

# *Pulsar observations with the Fermi LAT*

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*on behalf of the Fermi LAT Collaboration*

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# The *Fermi* Gamma-ray Space Telescope



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

Launched on 11 June 2008. Expected  
lifetime: at least 5 to 10 years.

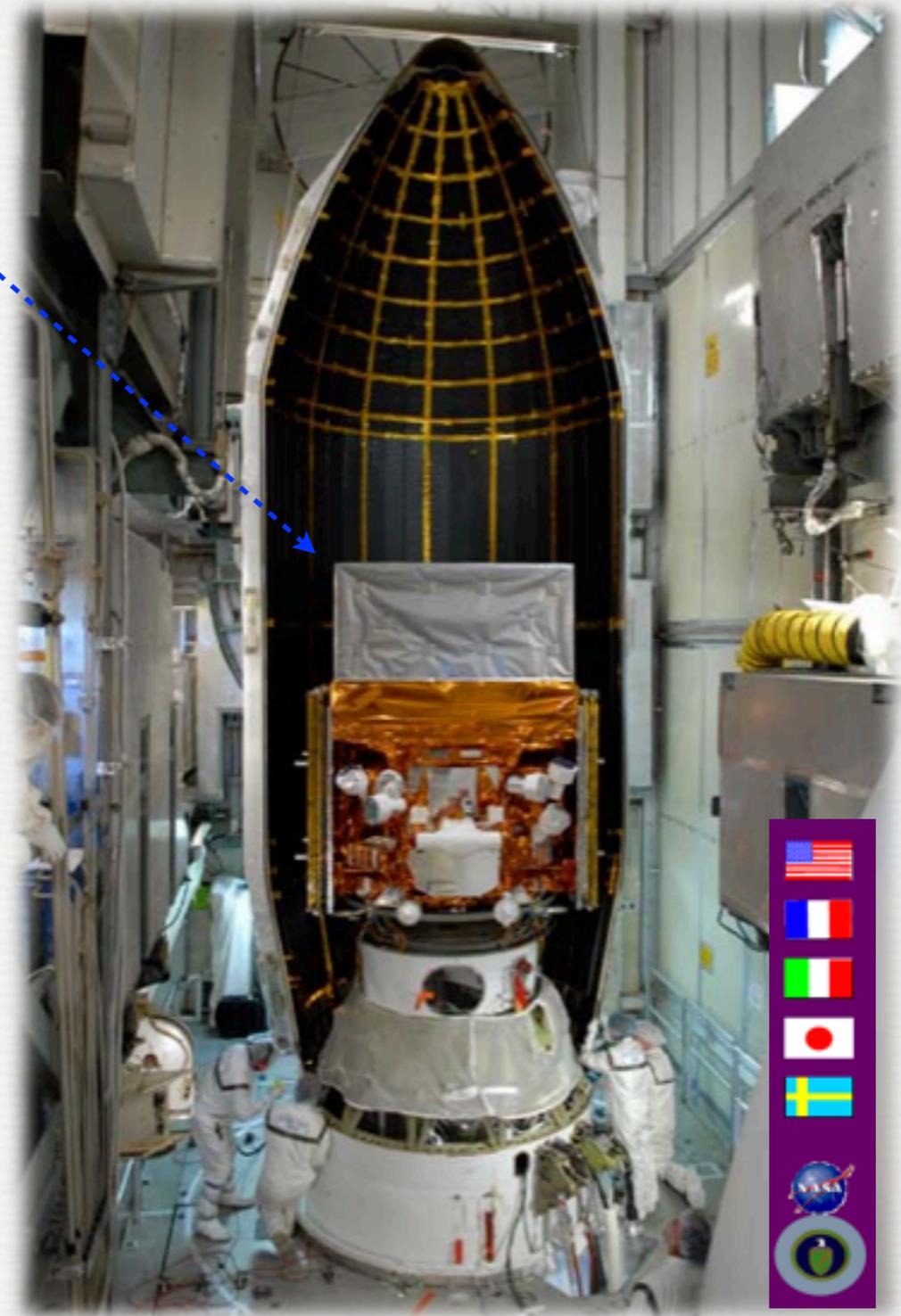
Energy range: 20 MeV to >300 GeV  
(including unexplored 10 - 100 GeV).

Area of 8000 cm<sup>2</sup>, viewing angle of 2.4 sr.

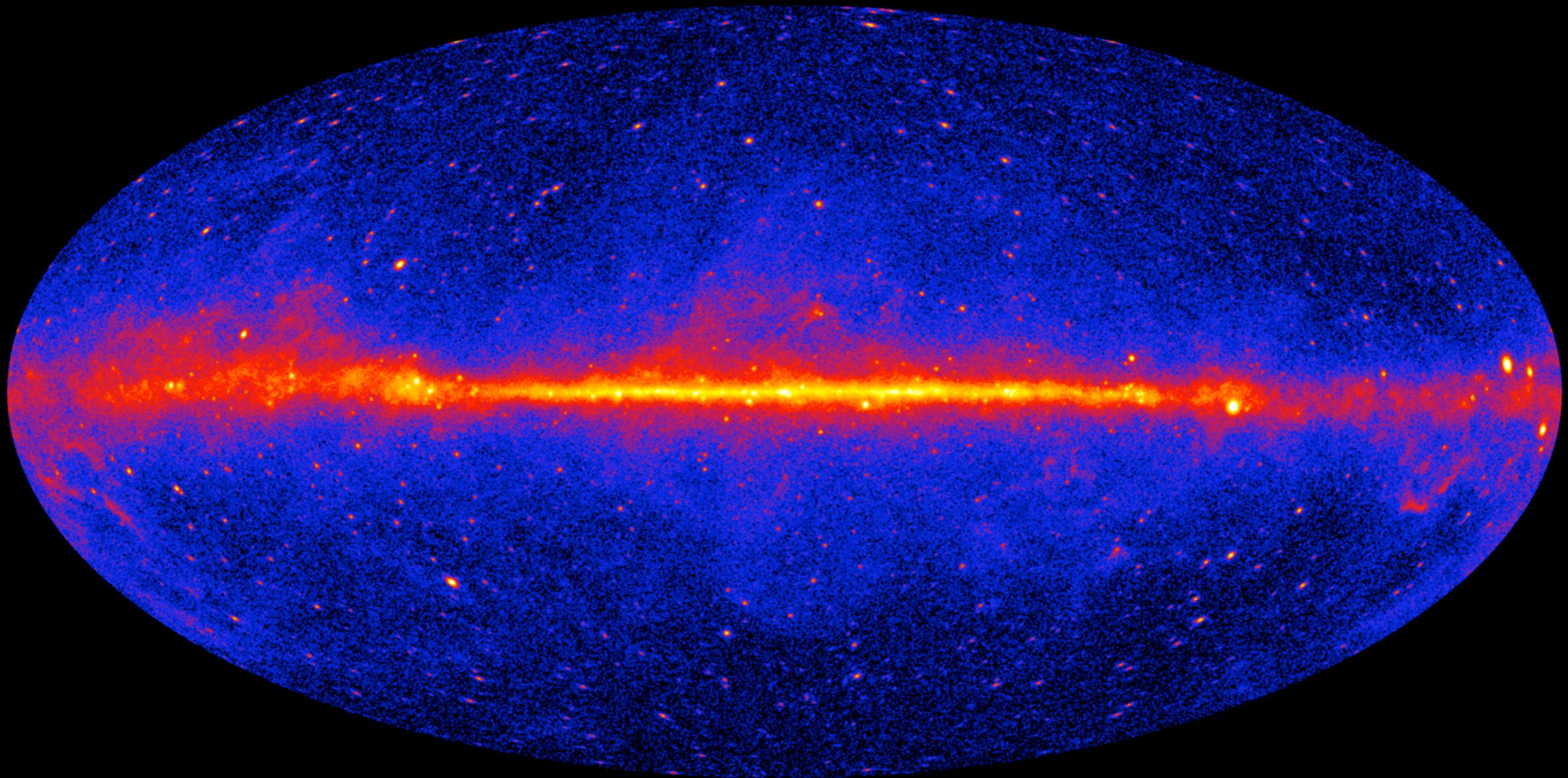
Survey strategy. Entire sky seen every 3h.

