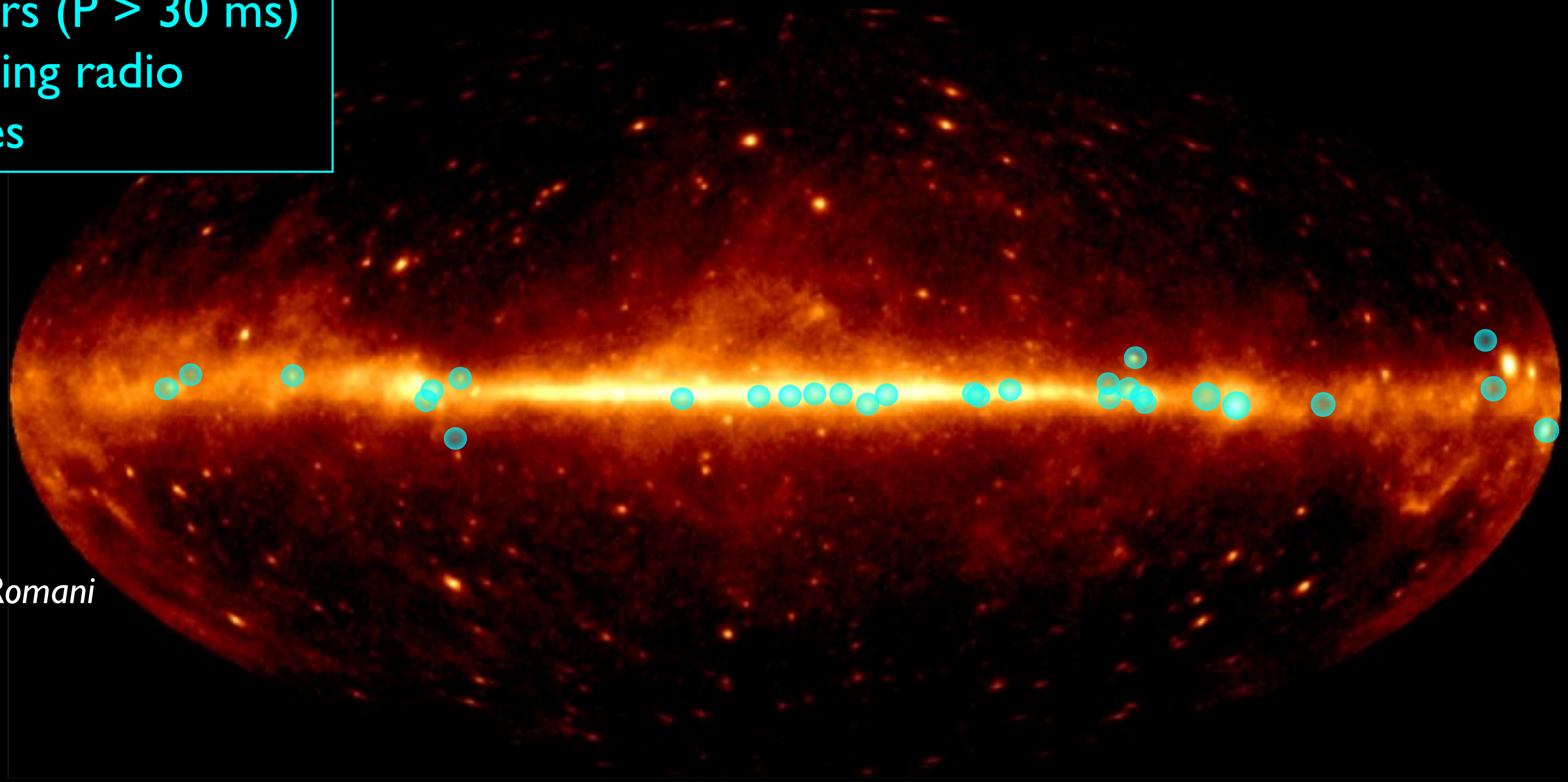
The LAT pulsar sky
(as of launch + 2 yrs)

Credit: Roger W. Romani

The LAT pulsar sky

(as of launch + 2 yrs)

<u>30 young radio-selected:</u>
young pulsars (P > 30 ms) detected using radio ephemerides



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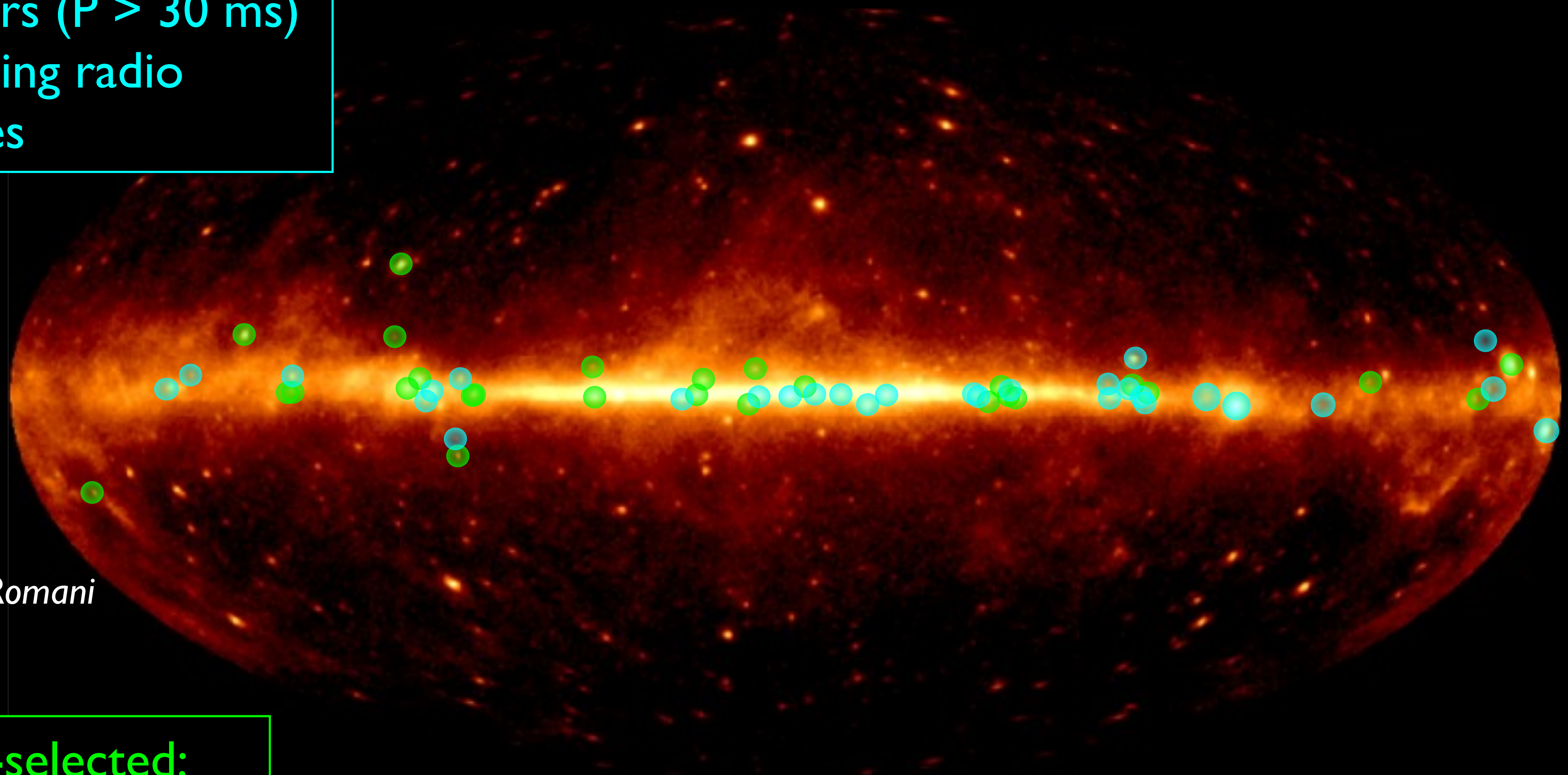

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25 young γ-selected:
young pulsars found in a blind search of the gamma-ray data

