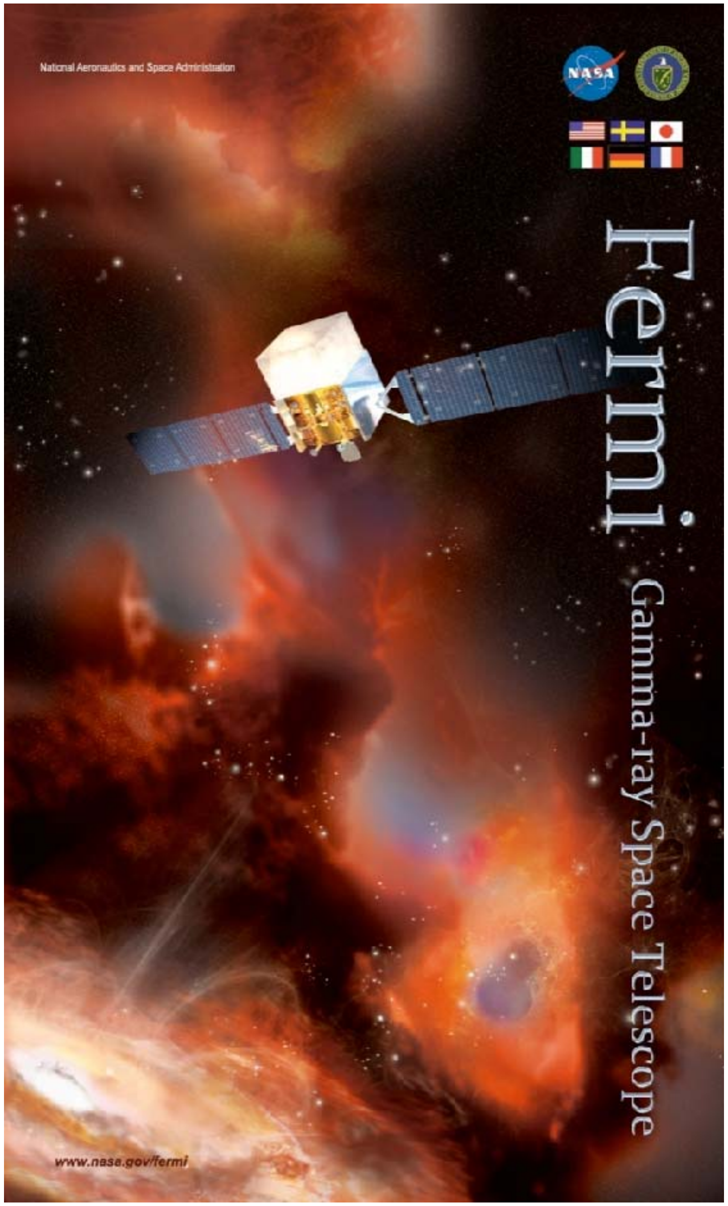


High Energy pulsars with Fermi LAT

F. Giordano
Physics Dep. and INFN Bari

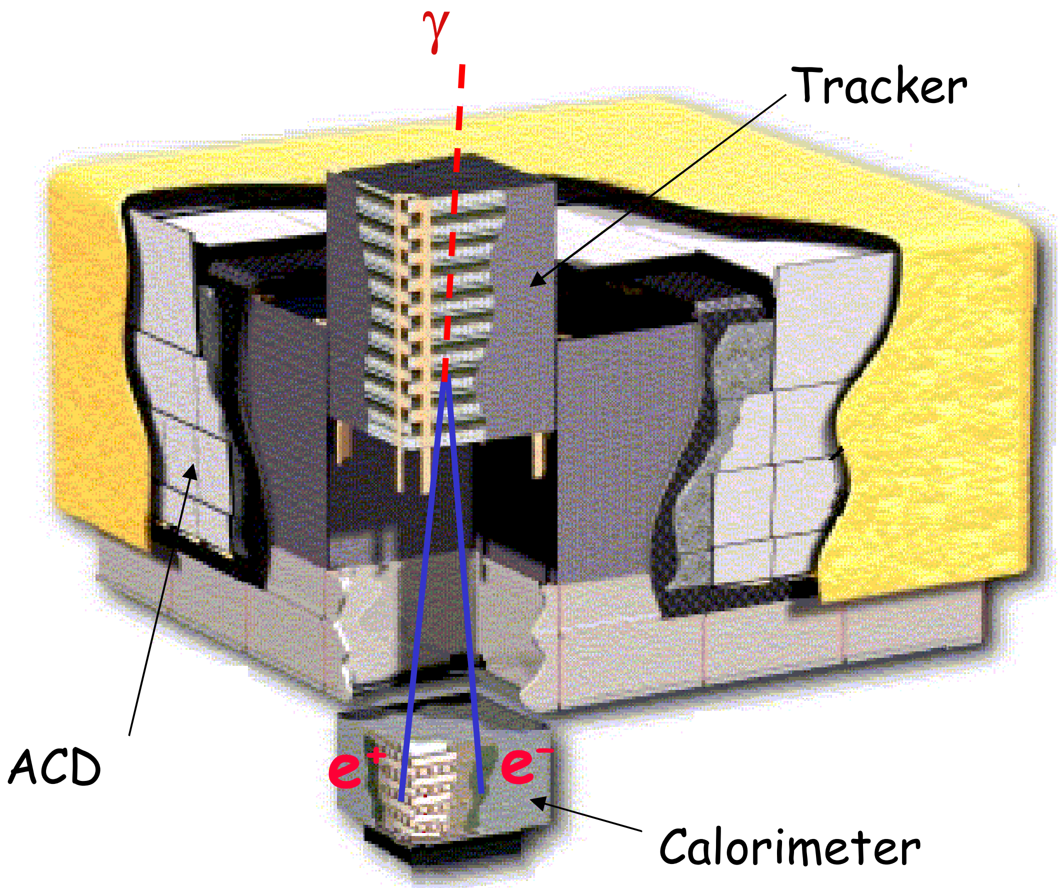
On behalf of the Fermi-LAT Collaboration and the Pulsar timing consortium

SciNeGHE 2009

Fermi
Gamma-ray
Space Telescope

The Hardware

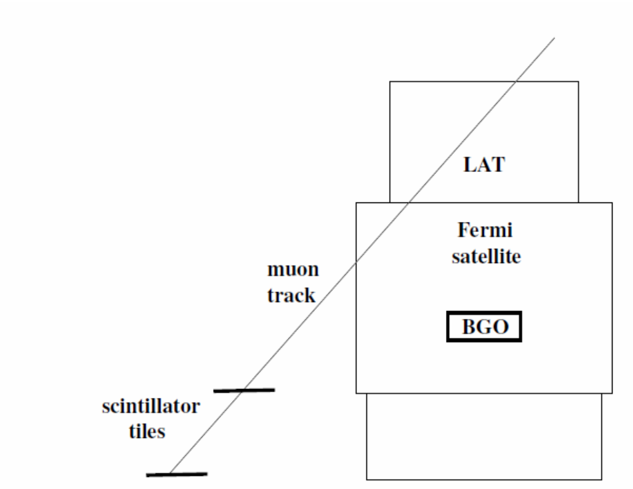
- **Precision Si-strip Tracker (TKR)** Measure the photon direction; gamma ID.
- **Hodoscopic CsI Calorimeter (CAL)** Measure the photon energy; image the shower.
- **Segmented Anticoincidence Detector (ACD)** Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- **Electronics System** Includes flexible, robust hardware trigger and software filters.



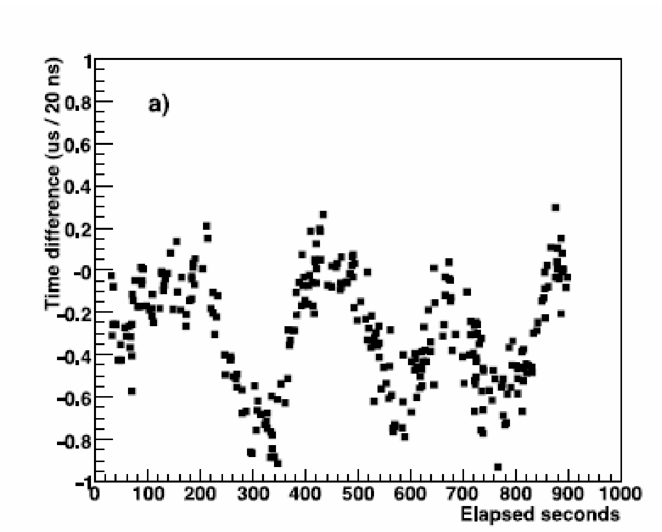
Atwood et al, ApJ submitted

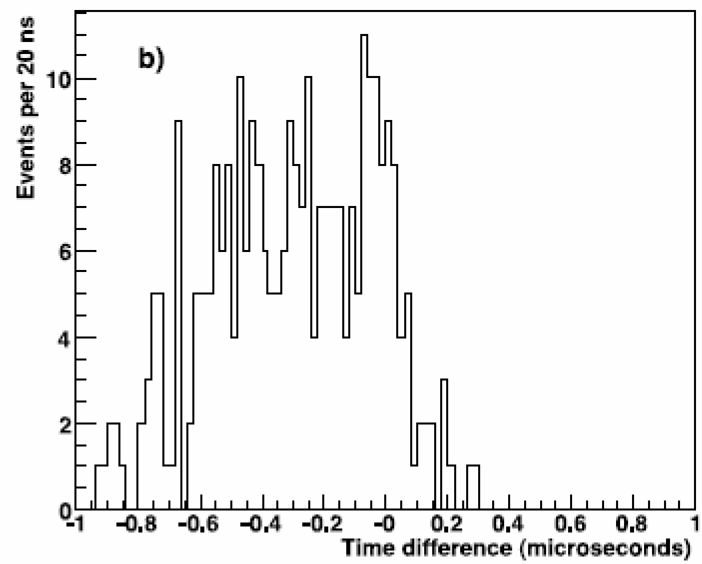
Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

LAT Timing



Reconstructed muon tracks traversing the LAT detector were extrapolated to their impact point on the laboratory door and their timestamps were measured with respect to the GPS of the Fermi satellite. If a muon passed through the pair of scintillators placed next to Fermi, a GPS timestamp from a standalone VME data acquisition system was also recorded