Timing accuracy < 1  $\mu$ s.

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

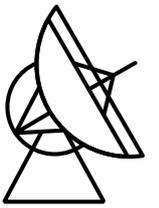


# *Fermi* LAT 3-year intensity map

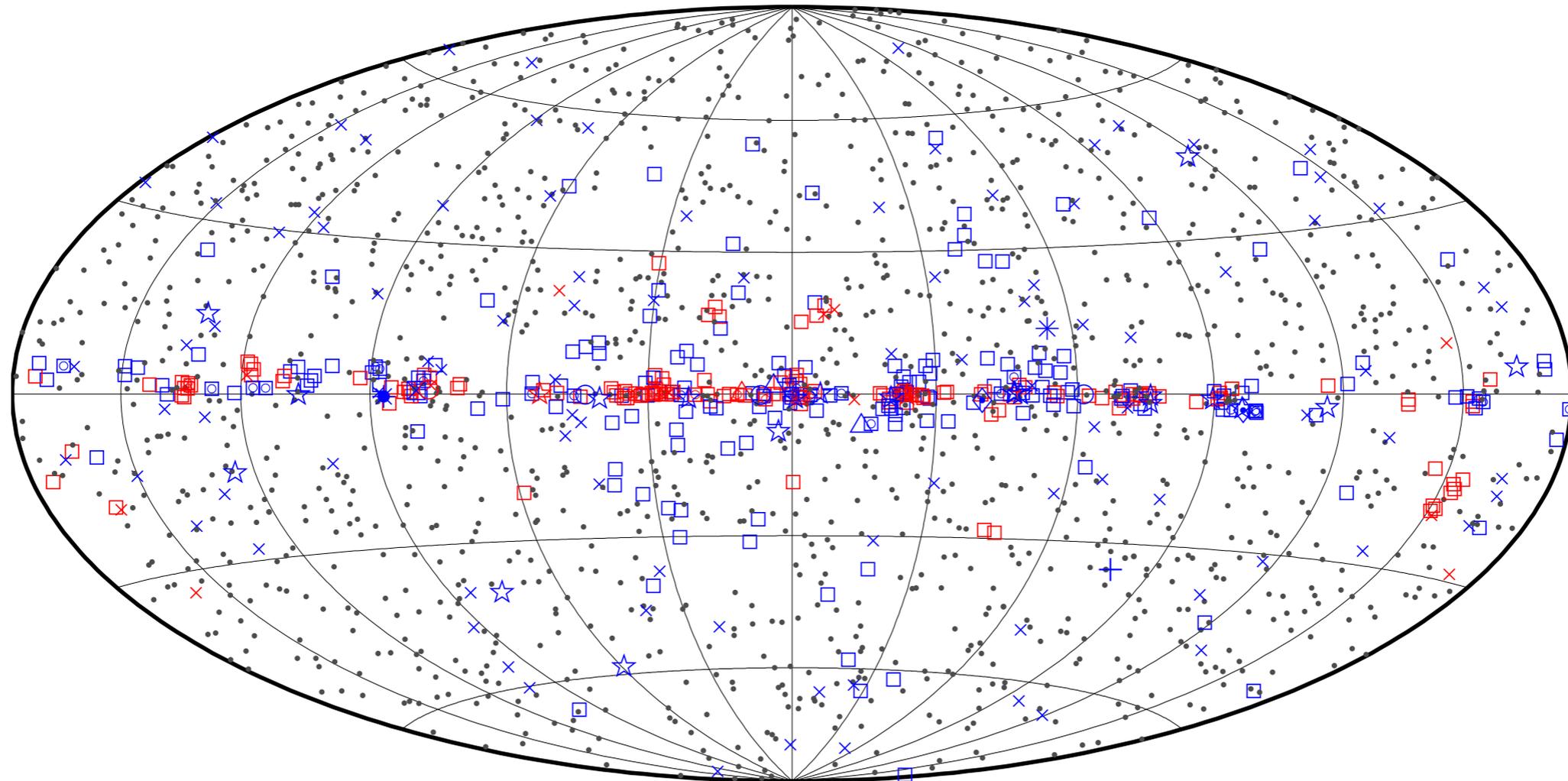


Pass 7.6 Source class events from August 4, 2008 through August 4, 2011.  
 $E > 1$  GeV, rocking angle  $< 52^\circ$  and zenith angle  $< 100^\circ$ .

# The LAT 2-year Point Source Catalog (2FGL)



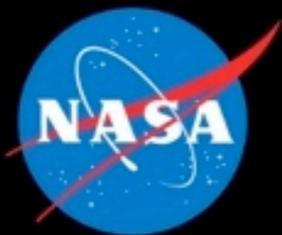
See Nolan et al., ApJS accepted (2012), and [http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr\\_catalog/](http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/)



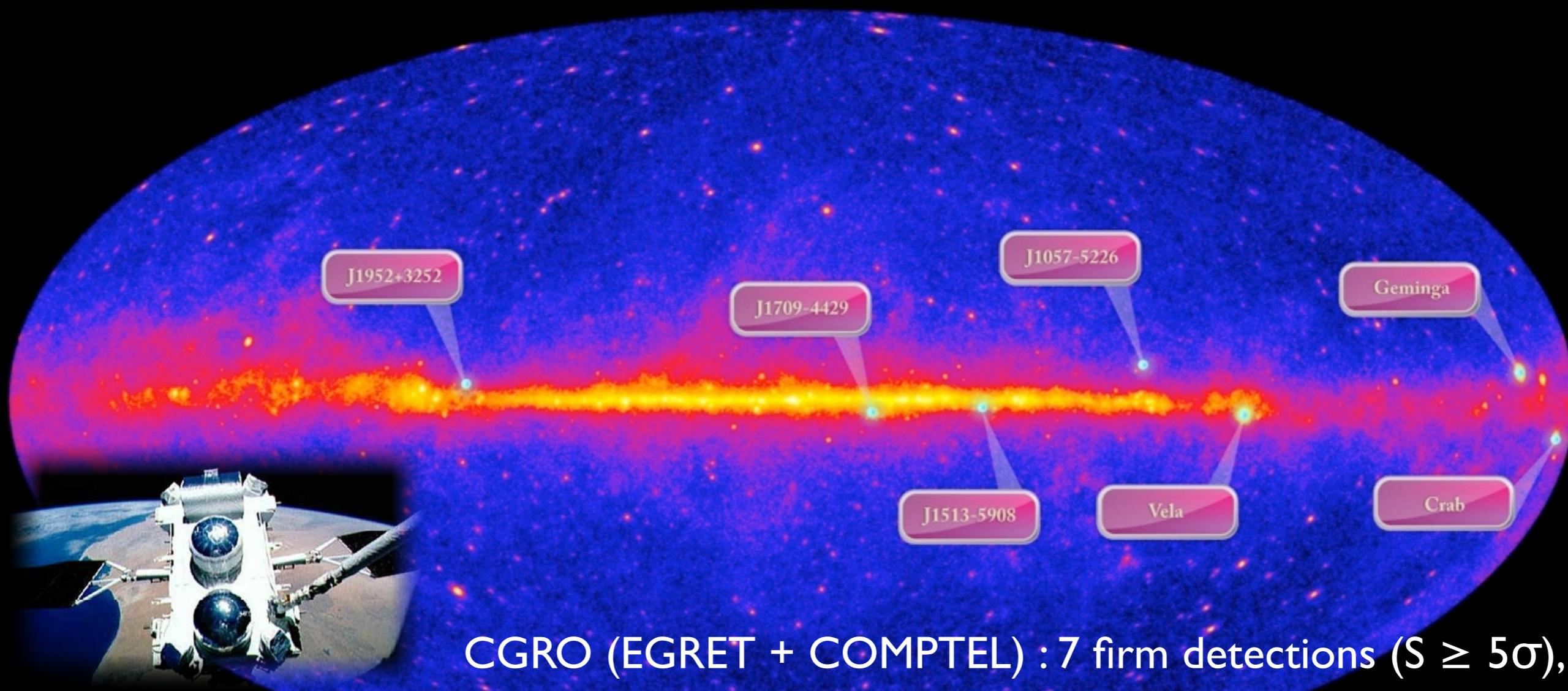
□ No association	⊠ Possible association with SNR or PWN	△ Globular cluster
× AGN	☆ Pulsar	⊠ HMB
* Starburst Gal	◇ PWN	○ SNR
+ Galaxy	○ SNR	* Nova