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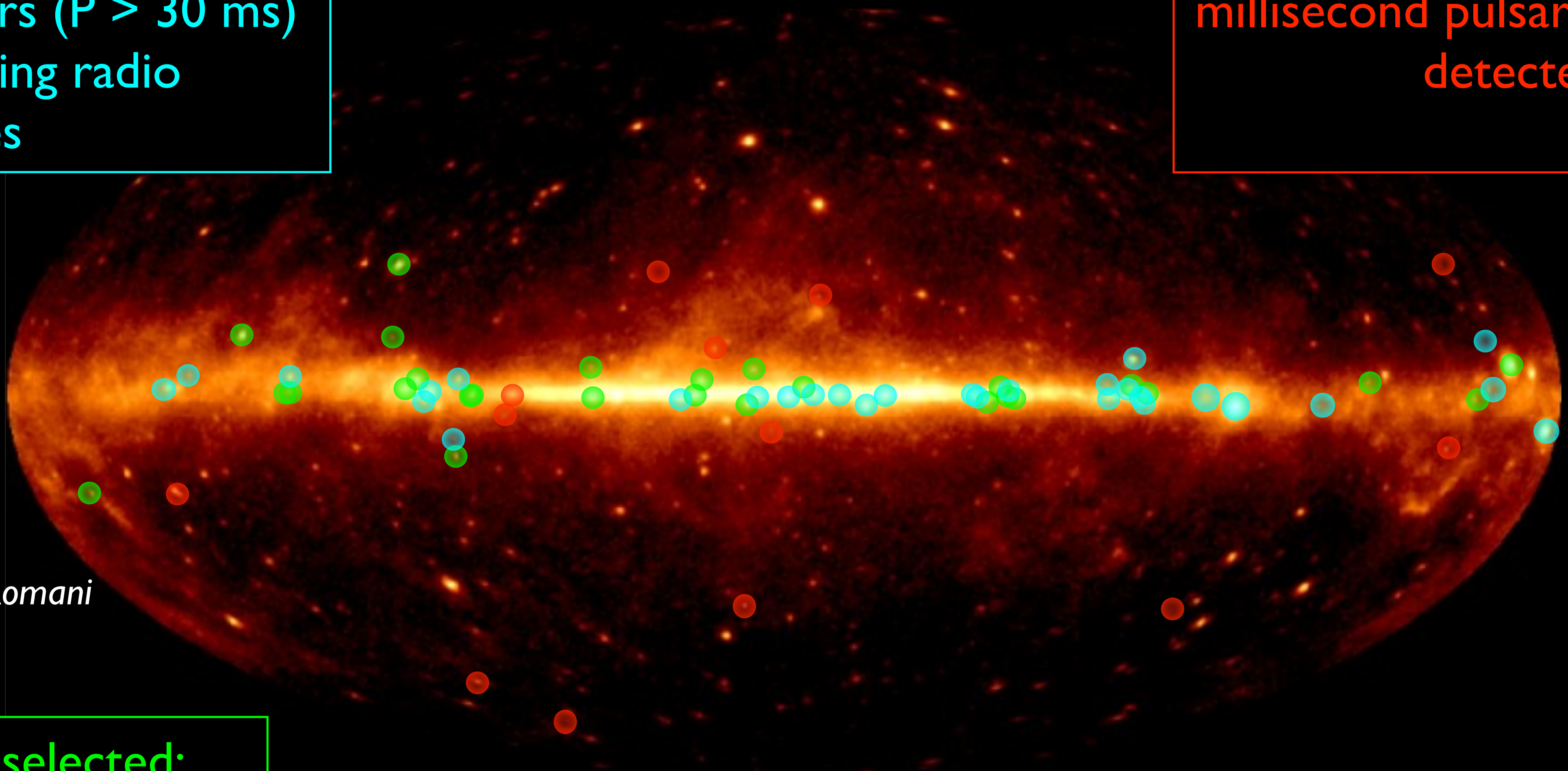

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14 radio-selected MSPs:
millisecond pulsars (P < 30 ms) detected using radio ephemerides

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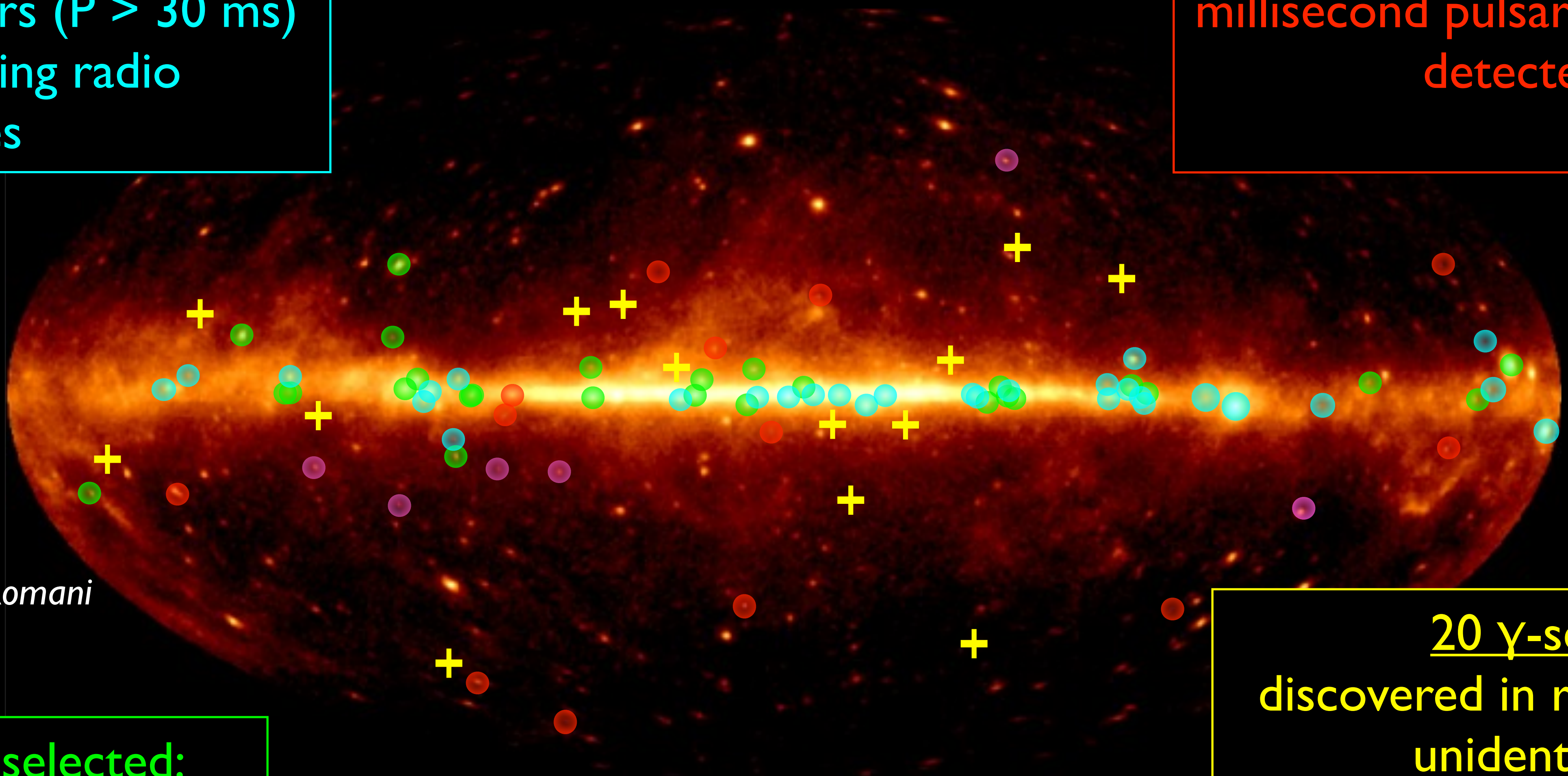