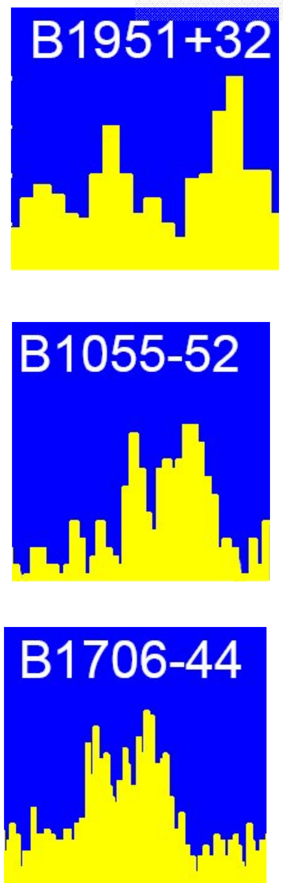


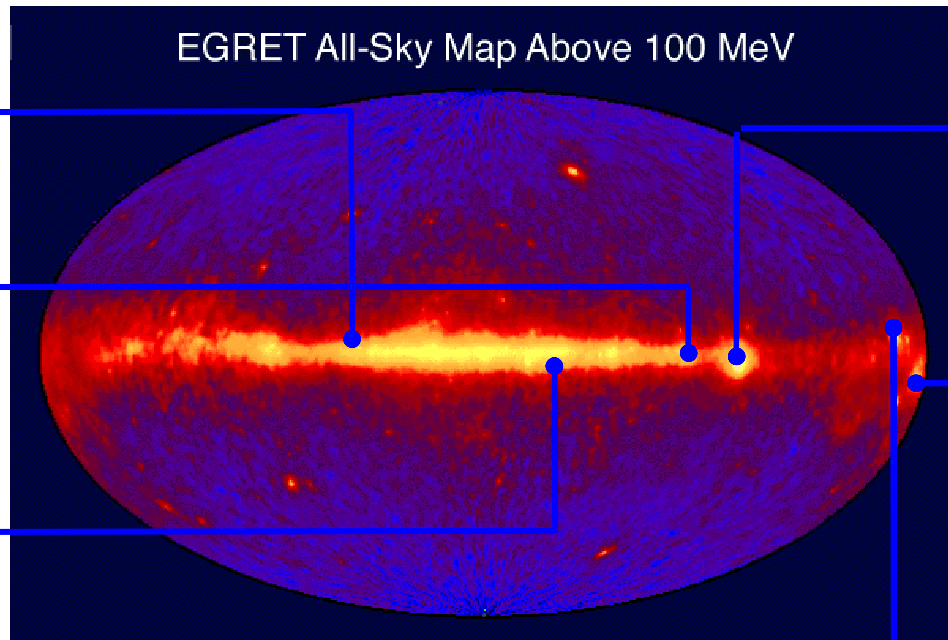
"The On-orbit calibration of the Fermi Large Area Telescope"
arXiv:0904.2226v1 [astro-ph.IM] 15 Apr 2009