1873 sources, including 1062 associated with blazars and other AGNs, 11 GCs, 5 binaries, 576 «unassociated».

Galactic plane: mainly pulsars and pulsar wind nebulae.



# Gamma-ray Pulsars before Fermi



CGRO (EGRET + COMPTEL) : 7 firm detections ( $S \geq 5\sigma$ ),  
3 marginal ones ( $3\sigma \leq S < 5\sigma$ ).

AGILE : 2 firm detections, 6 marginal ones.

**< 10  $\gamma$ -ray pulsars at the beginning of the *Fermi* mission!**

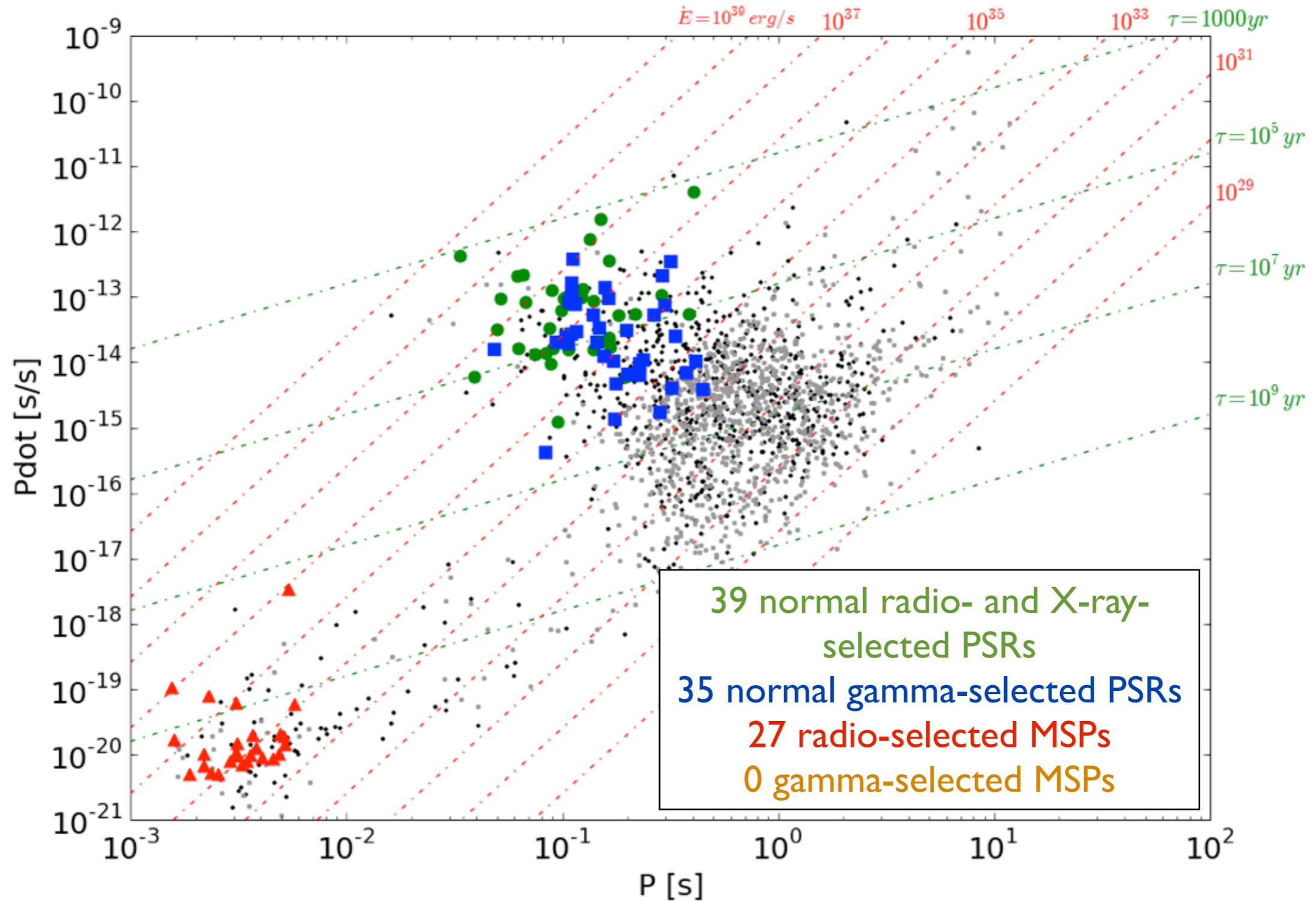


# 101 $\gamma$ -ray pulsars!



List of LAT-detected pulsars available at:

<https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars>



# $\gamma$ -ray pulsations from MSPs



EGRET detected marginally-significant pulsations from PSR J0218+4232.

(Kuiper et al., A&A 359, 615, 2000)

PSR J0030+0451: first ever firm detection of an MSP in  $\gamma$  rays.