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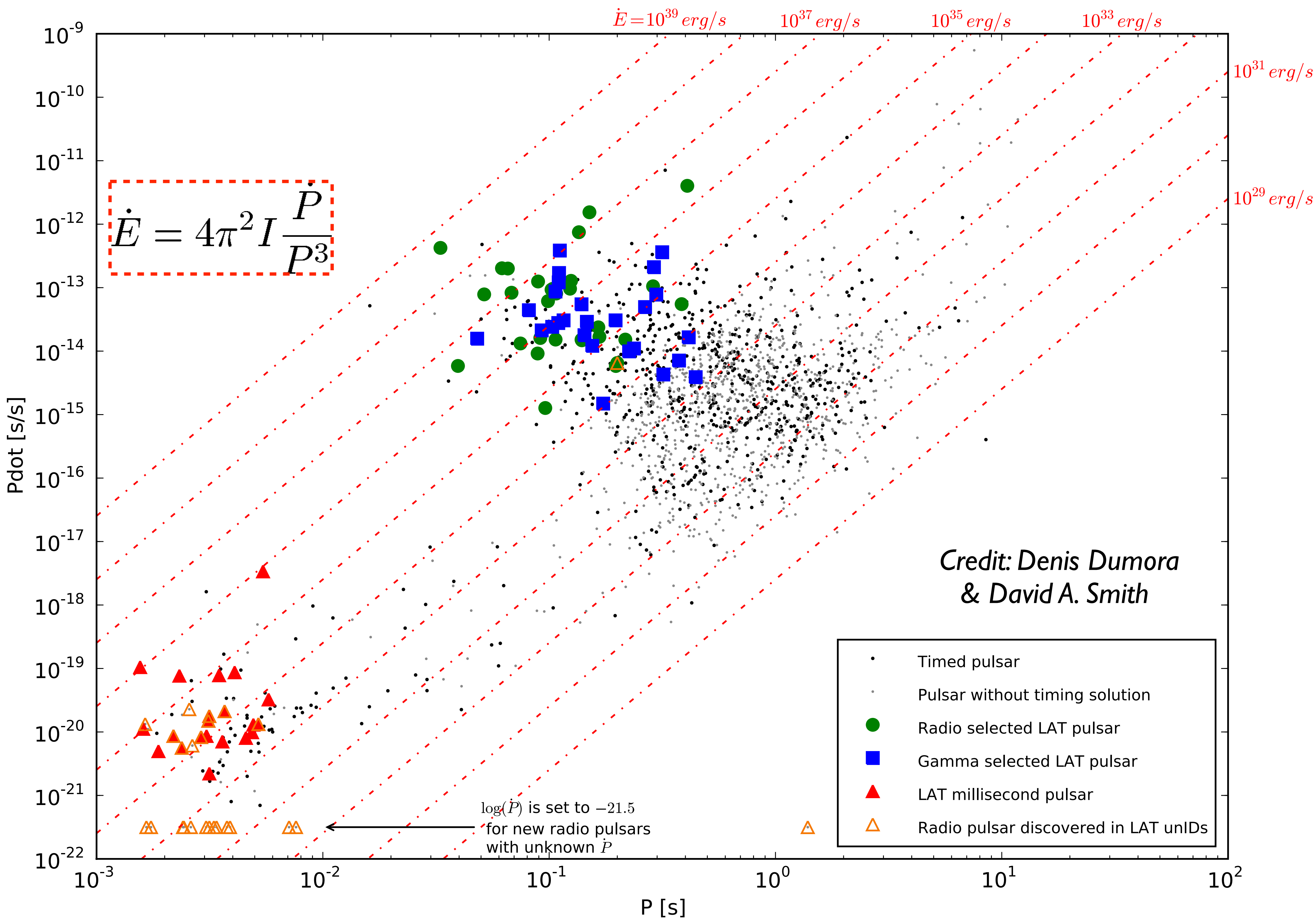
25 young γ-selected: young pulsars found in a blind search of the gamma-ray data

20 γ-selected MSPs: discovered in radio in Fermi unidentified sources. Pulsed gamma rays detected for 6 of them.

With 75 detections, the number of known gamma-ray pulsars has increased by an order of magnitude over previous experiments!

Which pulsars are we seeing?



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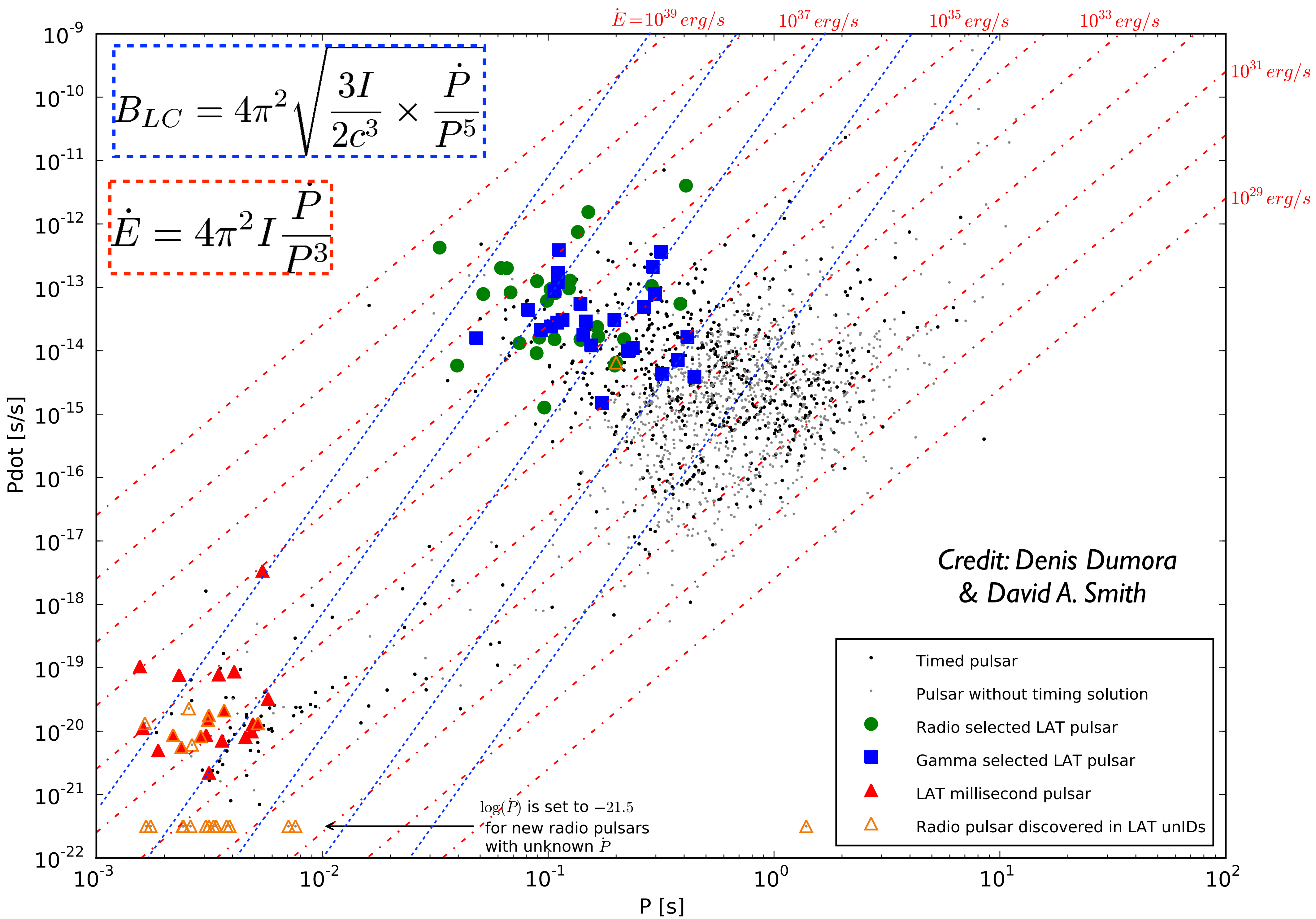