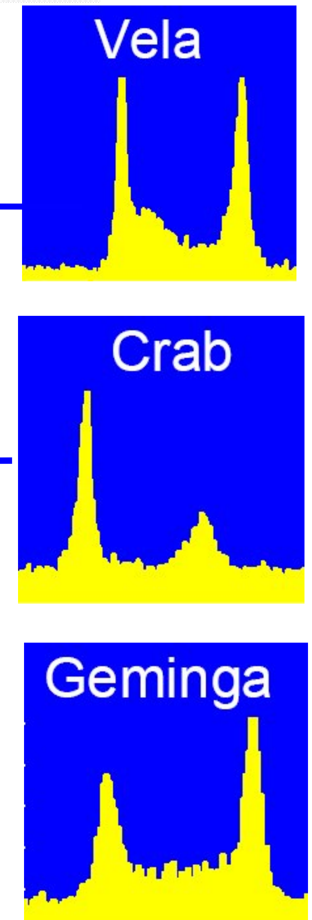
The EGRET Heritage

Vela, Crab & Geminga are the brightest sources in the Gamma-ray sky

Their Flux for E>100MeV $10^{-5} \div 10^{-6}$ph/cm^{2}s

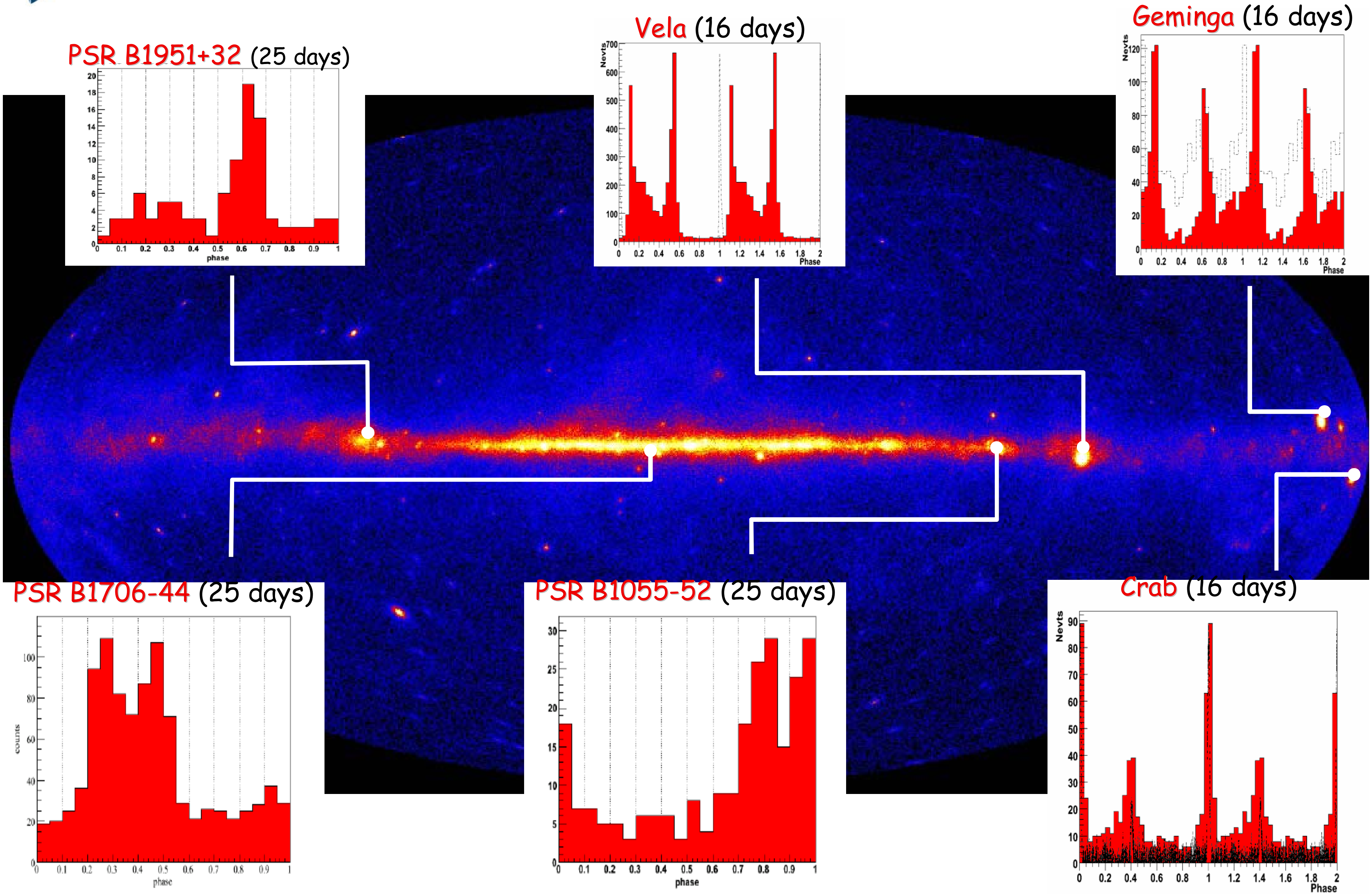




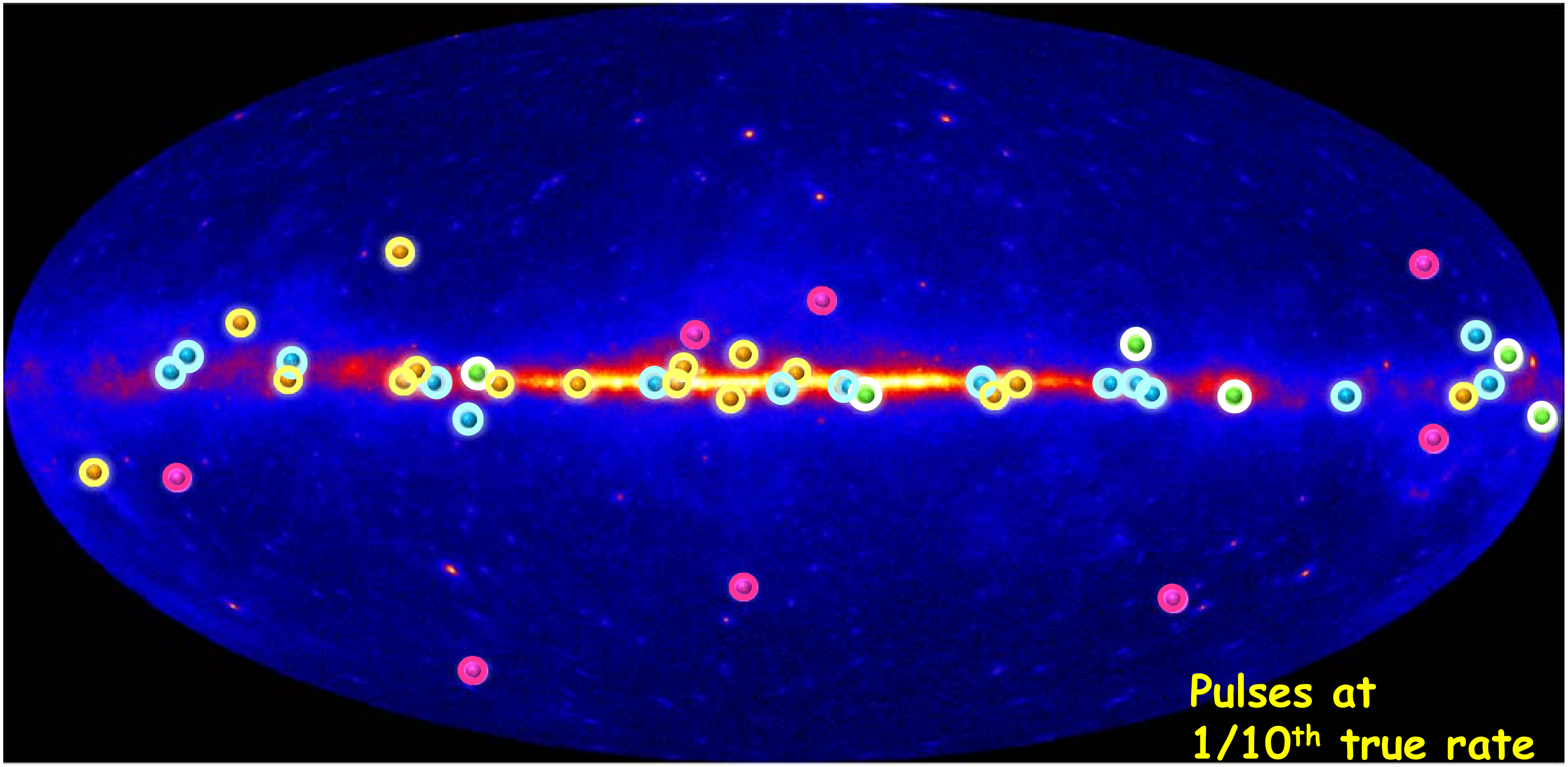


- PSR B1706-44
  - Flux ~$1.1 \cdot 10^{-6}$ph/cm^{2}s
- PSR B1951+32 & PSR B1055-52
  - Flux for E>100MeV ~10^{-7}ph/cm^{2}s

Our Starting point



… 6 Months later



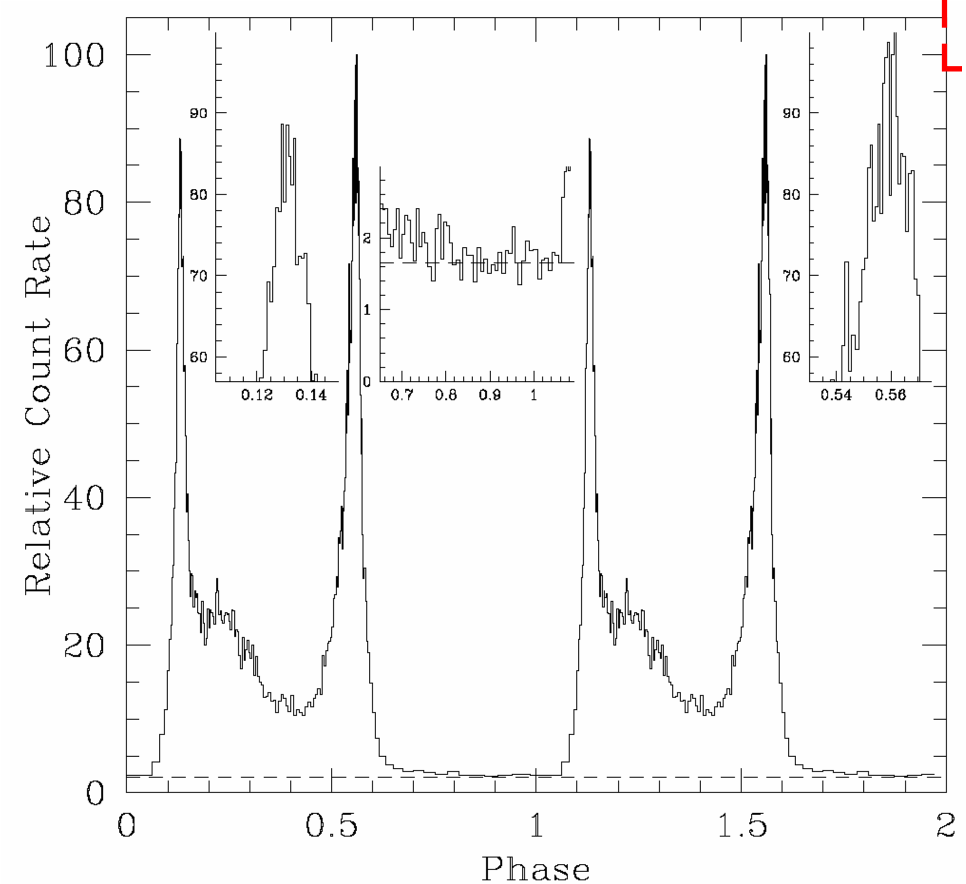
Fermi Pulsar Detections

- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Pulsars seen by Compton Observatory EGRET instrument

Vela

Abdo et al. 2008, ApJ 696, 1084

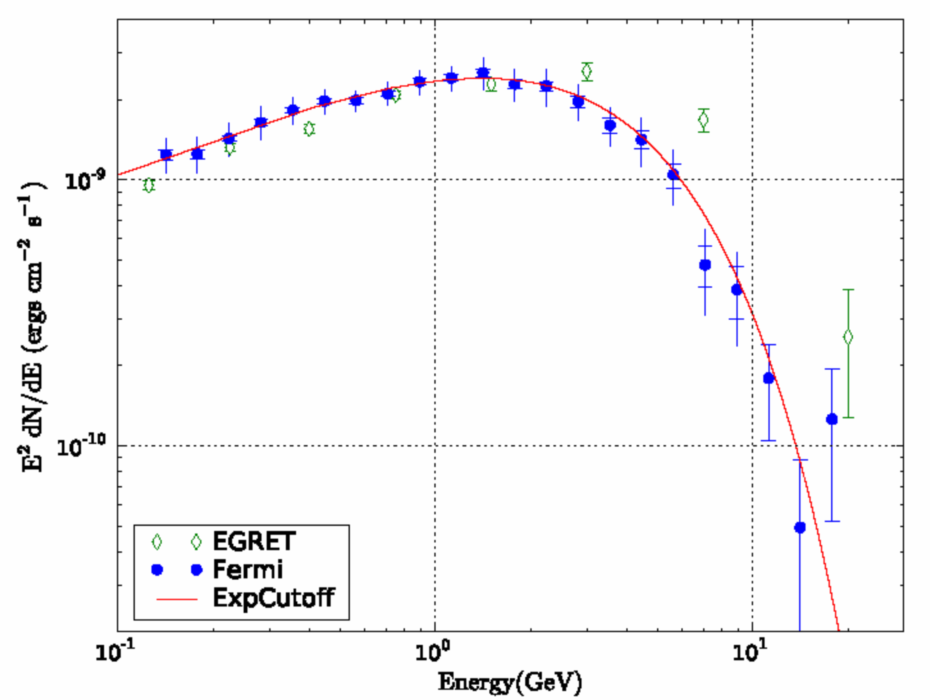
Remarkably sharp peaks (features to ~0.3 ms)
High statistics (~50k photons)



$$\Gamma = 1.51^{+0.04}_{-0.05}$$

$$E_c = 2.9 \pm 0.1 \text{ GeV}$$

P=89ms
E_{dot}=7x10^{36}erg/s

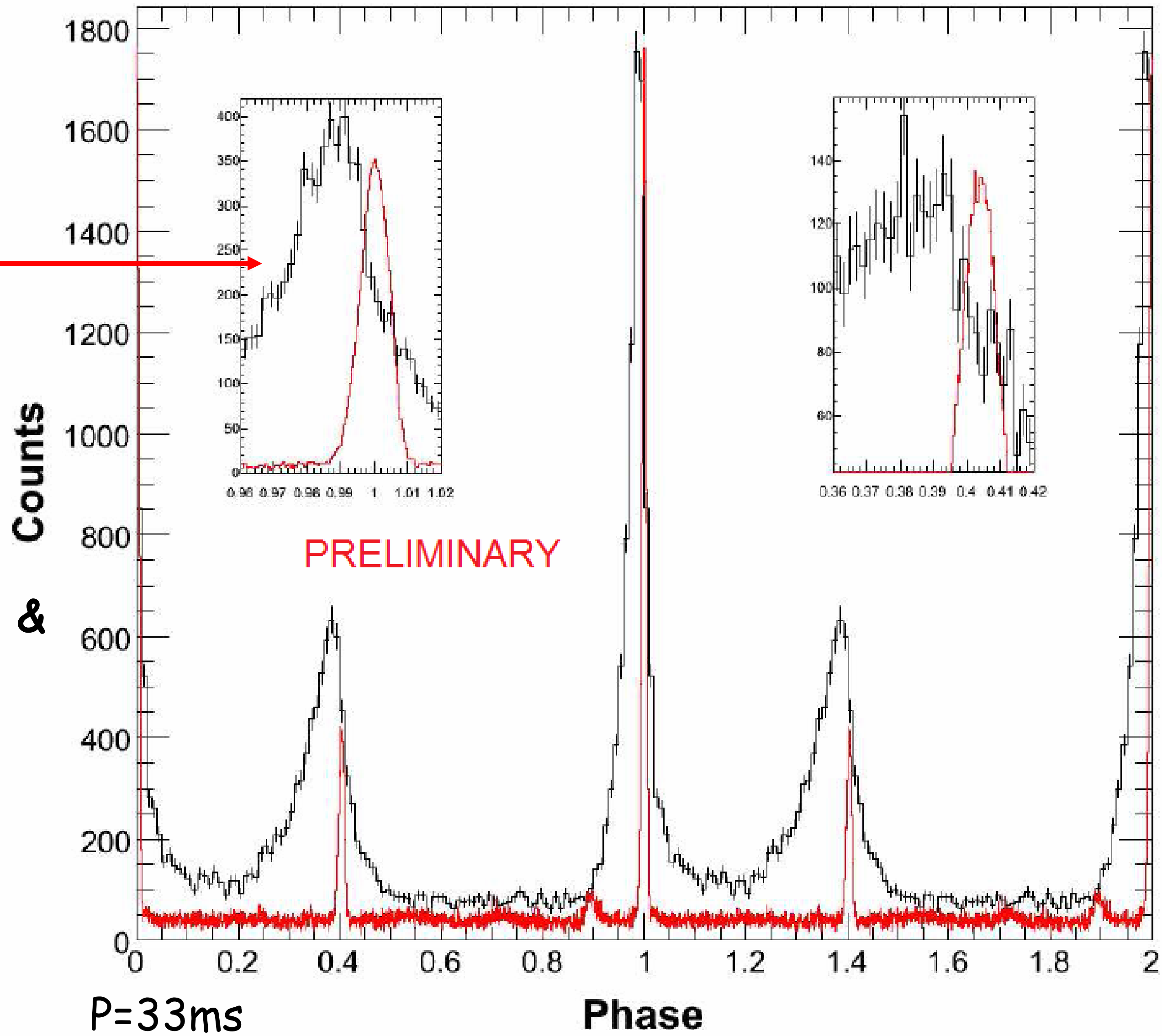


Crab...