(Abdo et al., ApJ 699, 1171, 2009)

**After 3 years, 27 firm detections!**

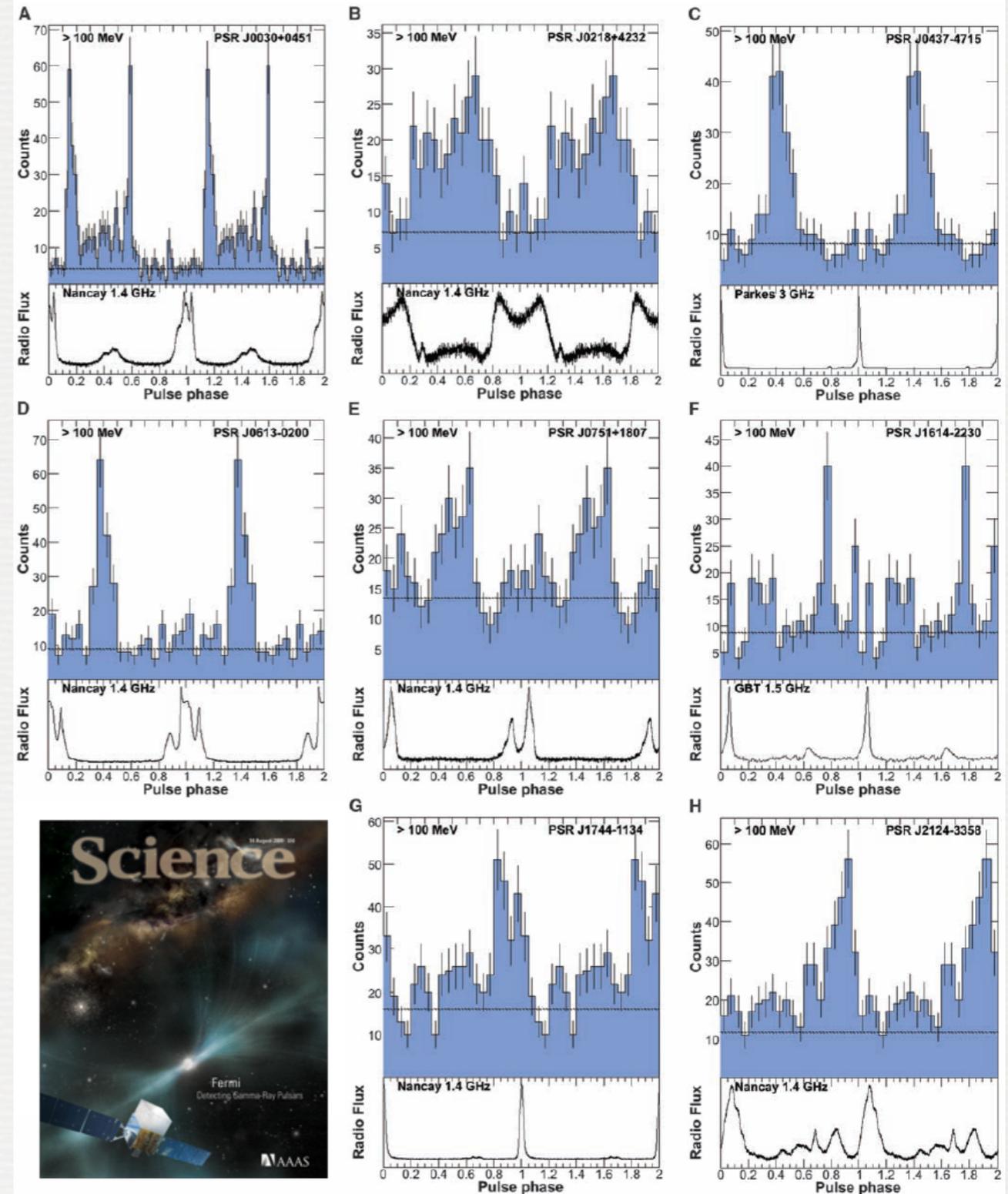
(see e.g. Abdo et al., Science 325, 848, 2009)

A subclass of MSPs with aligned radio/ $\gamma$ -ray pulses has been observed: B1937+21, B1957+20, J0034-0534, J1823-3021A, etc.

(Abdo et al., ApJ 712, 957, 2010,

Guillemot et al., ApJ 744, 33, 2012)

(see presentation by C. Espinoza for a study of radio & gamma-ray profiles of MSPs)



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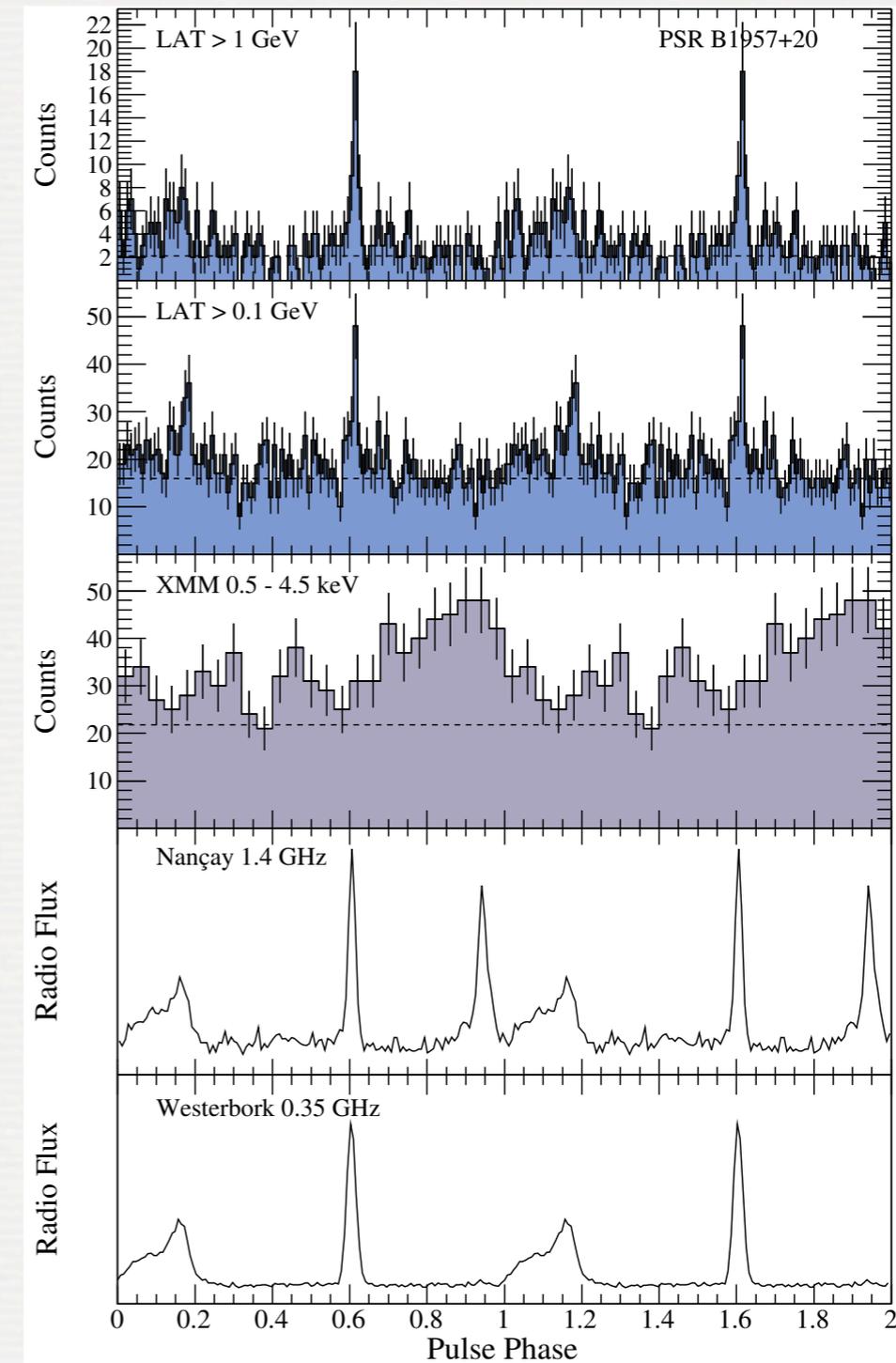
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B1957+20 ( $P = 1.607$  ms): radio and  $\gamma$  rays in close alignment. Co-located radio and  $\gamma$ -ray emission regions, in the outer magnetosphere?



First *Fermi* discovery: « blind » detection of a 317 ms pulsar in the supernova remnant CTA1.