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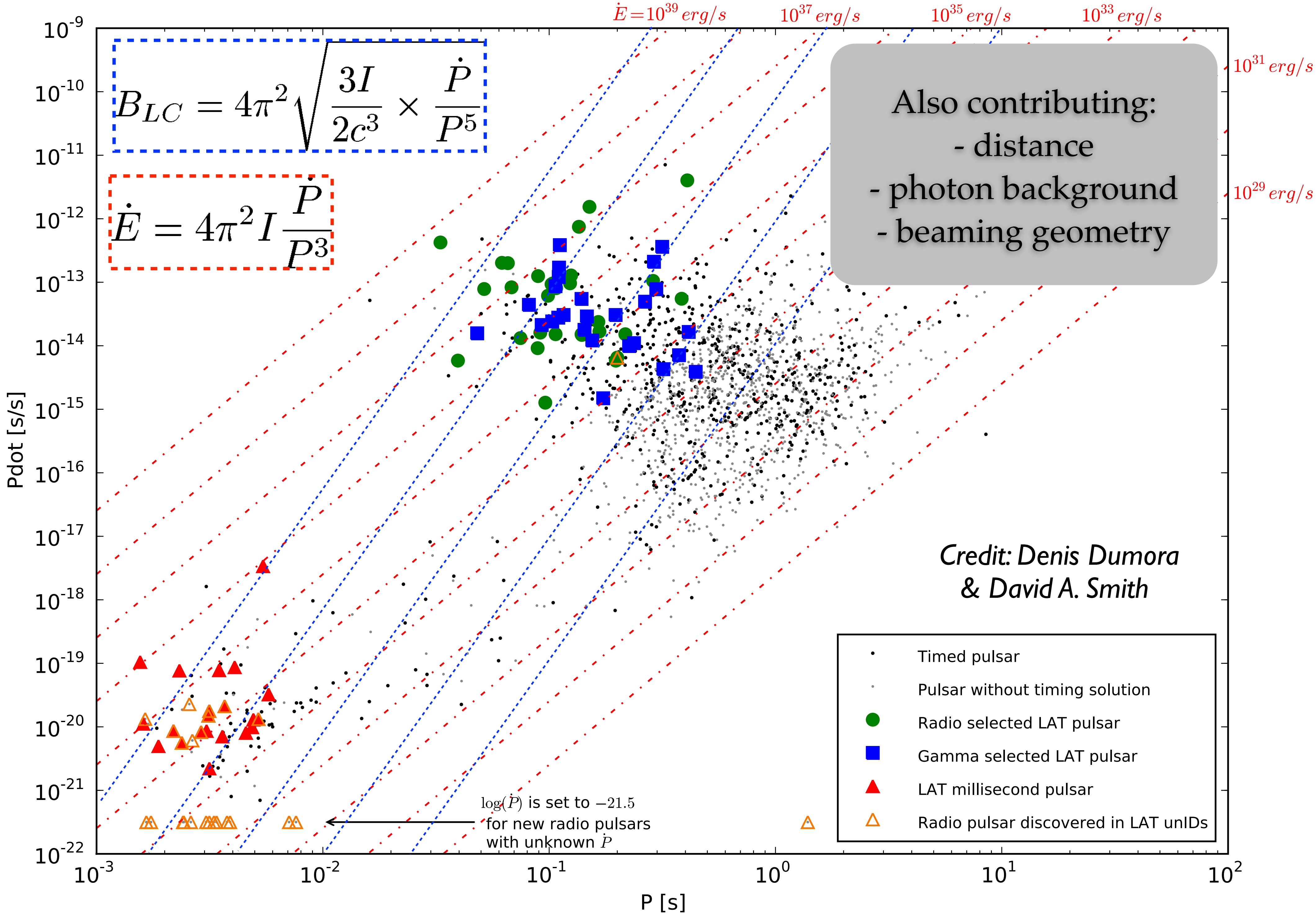


Also contributing:
- distance
- photon background
- beaming geometry

Credit: Denis Dumora & David A. Smith

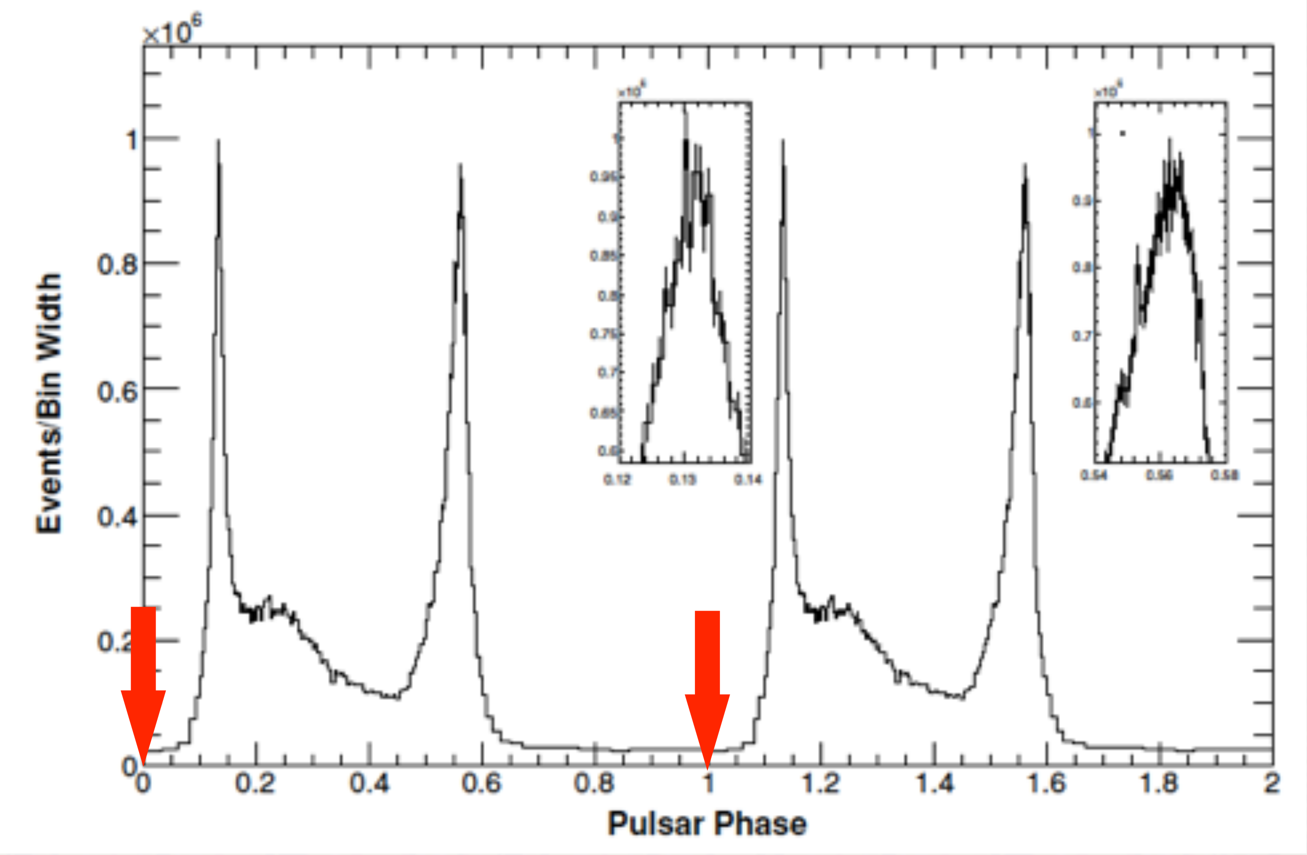
What is a gamma-ray pulsar like?

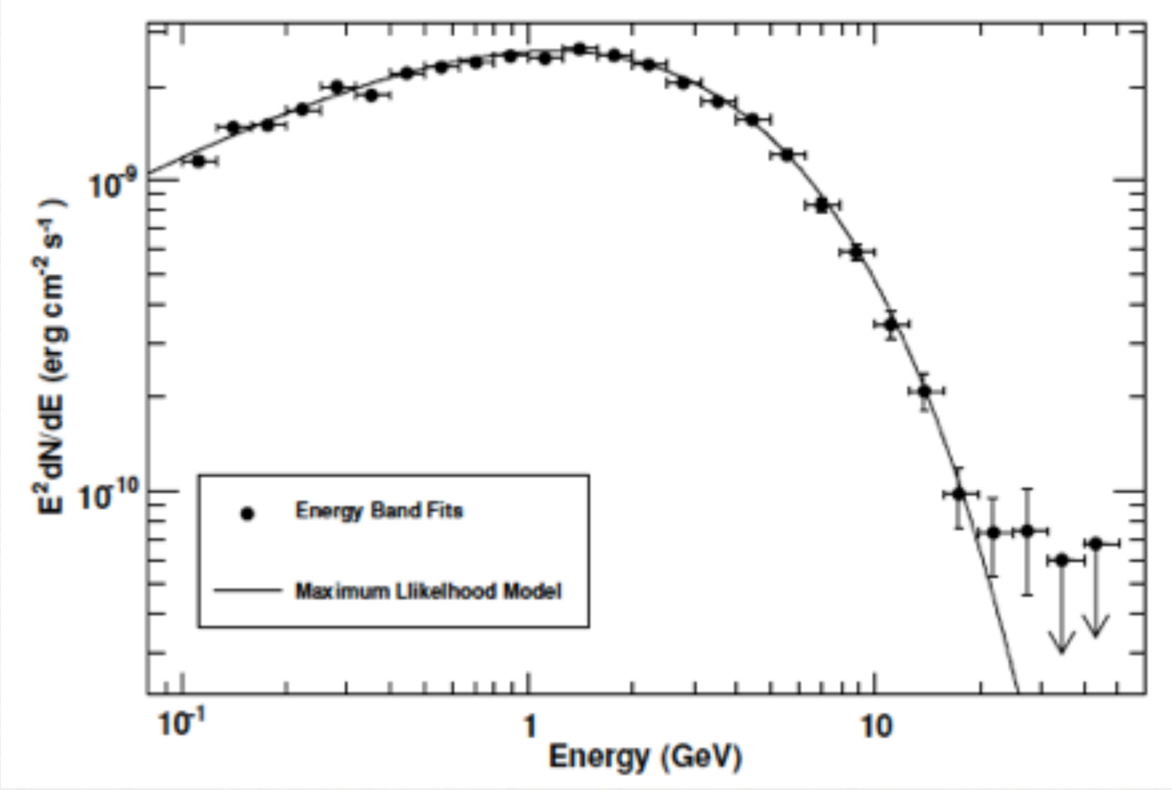
Vela pulsar in gamma rays:

- two sharp peaks separated by Δ~0.4, with bridge emission in between.
- first peak lagging the radio peak (red arrow) by ~0.15.
- Spectrum well modeled with an exponentially cut off power law, with Γ~1.37, and E_c~3.15 GeV.
- Dependence of spectral properties with phase.