>100 MeV (*Fermi*)
Phase 0.002 per bin
(66 ms per bin)

1.4 GHz radio (Nançay & Jodrell Bank)

Unprecedented timing accuracy

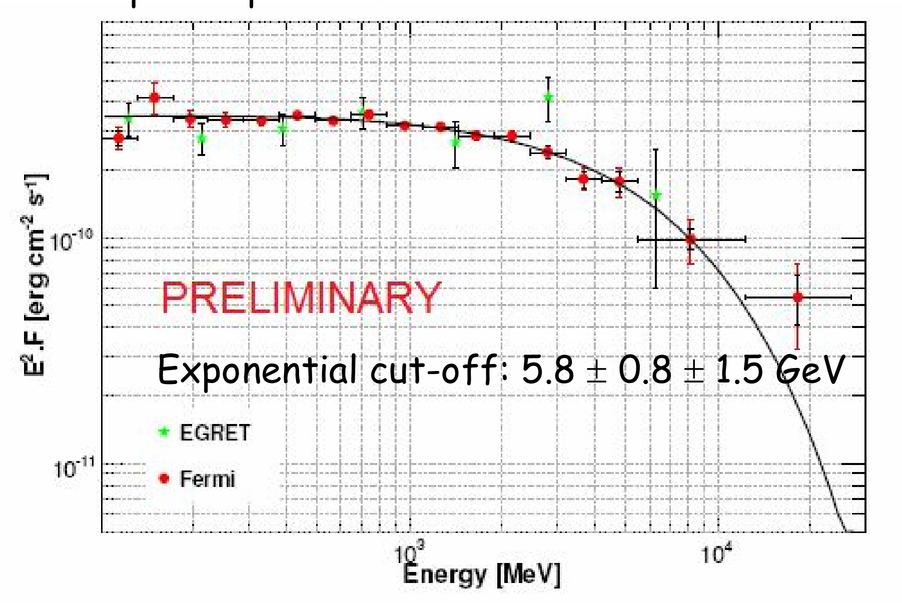


P=33ms
$E_{dot}=4x10^{38}erg/s$

Submitted to ApJ

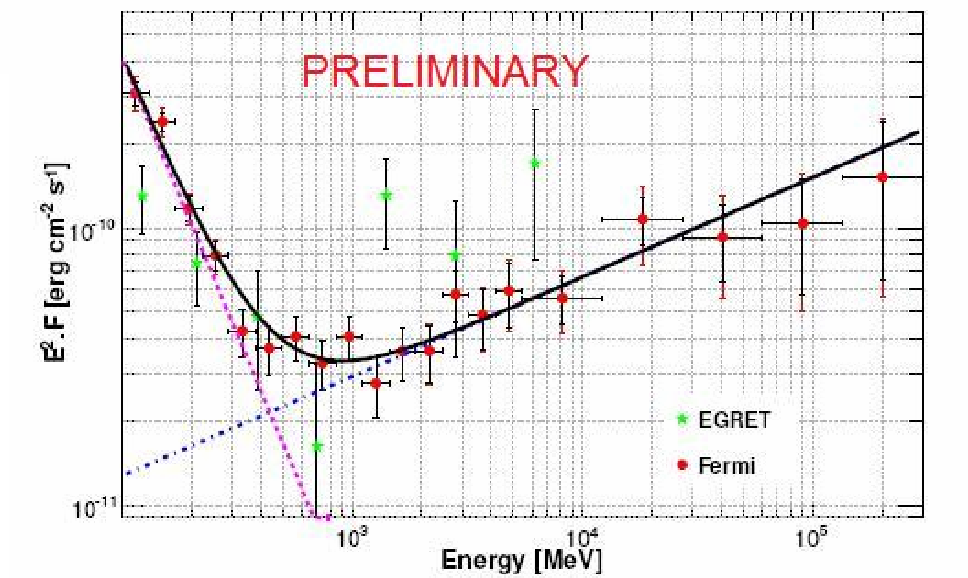
… and the Nebula

On-pulse spectrum.

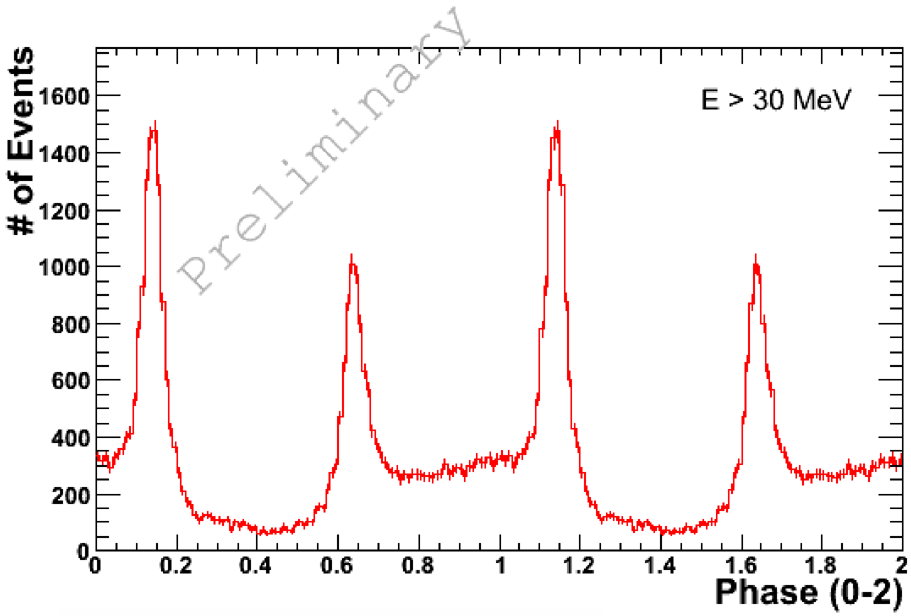


Exponential cut-off: 5.8 ± 0.8 ± 1.5 GeV

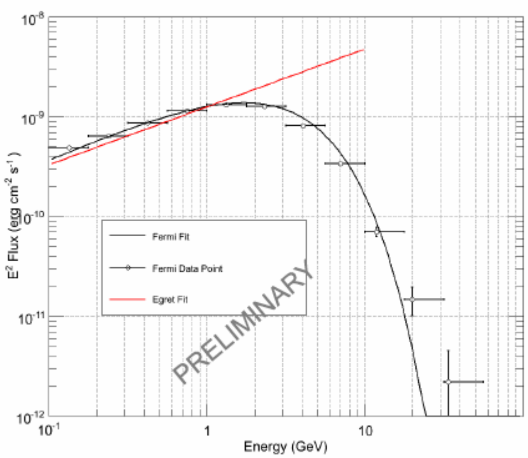
Nebula Synchrotron and
Inverse Compton components ("off-pulse")



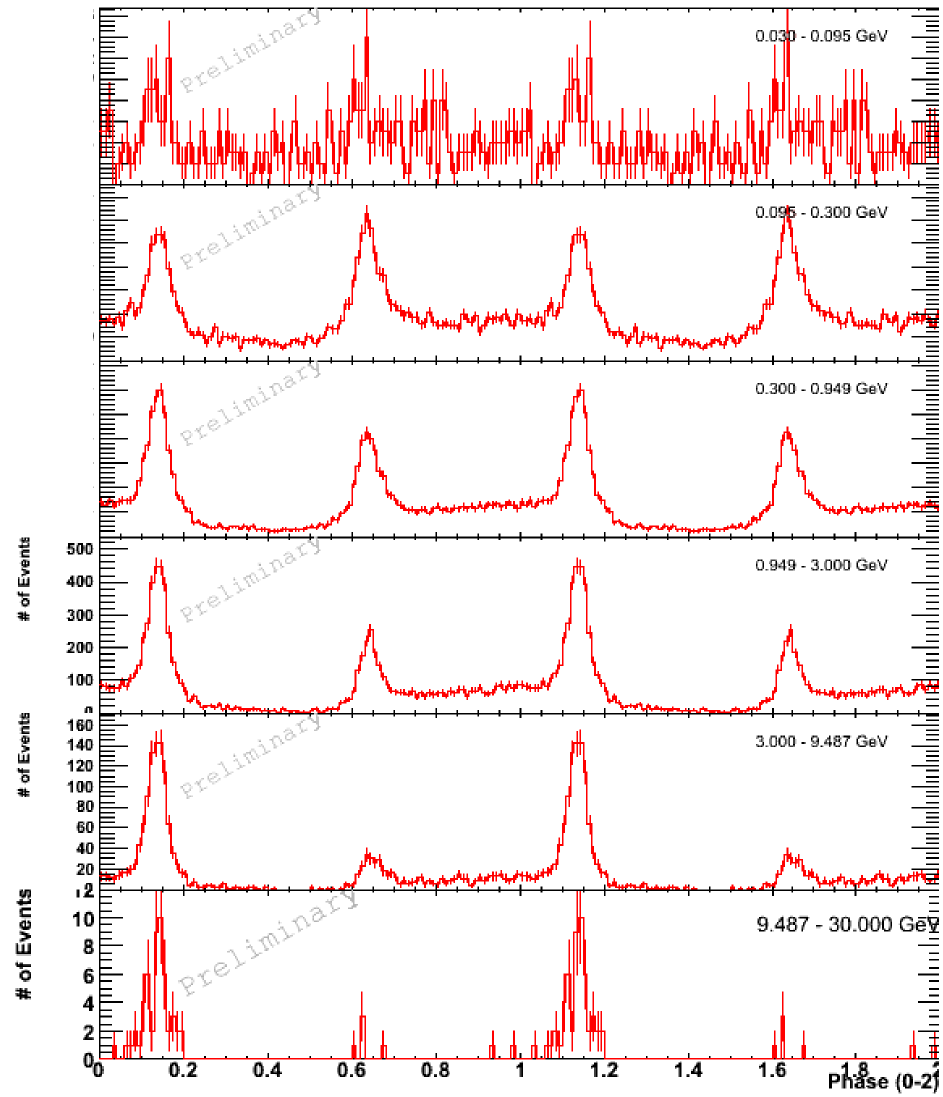
Geminga



E > 30 MeV
# of Events
Phase (0-2)
Preliminary



Fermi Fit
Fermi Data Point
Egret Fit
PRELIMINARY
Energy (GeV)