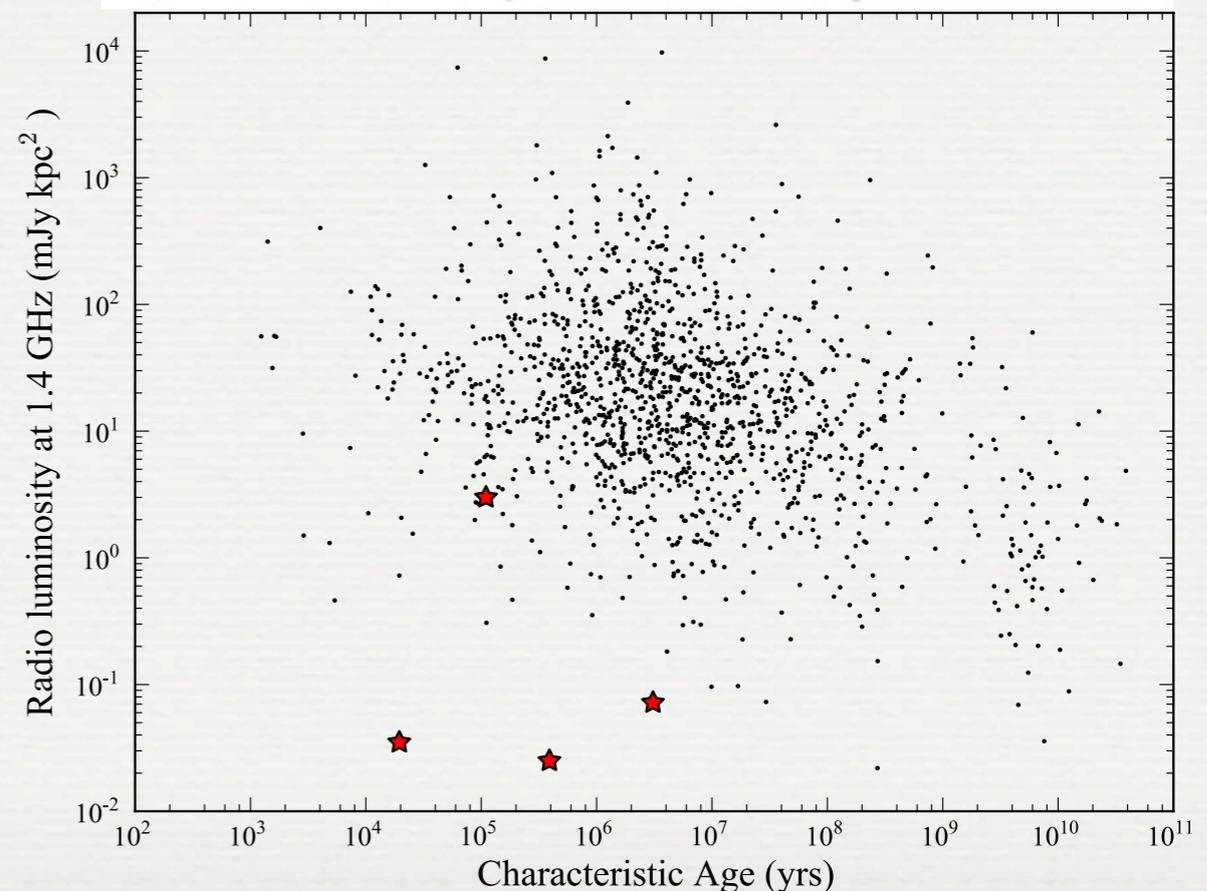
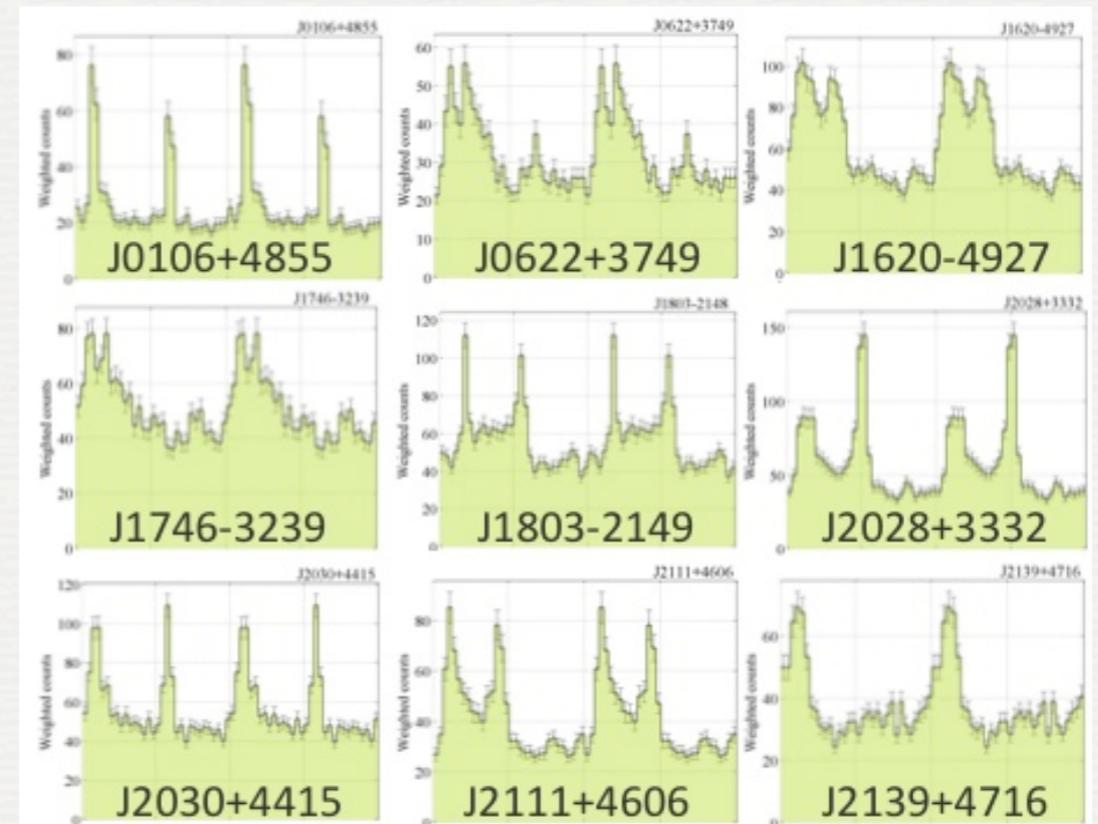
(*Abdo et al., Science 322, 1218, 2008*)

After 3 years, 35 pulsars discovered in the *Fermi* LAT data with the time-differencing technique.

(e.g. *Abdo et al., Science 325, 840, 2009*,  
*Pletsch et al., ApJ, 744, 105, 2012*)

Only 4/35 later detected in radio, with very small fluxes ( $\mu\text{Jy}$  level). Discoveries made significantly easier by *Fermi*!