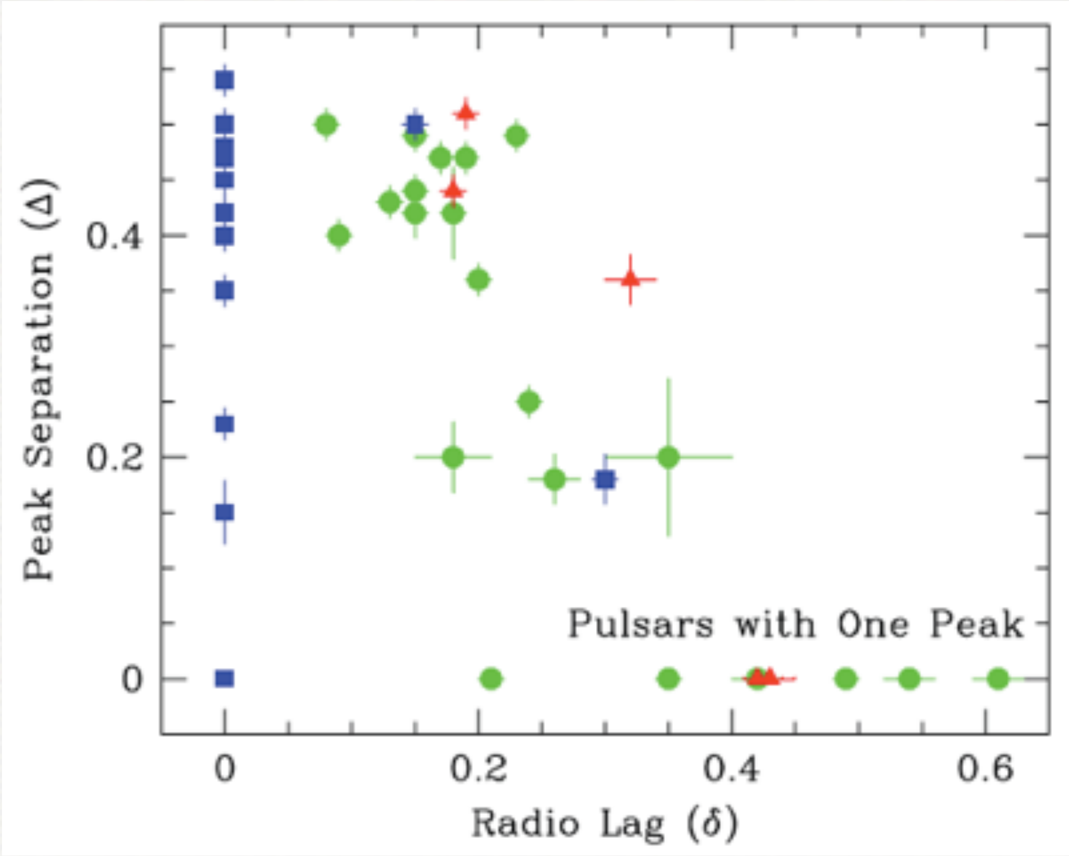
(See Abdo et al., ApJ 713, 154, 2010)

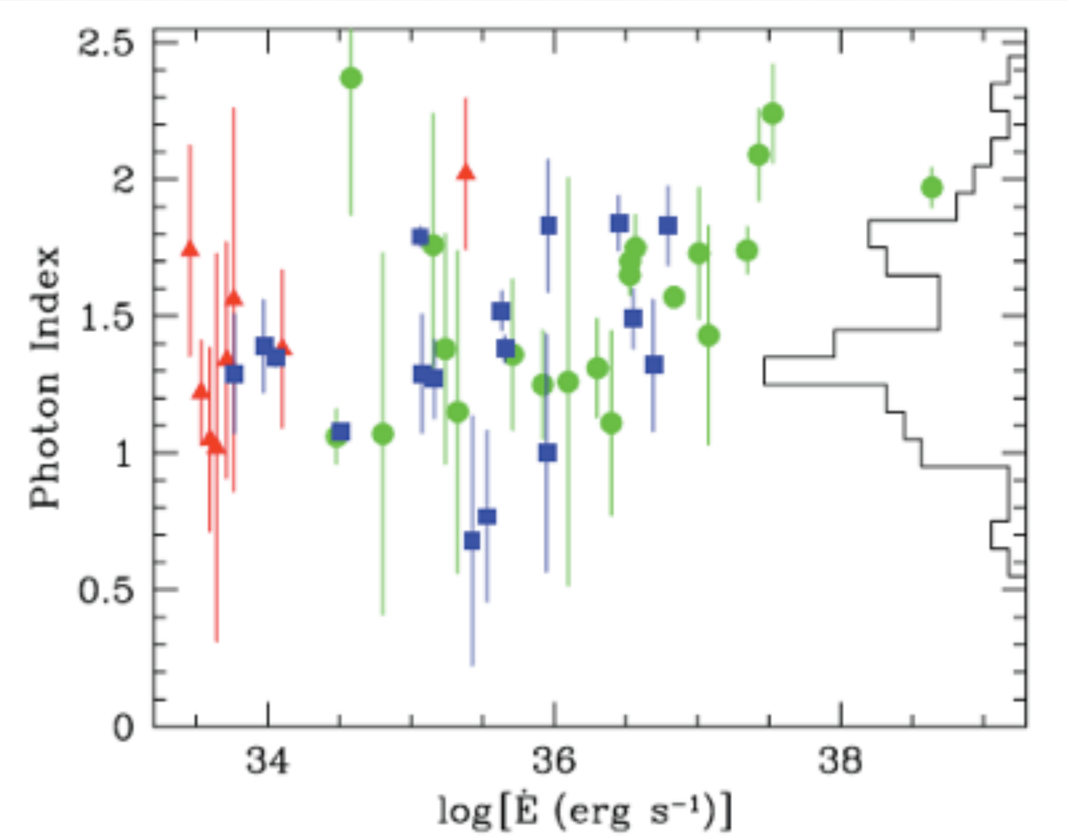
The above properties are very common among gamma-ray pulsars.

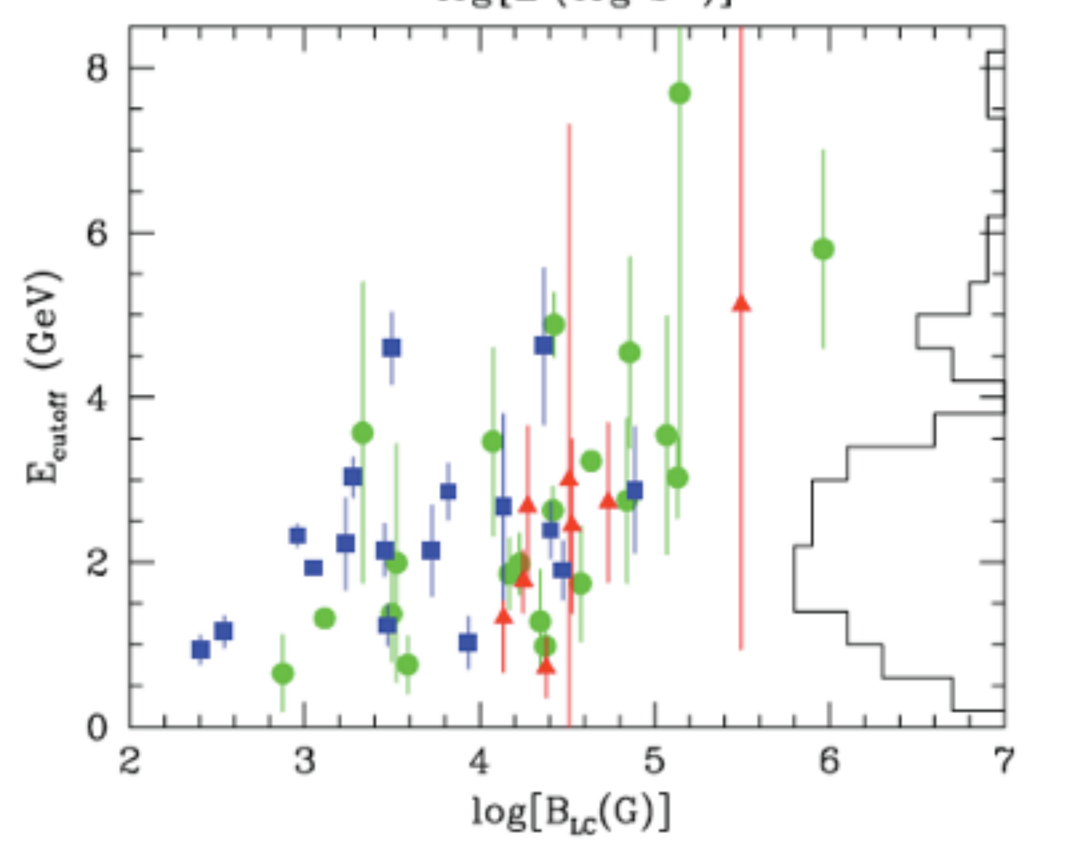




Trends







Light curves: most have two peaks, with $\Delta \sim 0.5 - \delta$. Some exceptions: single peak, triple peaks, aligned radio/gamma-ray emission.