0.030 - 0.095 GeV
0.095 - 0.300 GeV
0.300 - 0.949 GeV
0.949 - 3.000 GeV
3.000 - 9.487 GeV
9.487 - 30.000 GeV
# of Events
Phase (0-2)
Preliminary

Pulsar timing for *Fermi*

- Campaign to time 224 high Edot "Egret-like" pulsars
- *Excellent* working relation with the radio and X-ray pulsar experts.
- In addition 544 pulsars with observations shared with the LAT team

Pulsar Timing for the *Fermi* Gamma-ray Space Telescope

D. A. Smith[1,2], L. Guillemot[1,2], F. Camilo[3], I. Cognard[4,5], D. Dumora[1,2], C. Espinoza[6], P. C. C. Freire[7], E. V. Gotthelf[3], A. K. Harding[8], G. B. Hobbs[9], S. Johnston[9], V. M. Kaspi[10], M. Kramer[6], M. A. Livingstone[10], A. G. Lyne[6], R. N. Manchester[9], F. E. Marshall[8], M. A. McLaughlin[9], A. Noutsos[6], S. M. Ransom[10], M. S. E. Roberts[13], R. W. Romani[14], B. W. Stappers[6], G. Theureau[4,5], D. J. Thompson[8], S. E. Thorsett[15], N. Wang[16], and P. Weltevrede[9]

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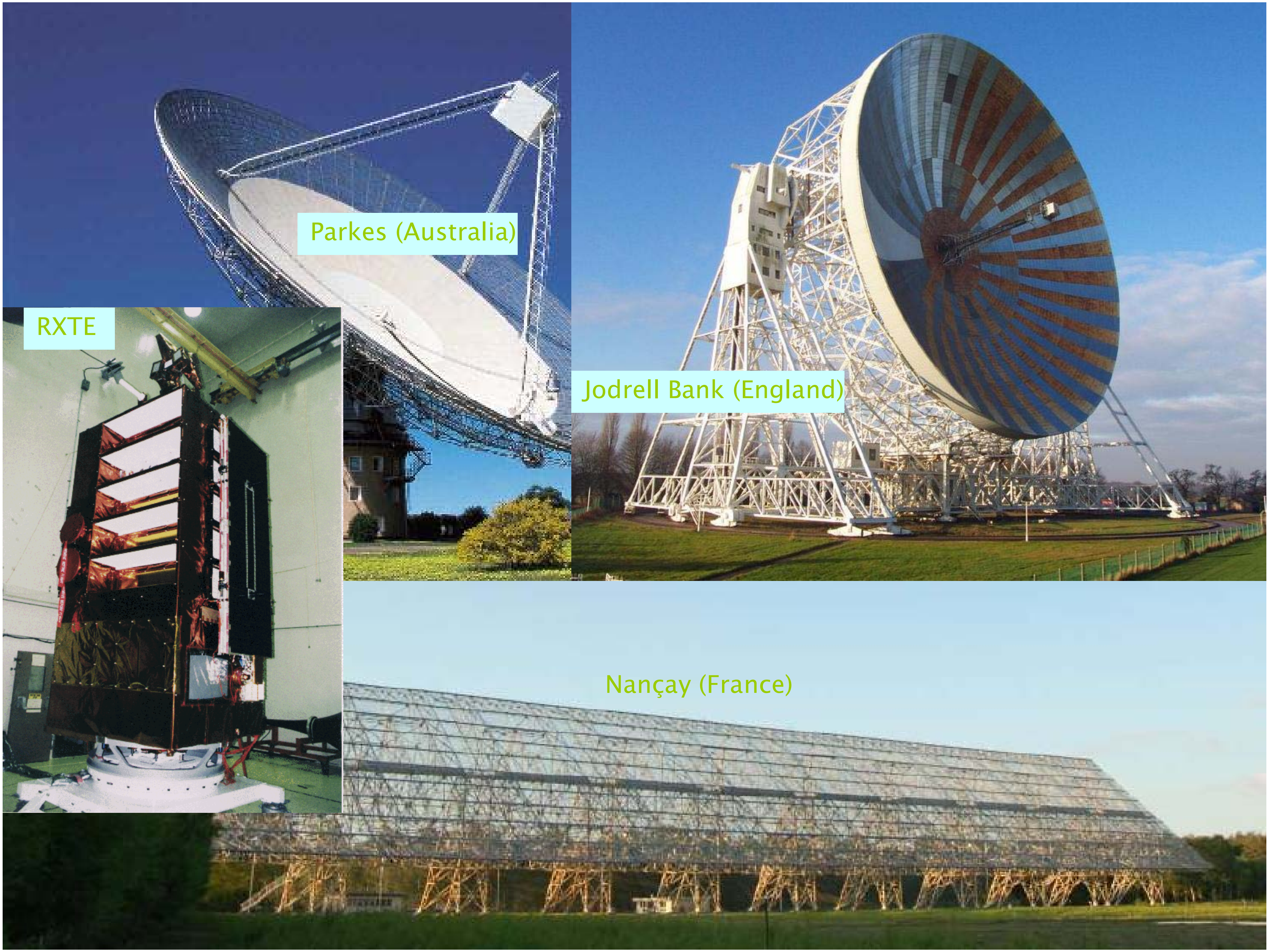
Preprint online version: September 4, 2008

ABSTRACT

We describe a comprehensive pulsar monitoring campaign for the Large Area Telescope (LAT) on the *Fermi Gamma-ray Space Telescope* (formerly GLAST). The detection and study of pulsars in gamma rays give insights into the populations of neutron stars and supernova rates in the Galaxy, into particle acceleration mechanisms in neutron star magnetospheres, and into the "engines" driving pulsar wind nebulae. LAT's unprecedented sensitivity between 20 MeV and 300 GeV together with its 2.4 sr field-of-view makes detection of many gamma-ray pulsars likely, justifying the monitoring of over two hundred pulsars with large spin-down powers. To search for gamma-ray pulsations from most of these pulsars requires a set of phase-connected timing solutions spanning a year or more to properly align the sparse photon arrival times. We describe the choice of pulsars and the instruments involved in the campaign. Attention is paid to verifications of the LAT pulsar software, using for example giant radio pulses from the Crab and from PSR B1937+21 recorded at Nançay, and using X-ray data on PSR J0218+4232 from XMM-Newton. We demonstrate accuracy of the pulsar phase calculations at the microsecond level.

Key words. pulsars:general – Gamma-rays:observations – Ephemerides

A&A 492, 293 (2008)

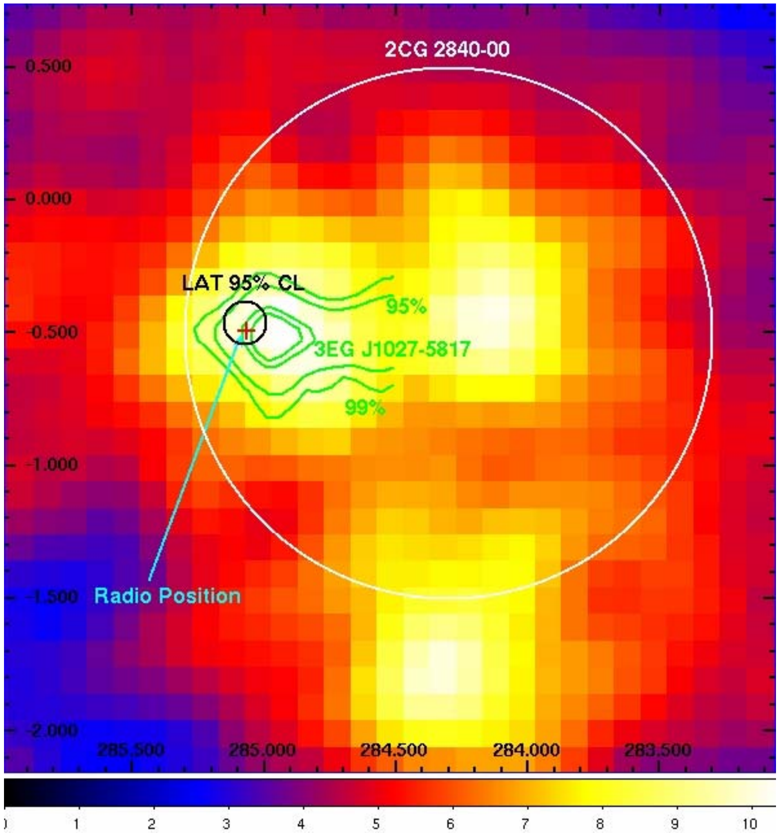

Parkes (Australia)
RXTE
Jodrell Bank (England)
Nançay (France)


GBT (US)


Westerbork WSRT (Netherland)


Arecibo (Puerto rico)

The 3EG UnIDs: PSR J1028-5819



Map for E>100MeV around PSR J1028-5819 (red cross), showing the LAT 95% CL error circle and the 3EG and 2CG source