**Pulsation searches are still underway. Are there radio-quiet MSPs to be found?**



# What is a $\gamma$ -ray pulsar like?

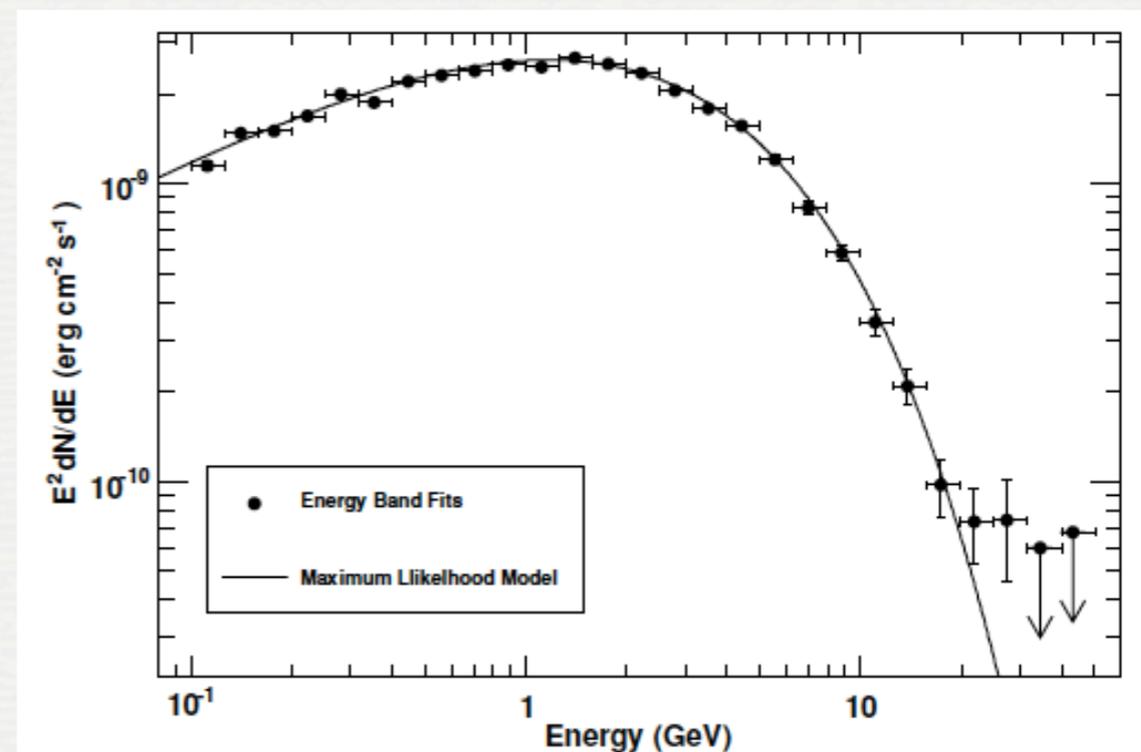
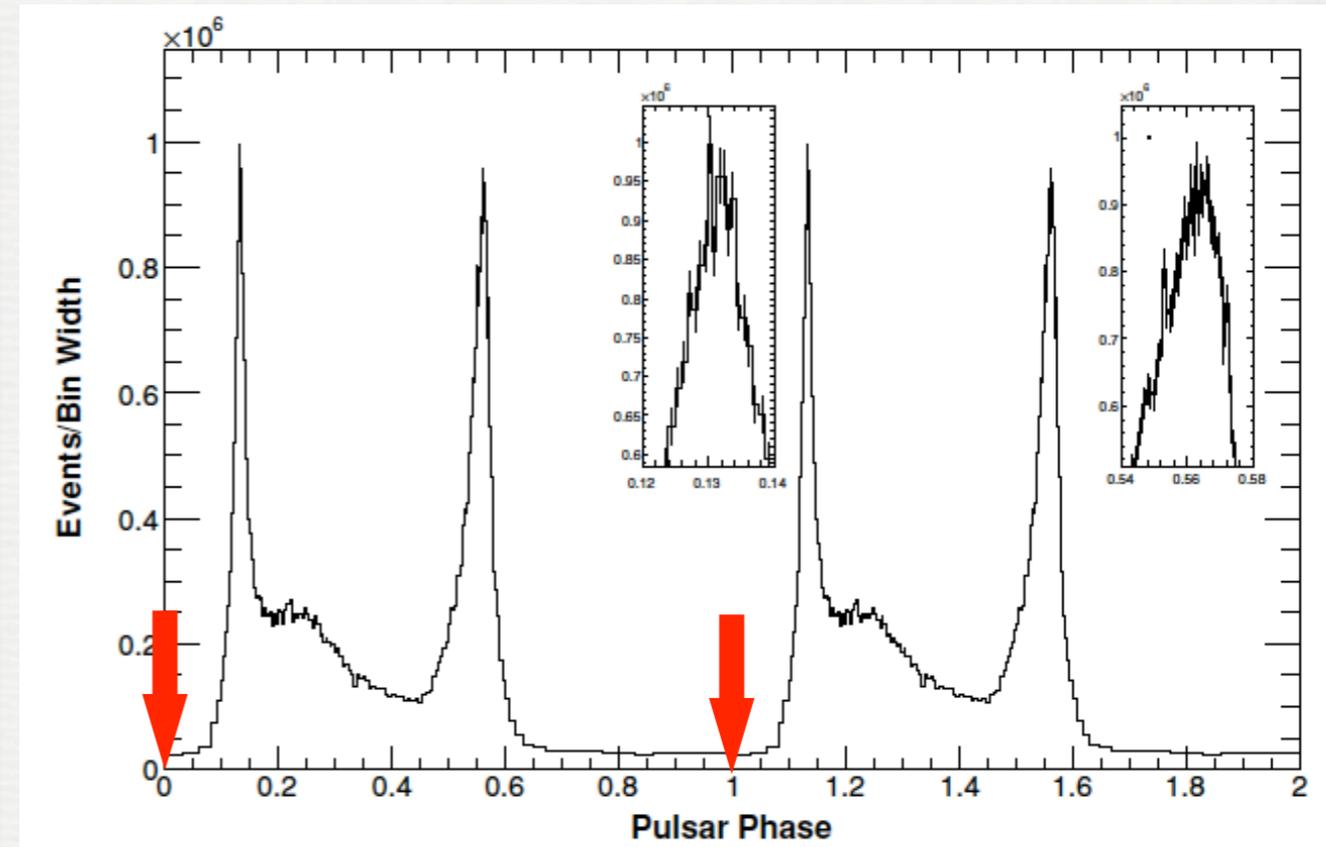


Vela = archetypal  $\gamma$ -ray pulsar.

- two sharp peaks separated by  $\Delta \sim 0.4$ , with bridge emission in between.
- first peak lagging the radio peak (**red arrow**) by  $\sim 0.15$ .
- Spectrum well modeled with an exponentially cut off power law, with  $\Gamma \sim 1.37$ , and  $E_c \sim 3.15$  GeV.
- Spectral properties vary with phase. (See Abdo et al., ApJ 713, 154, 2010)

Common properties among the  $\gamma$ -ray pulsar population.

Outer magnetospheric models are preferred.



# Finding unknown radio pulsars with the LAT



Searches for pulsars in EGRET unidentified sources had modest success, because of poor source localization.