Spectra: exponentially cut off power laws. Weak correlation of Γ and Edot, weak correlation of E_c and B_{LC}.

(See Abdo et al., ApJS 187, 460, 2010)

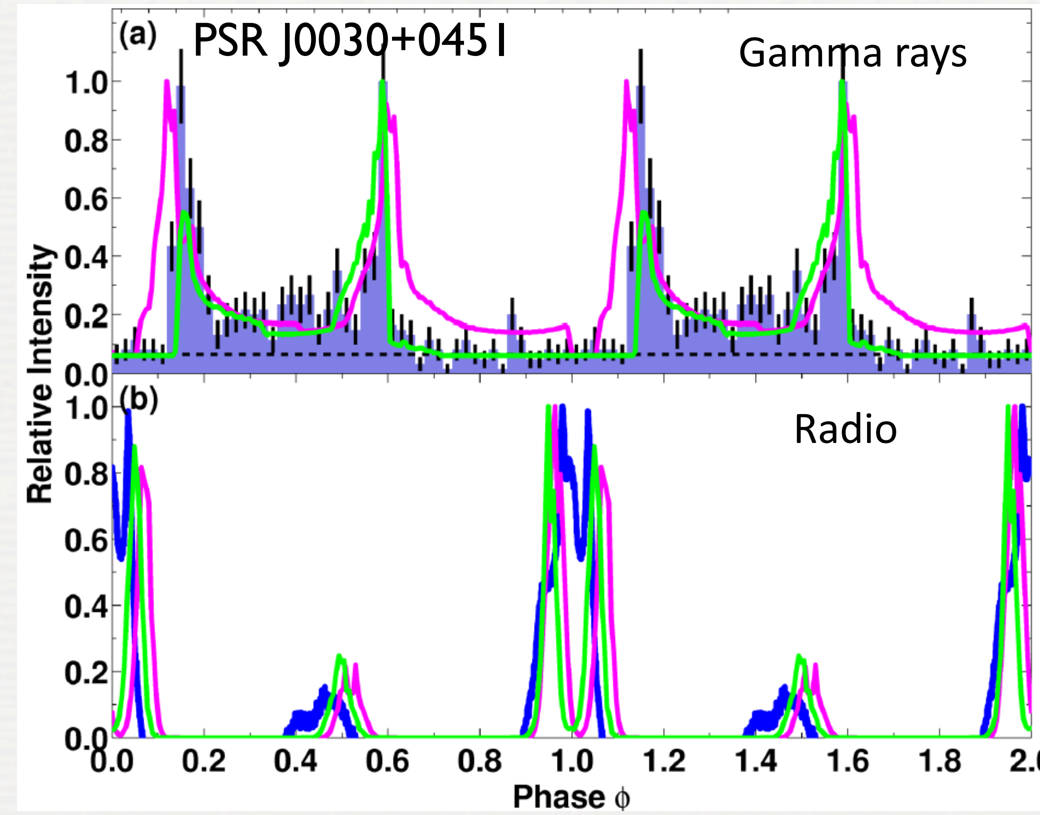
What do we learn?

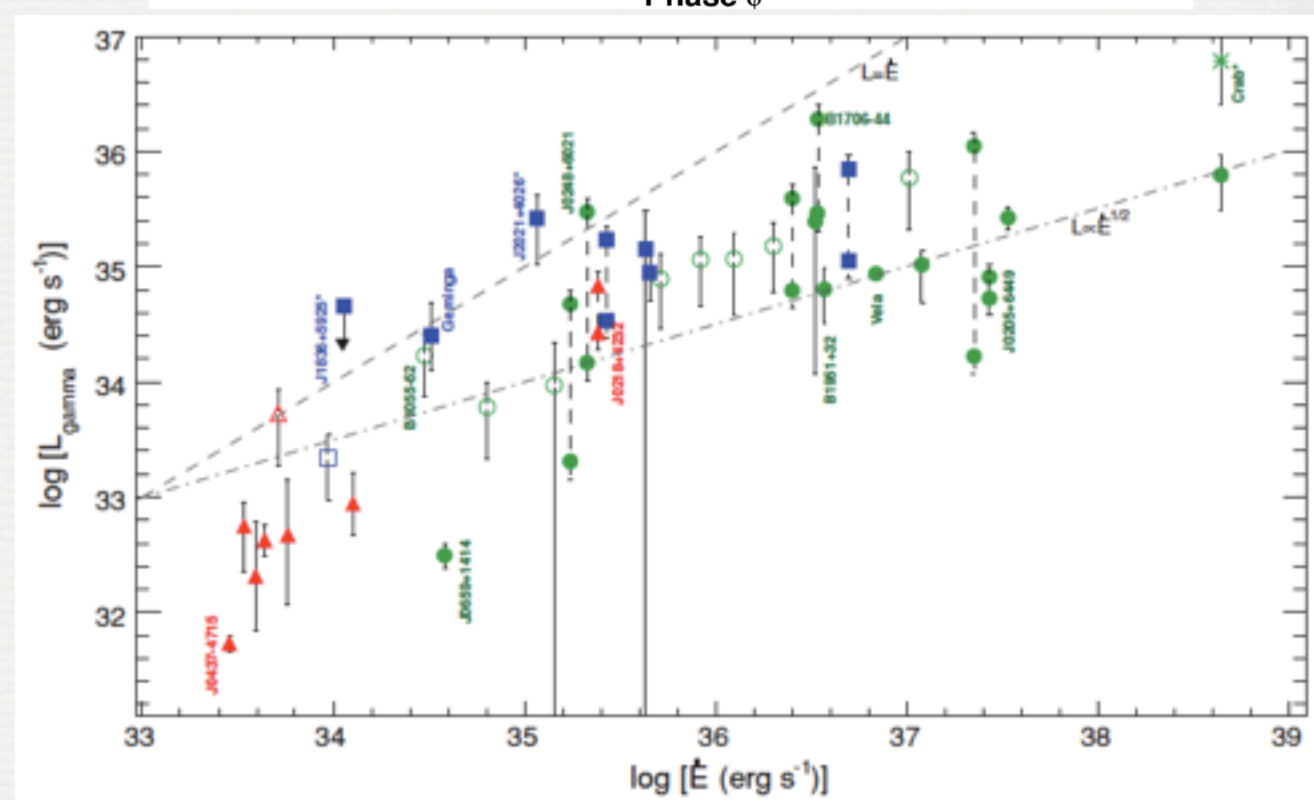
Both detected normal pulsars and MSPs have large values of Edot and B_{LC}. Similar emission mechanisms operating?

The Two-Pole Caustic (TPC) and the Outer Gap (OG) models generally provide good fits to the observed light curves of both normal pulsars and MSPs.

Gamma-ray spectra of MSPs and normal pulsars are very similar, and consistent with predictions of TPC and OG.

The luminosity grows with spin-down energy Edot. Exact relationship unclear.