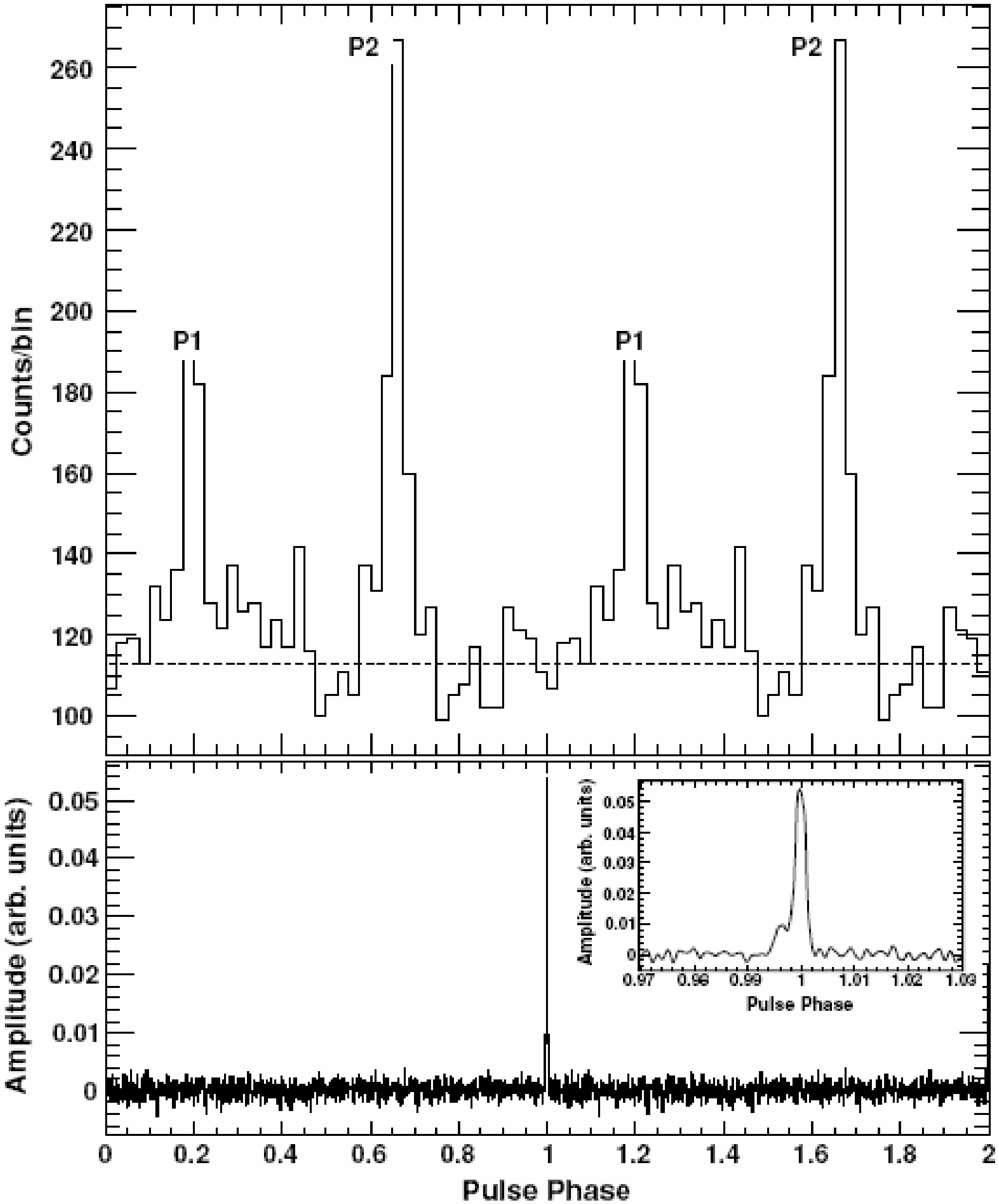
- ✓ Discovered in radio shortly before *Fermi* launch (*Keith et al., MNRAS 389:1881*, 2008)
- ✓ P = 91.4 ms
- ✓ P_{dot} = 1.6 x 10^{-14} s/s
- ✓ $\dot{E}_{SD}$ = 8.4 x 10^{35} erg/s
- ✓ Characteristic age t_c = 9.2 x 10^4 yr
- ✓ DM derived distance = 2.3 kpc

Disentangling

an unidentified gamma-ray source

1. *Within COS-B source 2CG 284-00*
2. *Within 3EG J1027-5817*

Light curve of PSR J1028-5819



June 30-Nov 16

E-dependent cut $q < q_c * (E/100MeV)^{-0.75}$

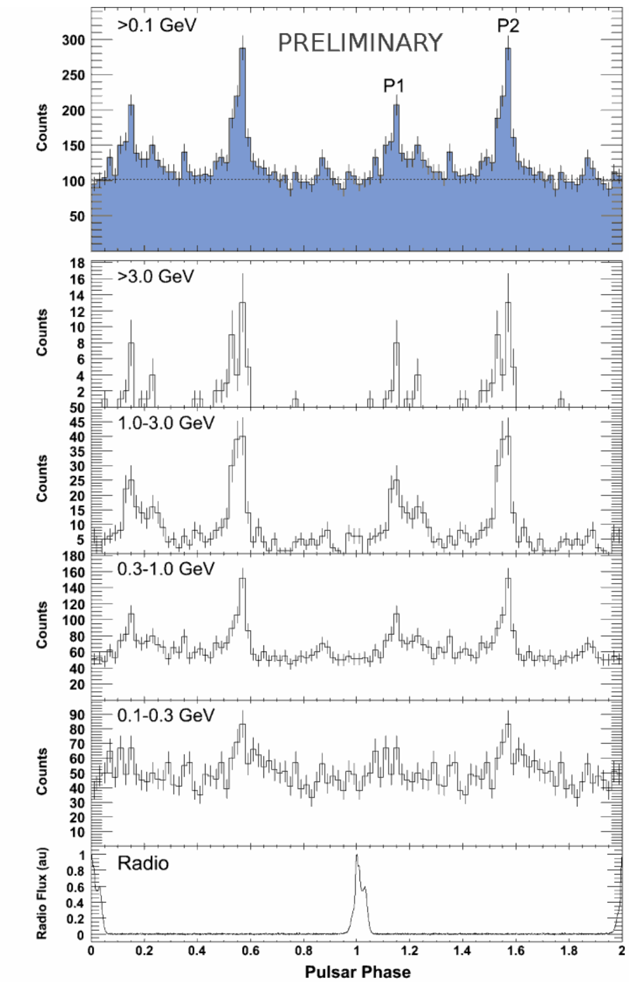
(q_c=3° thin section, q_c=4.1° thick section)

Detection: H-test chance probability $< 4 \times 10^{-8}$

- ✓Radio peak is very sharp
- ✓2 Gamma-ray peaks:
  - ✓P1 @ f = 0.200 ±0.003
    - ✓FWHM 0.040±0.011
  - ✓P2 @ f = 0.460 ± 0.004
    - ✓FWHM 0.035±0.007