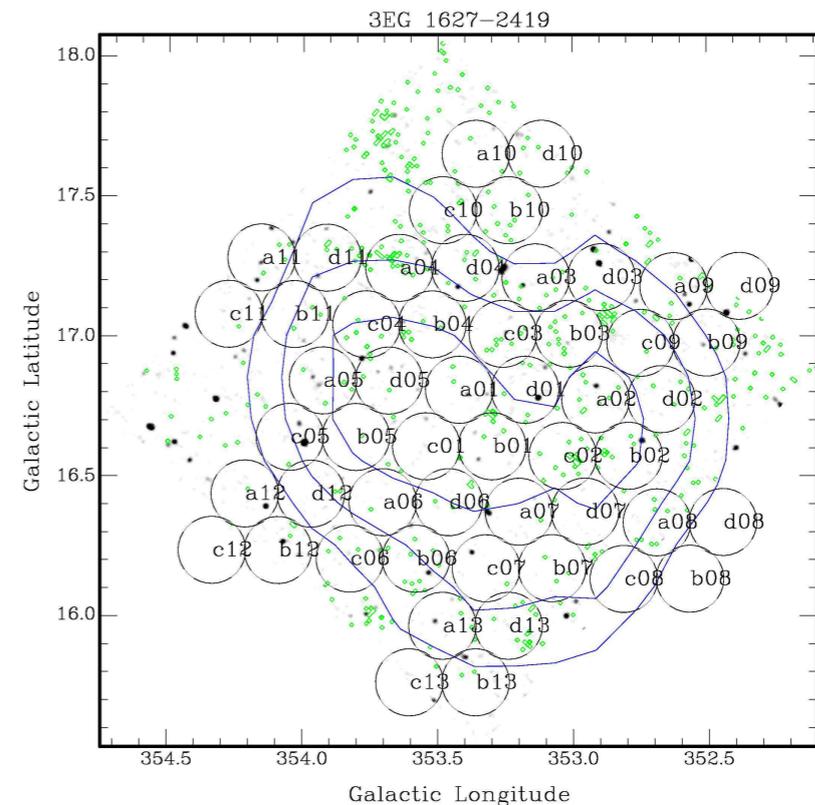
Typical localization accuracy (95% CL):  $< 10'$ .

$\Rightarrow$  same size as radio telescope beams!

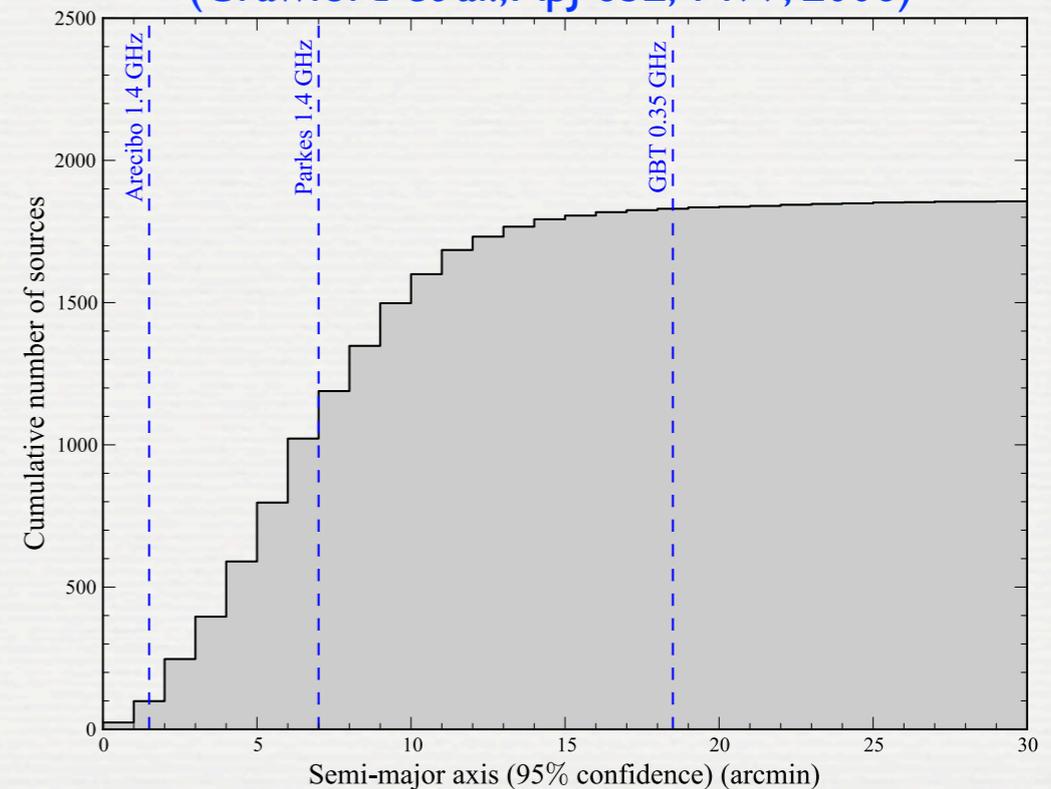
Pulsars can be missed in radio surveys for several reasons: sensitivity, binary motion, dispersion & scintillation, eclipses, insufficient sky coverage...

30% of the 2FGL sources are unassociated.

Best targets have pulsar-like spectra.

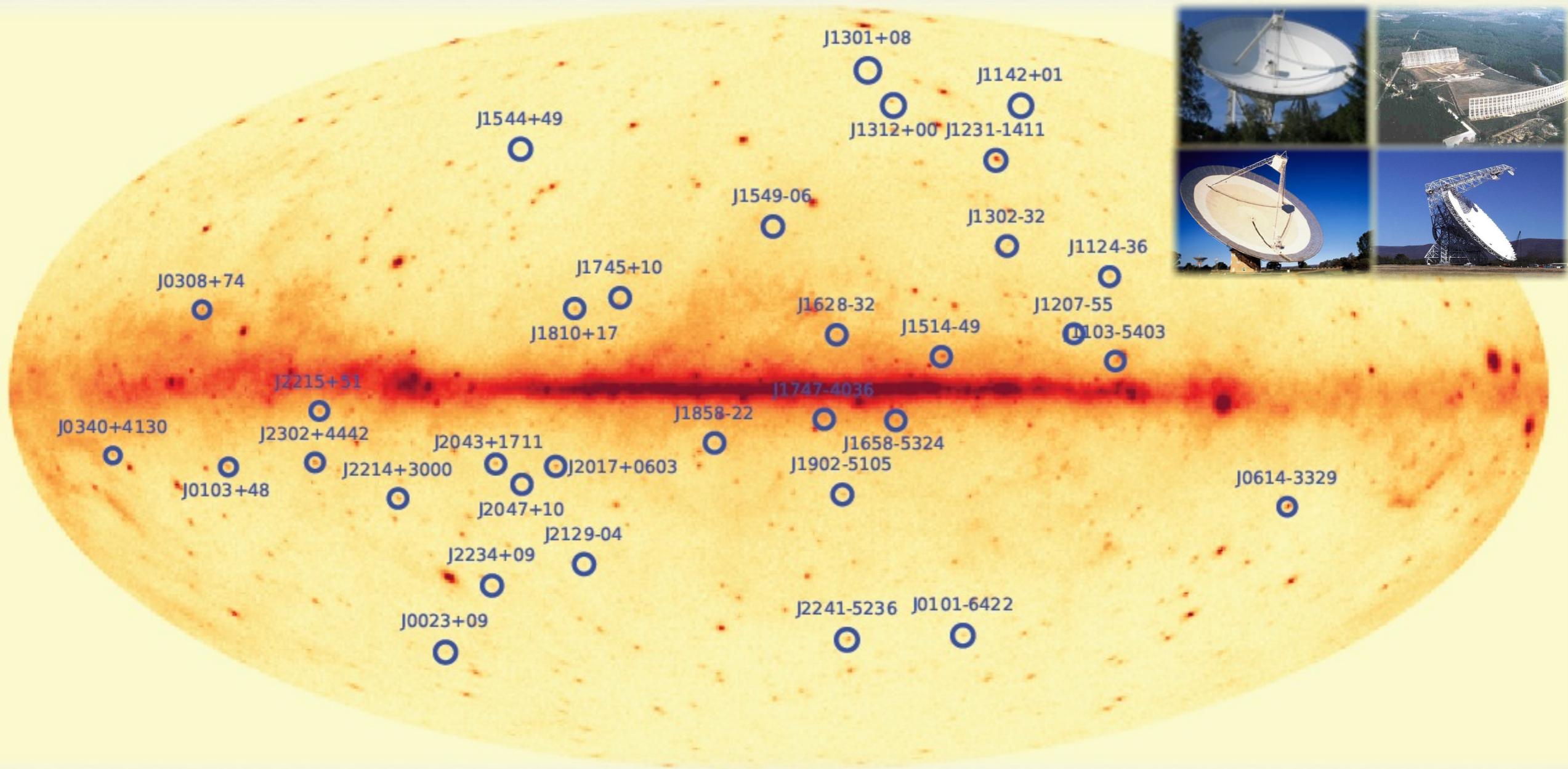


Radio pointings required to cover 3EG 1627-2419  
(Crawford et al., ApJ 652, 1499, 2006)