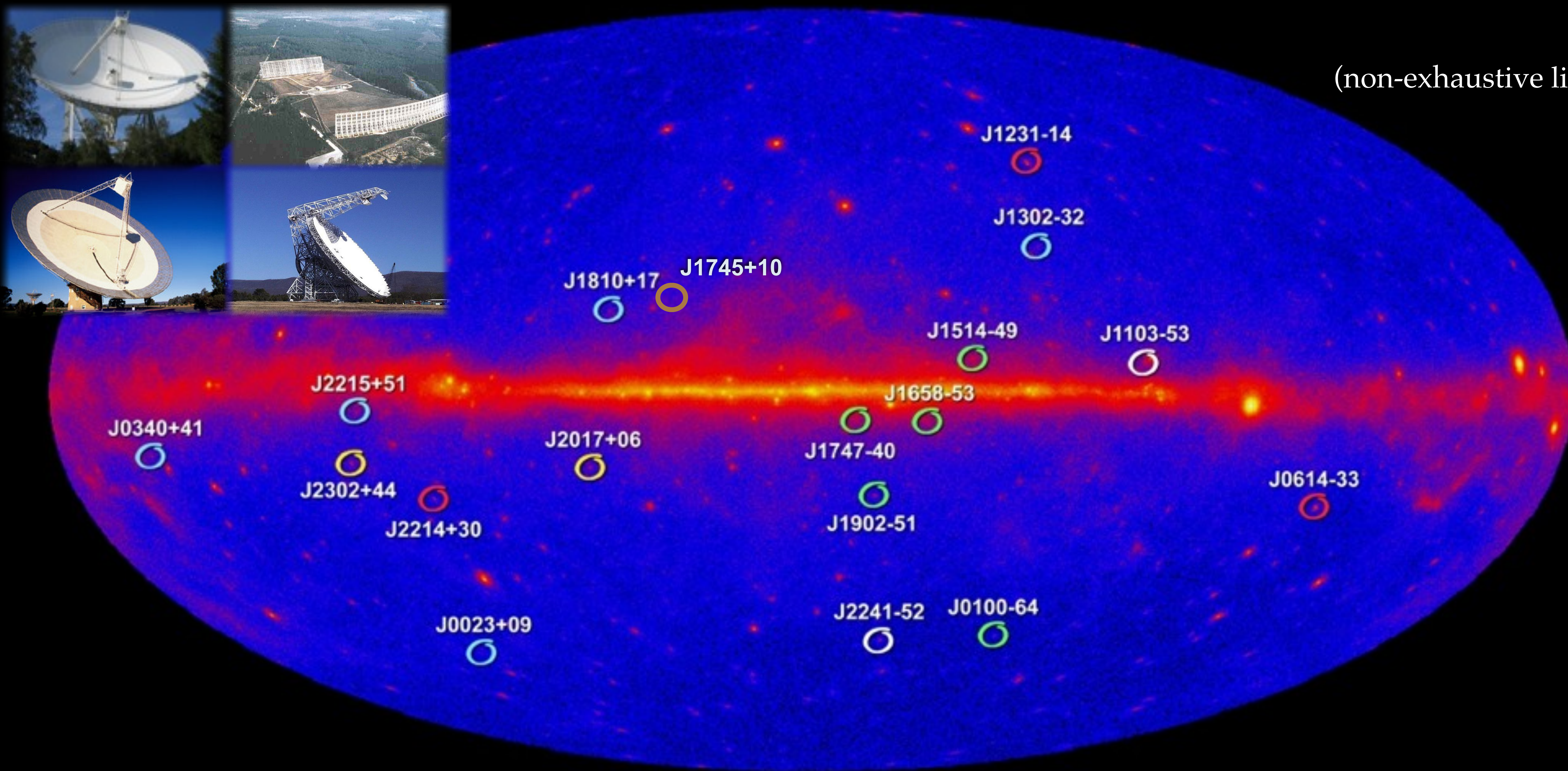




Top: OG (green) and TPC (magenta) fits to J0030+0451's light curve, see Venter, Harding & Guillemot, ApJ 707, 800, 2009.

Bottom: gamma-ray luminosity versus spin-down energy for the catalog pulsars, see Abdo et al., ApJS 187, 460, 2010.

New MSPs in Fermi unidentified sources!



Led by Fernando Camilo (Columbia Univ.) using Australia's CSIRO Parkes Observatory
Led by Mallory Roberts (Eureka Scientific/GMU/NRL) using the NRAO's Green Bank Telescope
Led by Scott Ransom (NRAO) using the Green Bank Telescope
Led by Ismael Cognard (CNRS) using France's Nançay Radiotelescope
Led by Mike Keith (ATNF) also using Parkes Observatory

Fermi Gamma-ray Space Telescope

With a typical localization accuracy of several arcmin, Fermi points radio telescopes to unknown pulsars!

Prospects from the new discoveries

20 new galactic-disk MSPs in a few months.
Previously: ~70 in 30 years!

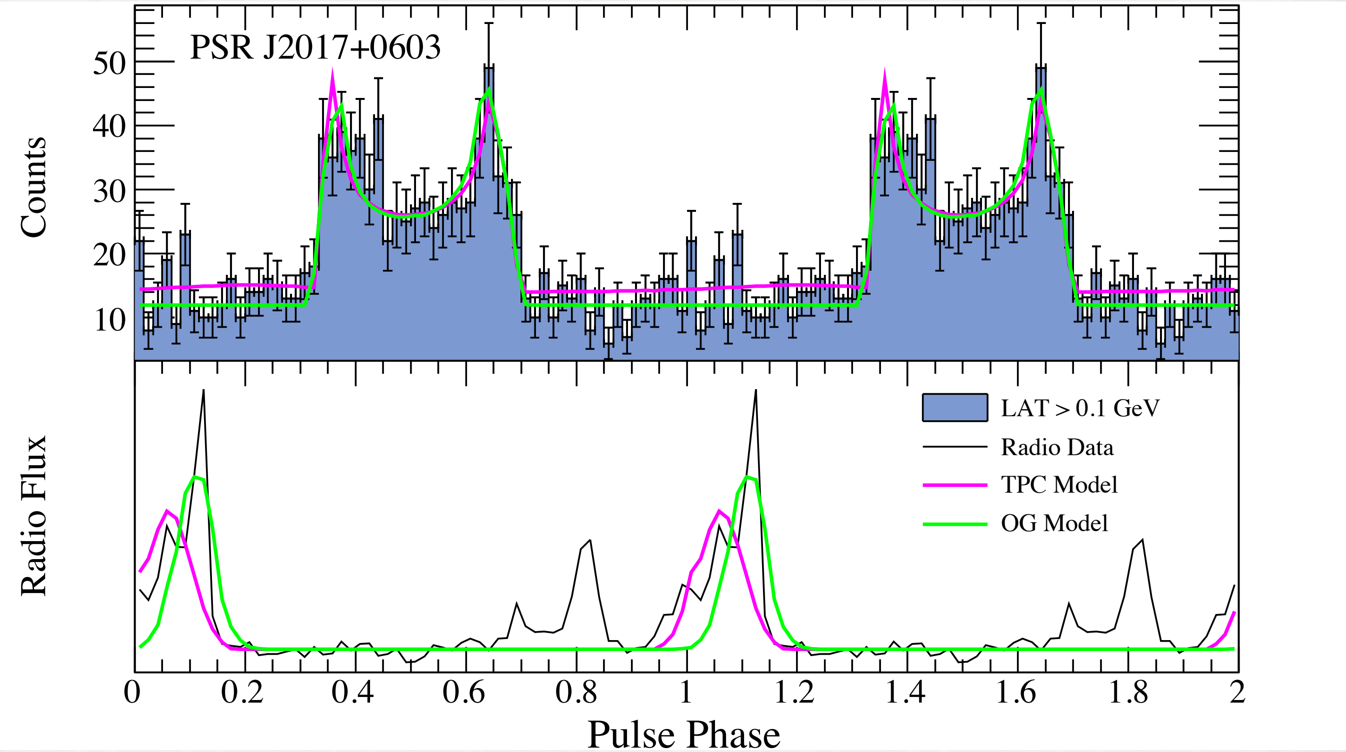
Better understanding of the underlying population of MSPs.

Many new « Black Widow » systems: pulsars and binary evolution.