Published in ApJL 695:L72

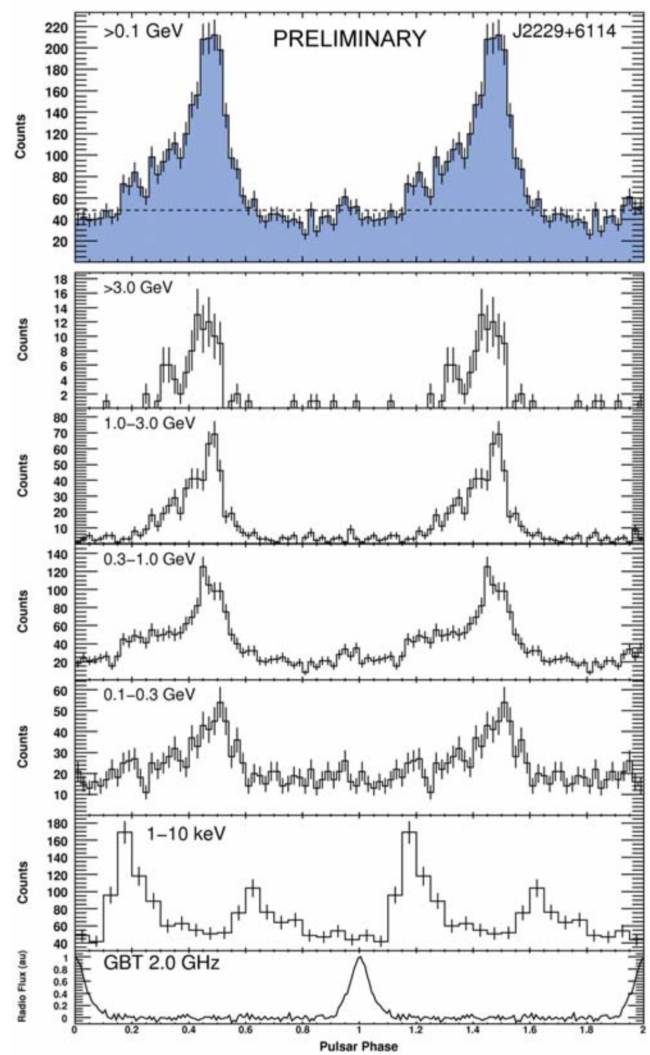
2 "Vela-like" pulsars



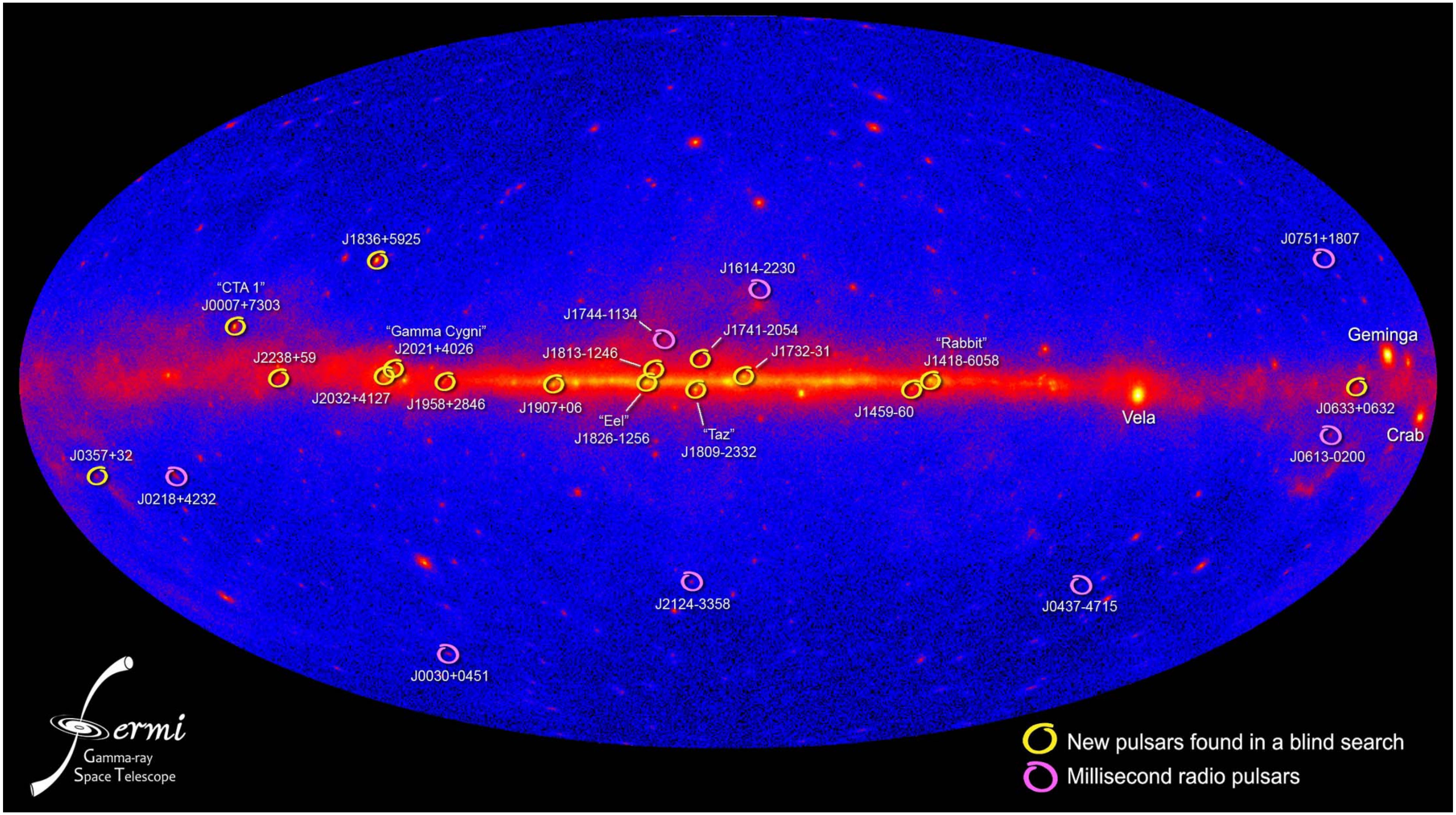
- PSR J1048-5832
  - P=123.7 ms
  - t=20kyr
  - 2x10^{36}
- PSR J2229+6114
  - P=51.6 ms
  - t=10 kyr
  - 2x10^{37}
- Spin parameters similar (vela-like)

..but quite different light curves…Why?

- *(Abdo et al., accepted by ApJ)*

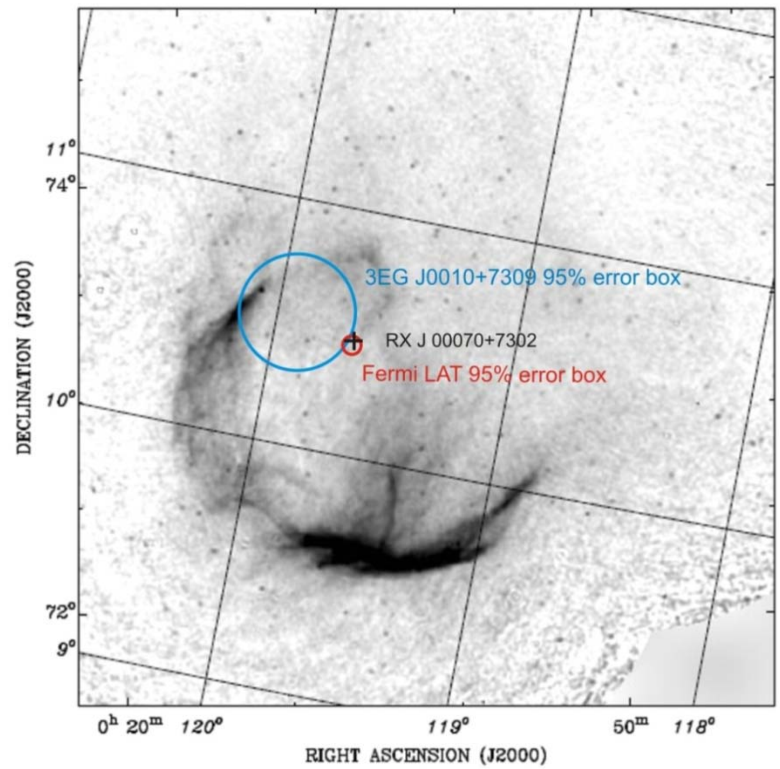


New populations!



Blind search period PSRs

- Search is "blind" in terms of timing parameters
- Where do we look?
  - ~100 "interesting" locations in the sky
  - ~200 LAT unidentified sources
- How do we search?
  - Time-differencing technique (Atwood et al. 2006, Ziegler et al. 2008)
  - Once a good candidate is found, standard pulsar tools are used: e.g. PRESTO, tempo2



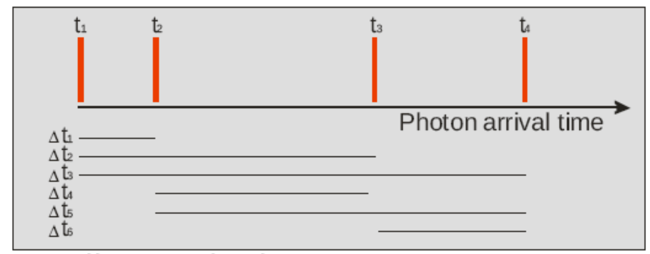
The "Time-Differencing" Technique

Periodicity in photon arrival times will also show up in differences of photon arrival times.

Time differences cancel out long term phase slips and glitches because differencing starts the "clock" over (and over, and over...)

Despite the reduced frequency resolution (and therefore number of bins), the sensitivity is not much reduced because of a compensating reduction in the number of fdot trials

Atwood et. al., **ApJ Lett., 652, 49 (2006)**
Ziegler et. al., **ApJ 680, 620 (2008)**



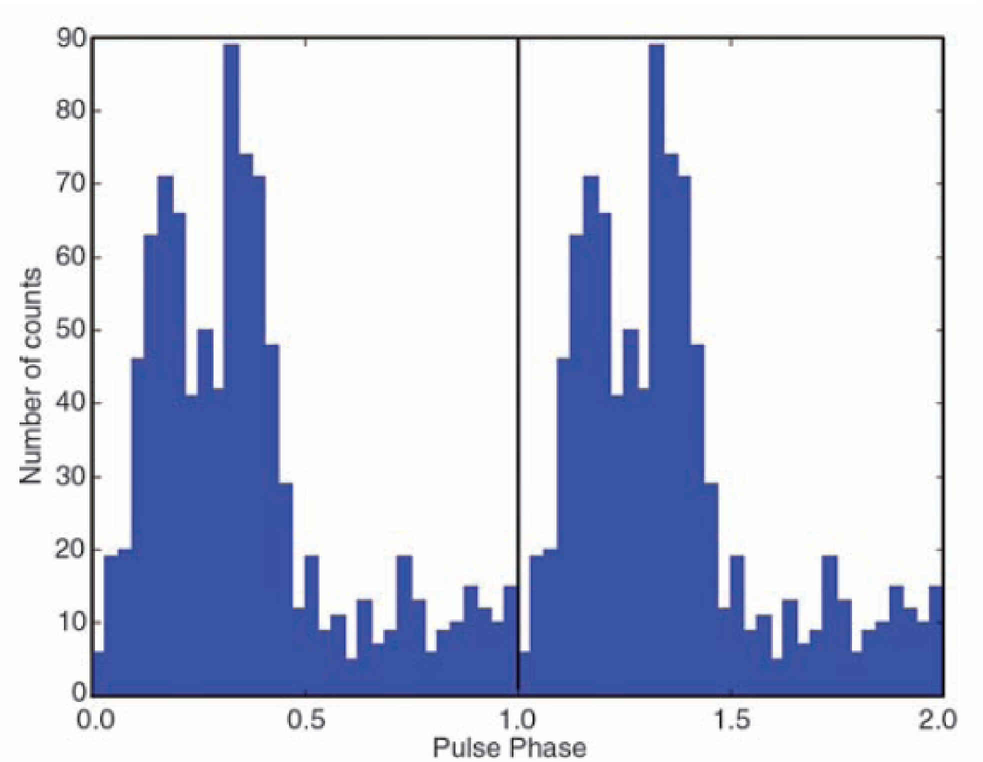
Credit: M. Ziegler

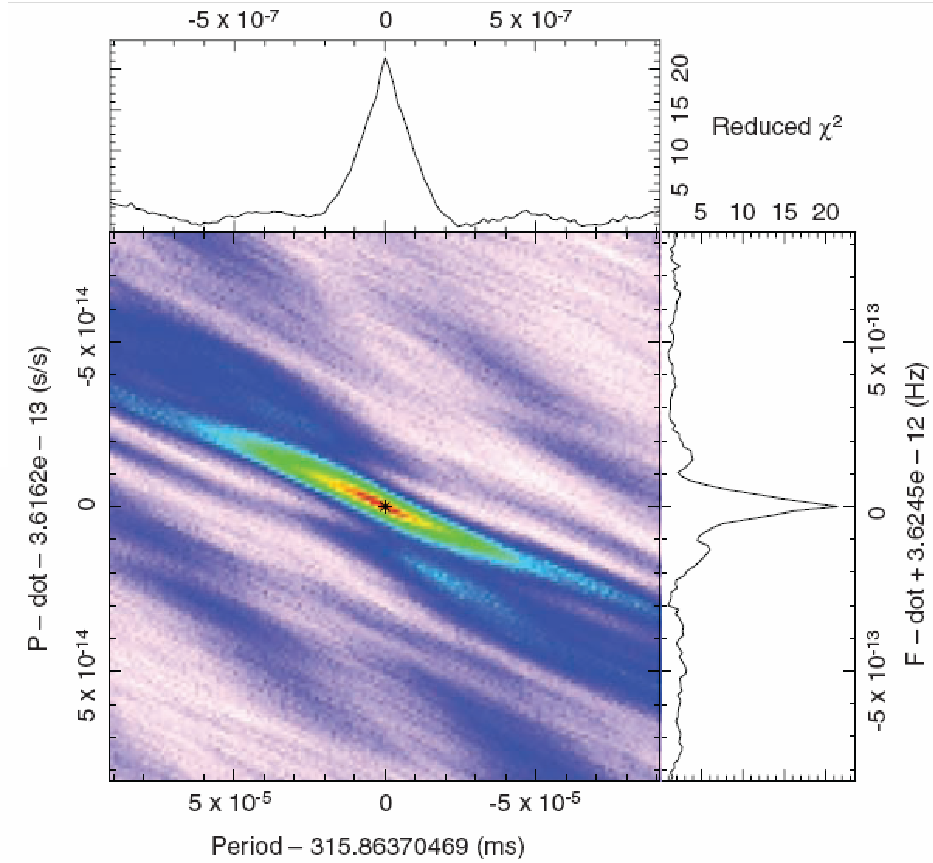
# of FFT bins = f * t_{max_diff} * 2

PC with 2GB can handle 33 x 10^6 bin FFT

The pulsar in CTA 1

- First discovery of the LAT
- †=14 kyr
- Science 322 (21 nov 08)