Distribution of 2FGL source localization accuracies | 0

# 35 new MSPs in *Fermi* unassociated sources!



35 new Galactic disk MSPs in 2 years >> 70 in the previous 30 years!



Better understanding of the underlying population of MSPs.

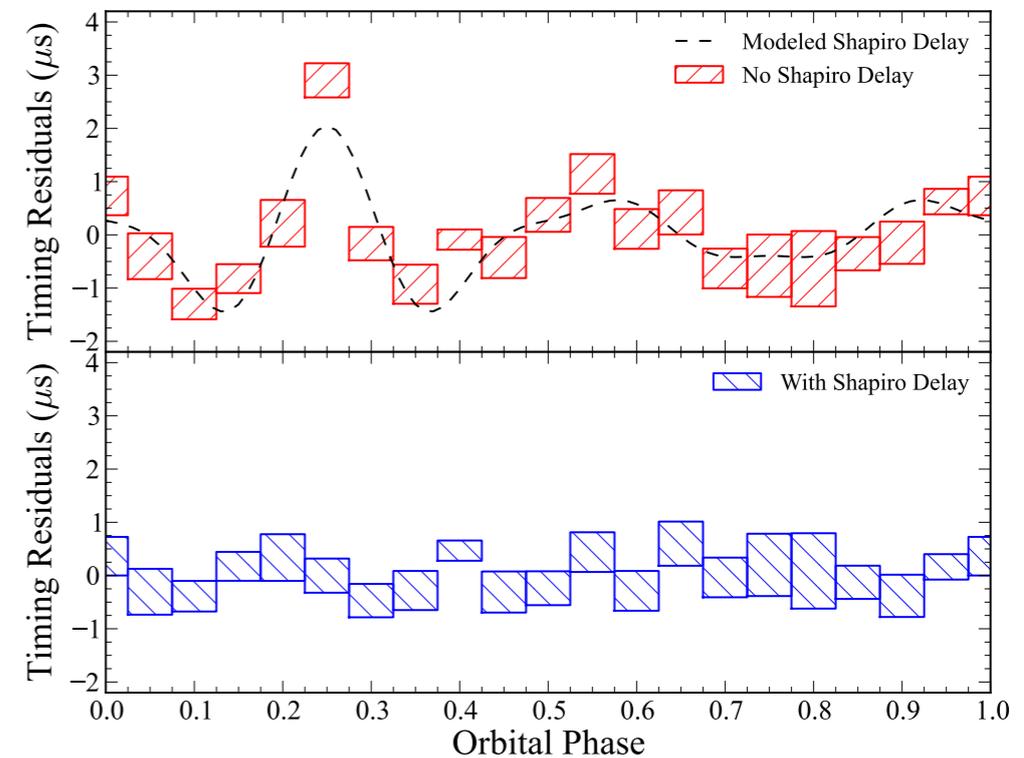
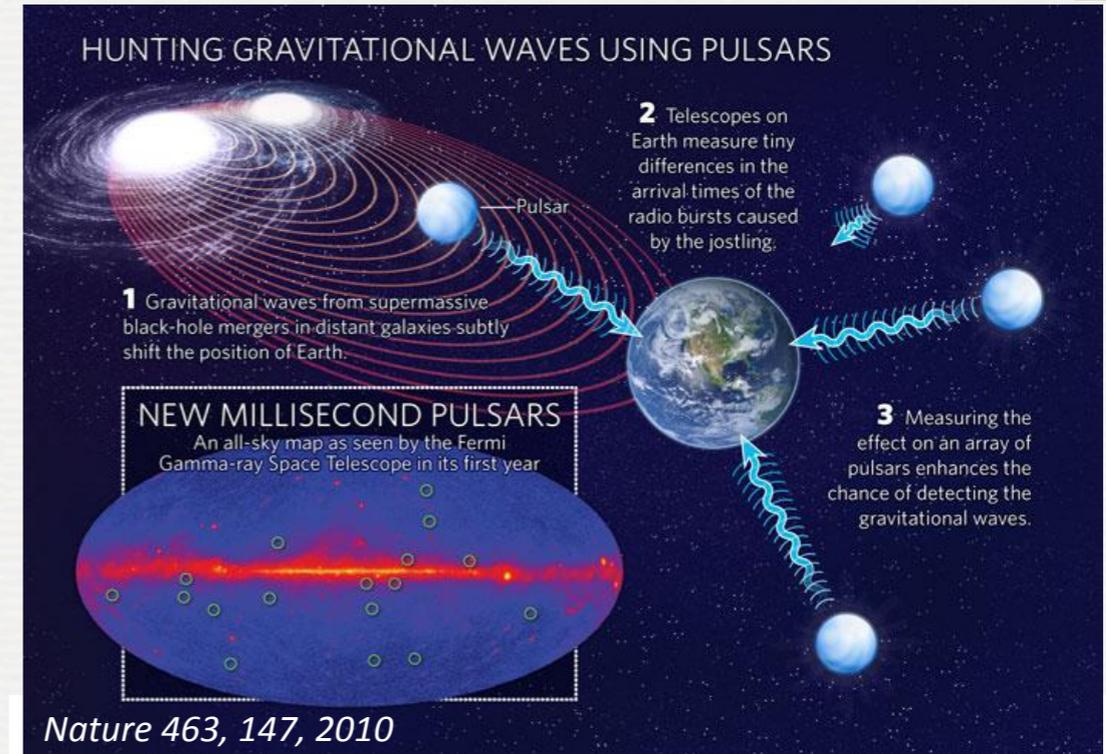
At least 9 « Black Widow » systems (only ~4 previously outside of globular clusters)

At least 4 « Red Backs »: eclipsing pulsars with  $\sim 0.2 M_{\text{sun}}$  companions.

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

Radio timing of MSPs allows:

- tests of theories of gravity.
- neutron star mass measurements.
- cosmic gravitational wave detector!



Detection of the Shapiro delay for PSR J2043+1711!

(Guillemot et al., MNRAS in press, [astro-ph/1202.1128G](https://arxiv.org/abs/1202.1128G))



101 pulsars detected in  $\gamma$  rays after 3 years of *Fermi* mission, including 27 MSPs.

**Pulsars are the dominant class of Galactic  $\gamma$ -ray sources. Pulsar emission from globular clusters also detected!**

***Fermi* points radio telescopes to unknown galactic disk MSPs. 50% population increase!**

2nd Pulsar Catalog paper in preparation.

Radio/X-ray follow-up of *Fermi* sources will continue. More pulsars to be found.

**Thank you for your attention!**