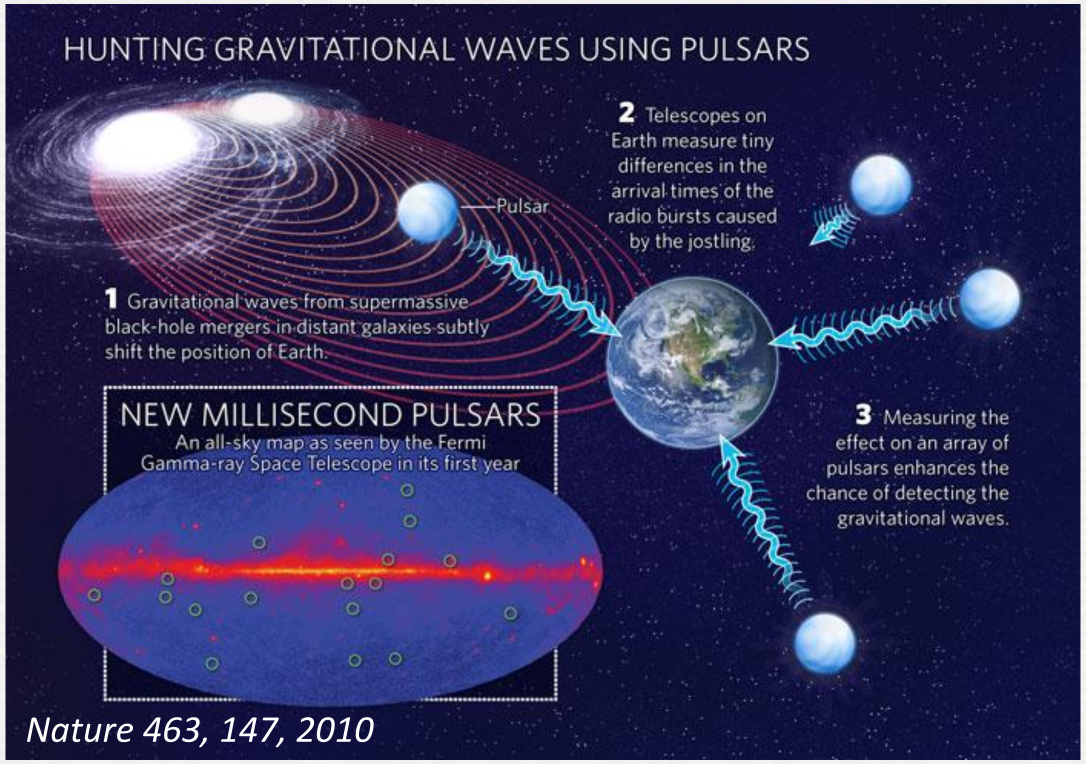
Most probably gamma-ray pulsars. Several pulsed detections already.

Radio timing of MSPs allows:

- ✓ tests of theories of gravity in the strong field regime.
- ✓ neutron star mass measurements.
- ✓ cosmic gravitational wave detector!



(Cognard, Guillemot, et al., ApJ submitted)



Pulsars in Globular Clusters

Globular clusters are known to host large populations of millisecond pulsars.

The LAT has detected gamma-ray emission from 8 globular clusters.

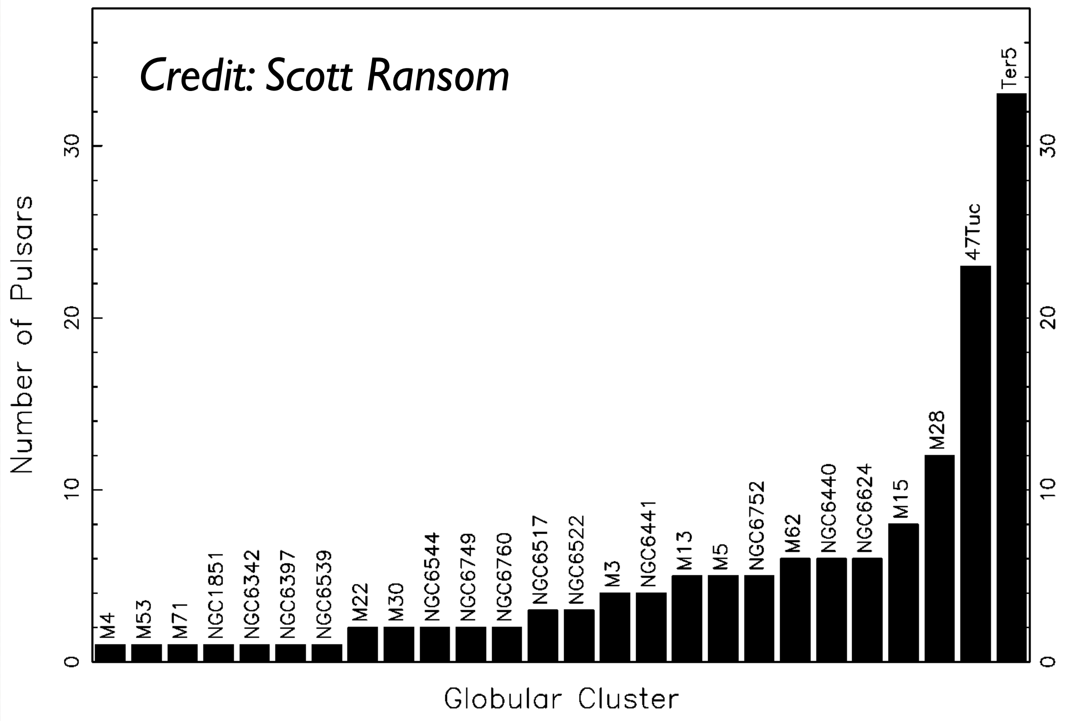
The observed emission is consistent with the added contribution of realistic numbers of gamma-ray MSPs.

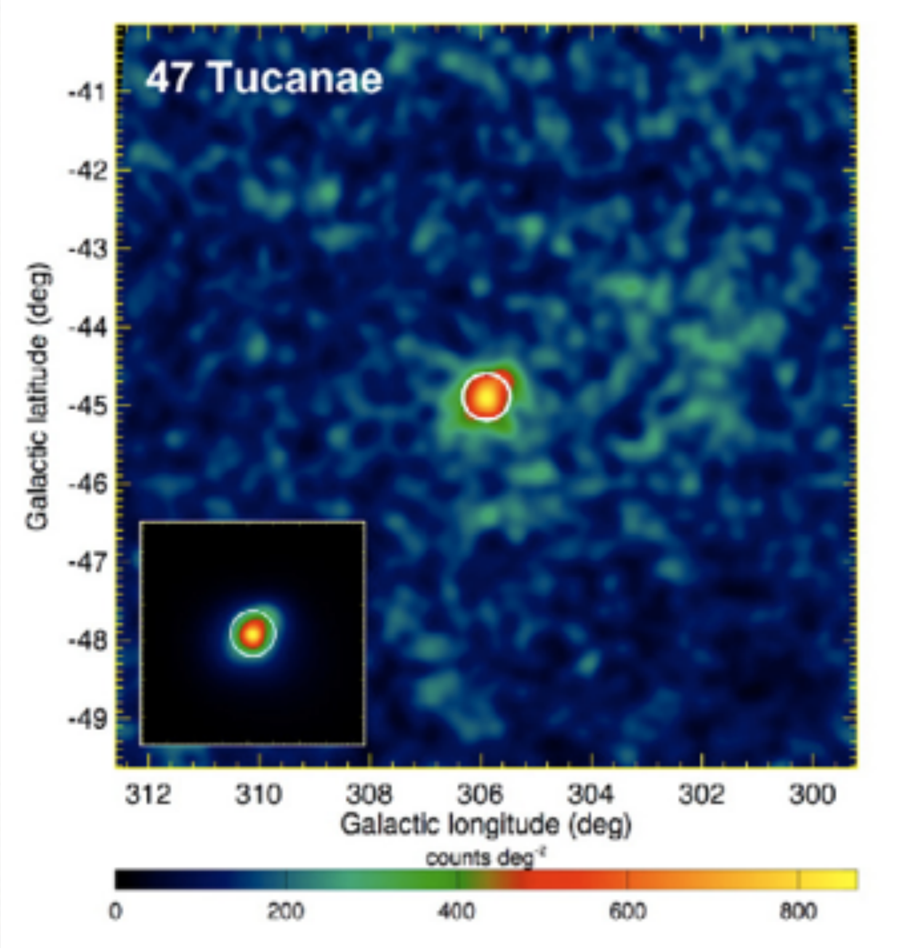
47 Tucanae: 33 +/- 15 MSPs, vs 23 observed in radio.

Pulsed searches are underway. Gamma-ray pulsations already detected from one, PSR J1823-3021A in NGC6624!

(See Abdo et al., Science 345, 845, 2009;

Abdo et al., A&A 524, 75, 2010)





Summary

>70 pulsars detected in gamma rays after two years of Fermi mission:

- either detected using radio ephemerides
- by blind searching the gamma-ray data
- by observing Fermi unidentified sources in radio.

From light curve shapes and spectral properties, outer magnetospheric models are preferred.

Globular clusters seen in gamma rays, with properties that resemble those of MSPs.

Fermi points radio telescopes to unknown galactic disk MSPs. 30% increase in 1 year!

Prospects

- Continue radio/X-ray followup of Fermi pulsars and unidentified sources.
- Use Fermi data to improve / constrain / reject theoretical models.
- What is the contribution of gamma-ray pulsars to the diffuse emission?
- Are there transient gamma-ray pulsars?
- Can we find radio-quiet MSPs?