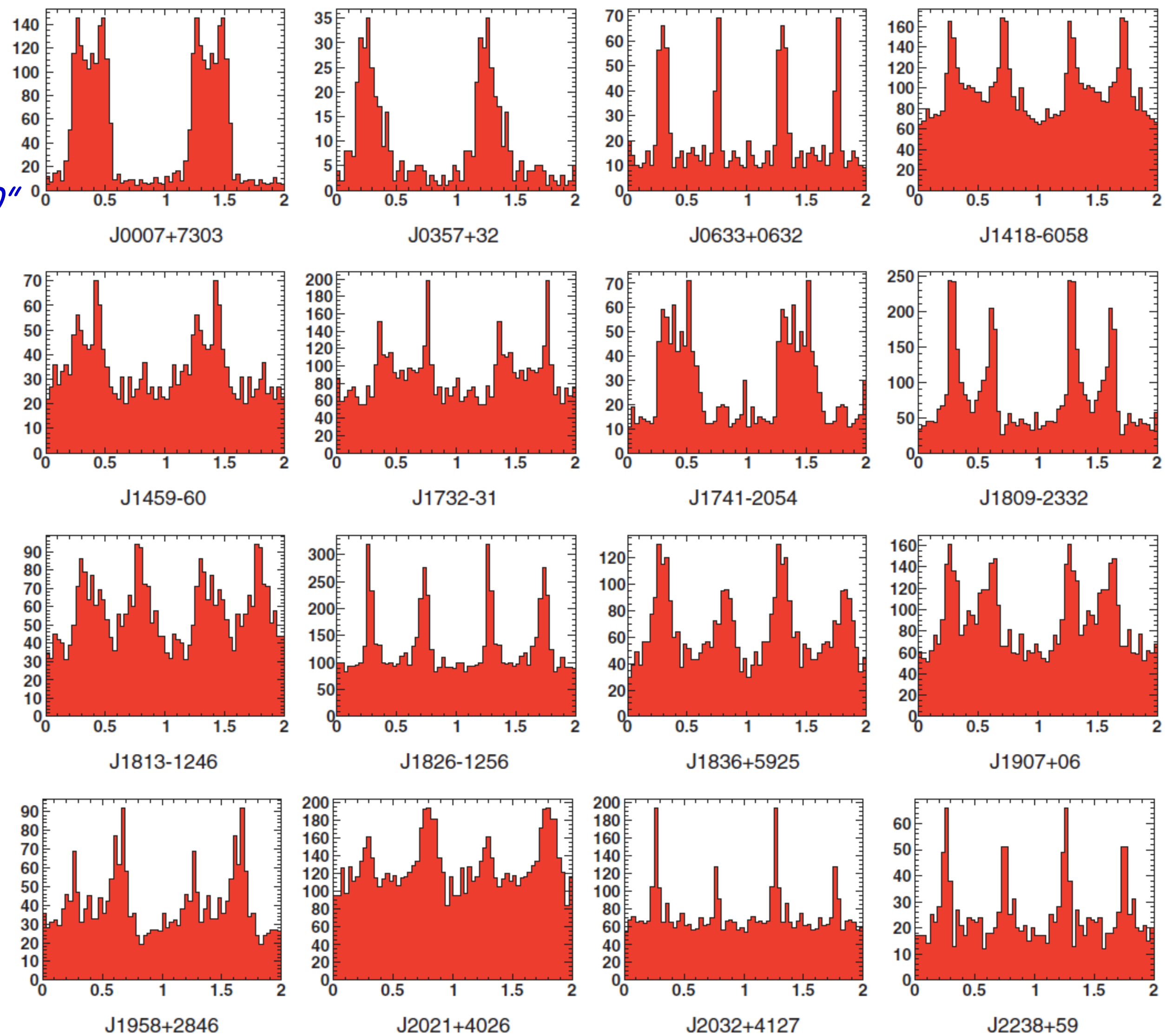


"The Fermi Gamma-Ray Space Telescope Discovers the Pulsar in the Young Galactic Supernova Remnant CTA 1"
Science 322, 1218 (2008)

Gamma-ray only (?) pulsars

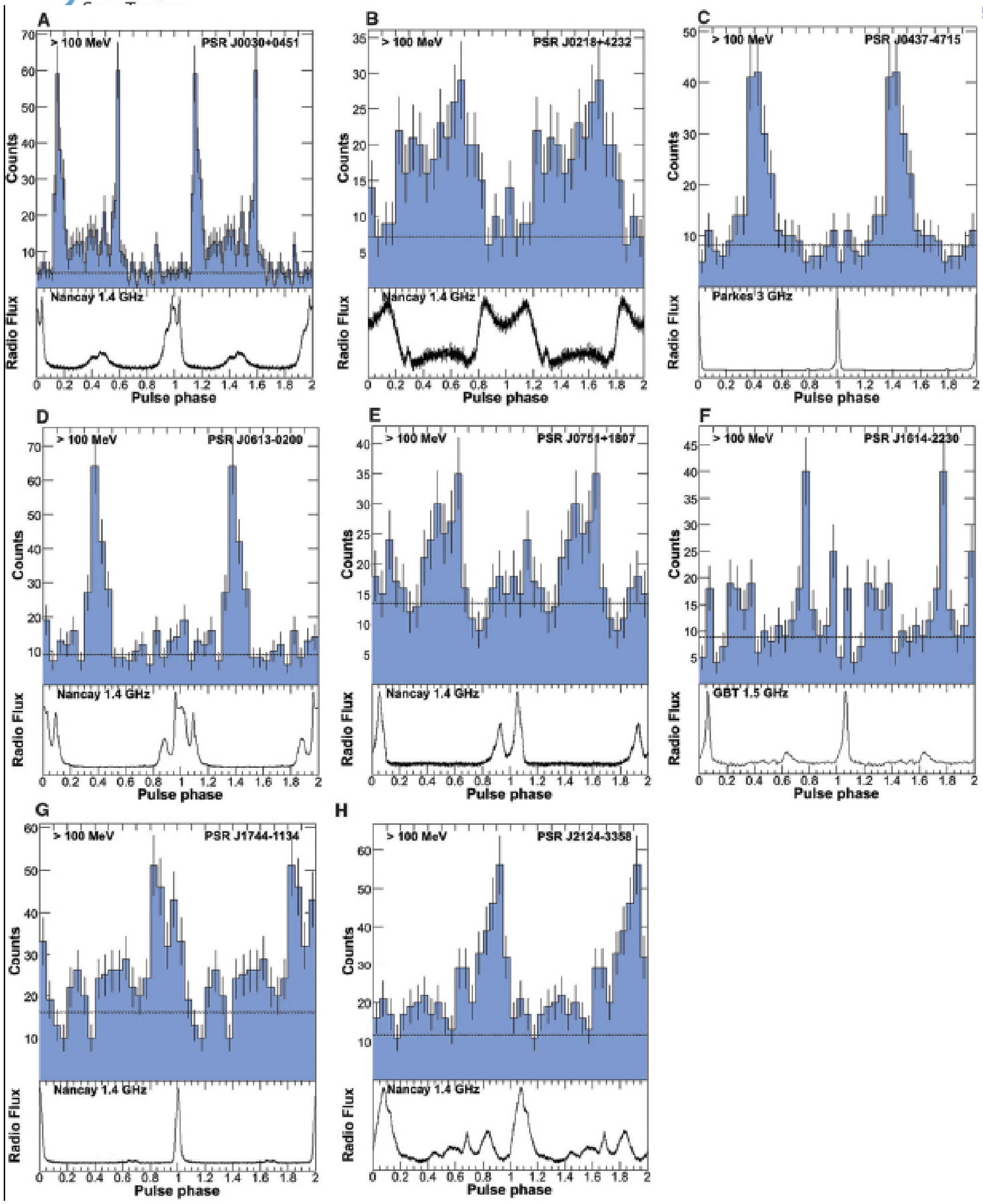
Blind search pulsars

Abdo et al. 2009 "Science 325 840"



- **Favor broad gamma-ray emission**
- **"Radio detection of LAT PSRs J1741-2054 and J2032+4127: no longer just gamma-ray pulsars"**
- ***Camilo, Ray et al., ApJ accepted (arXiv:0908.2626)***
- **Detected at Parkes & GBT**

Gamma-ray millisecond pulsars

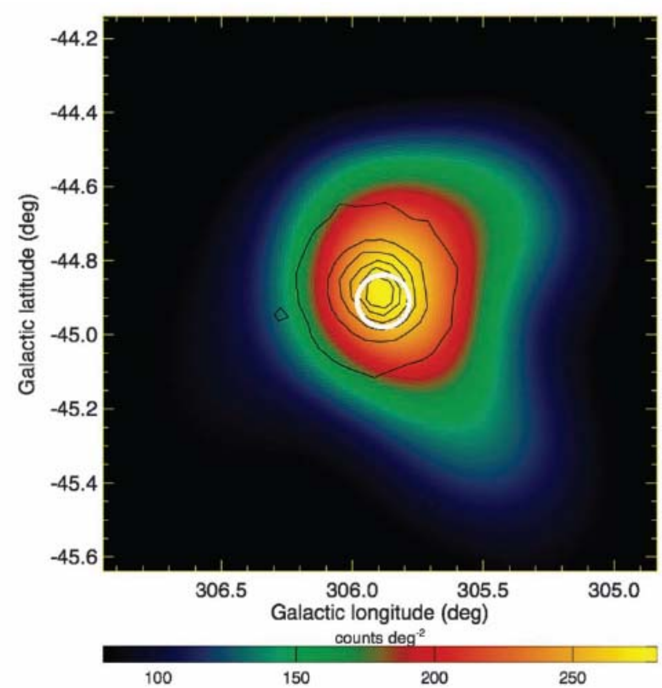


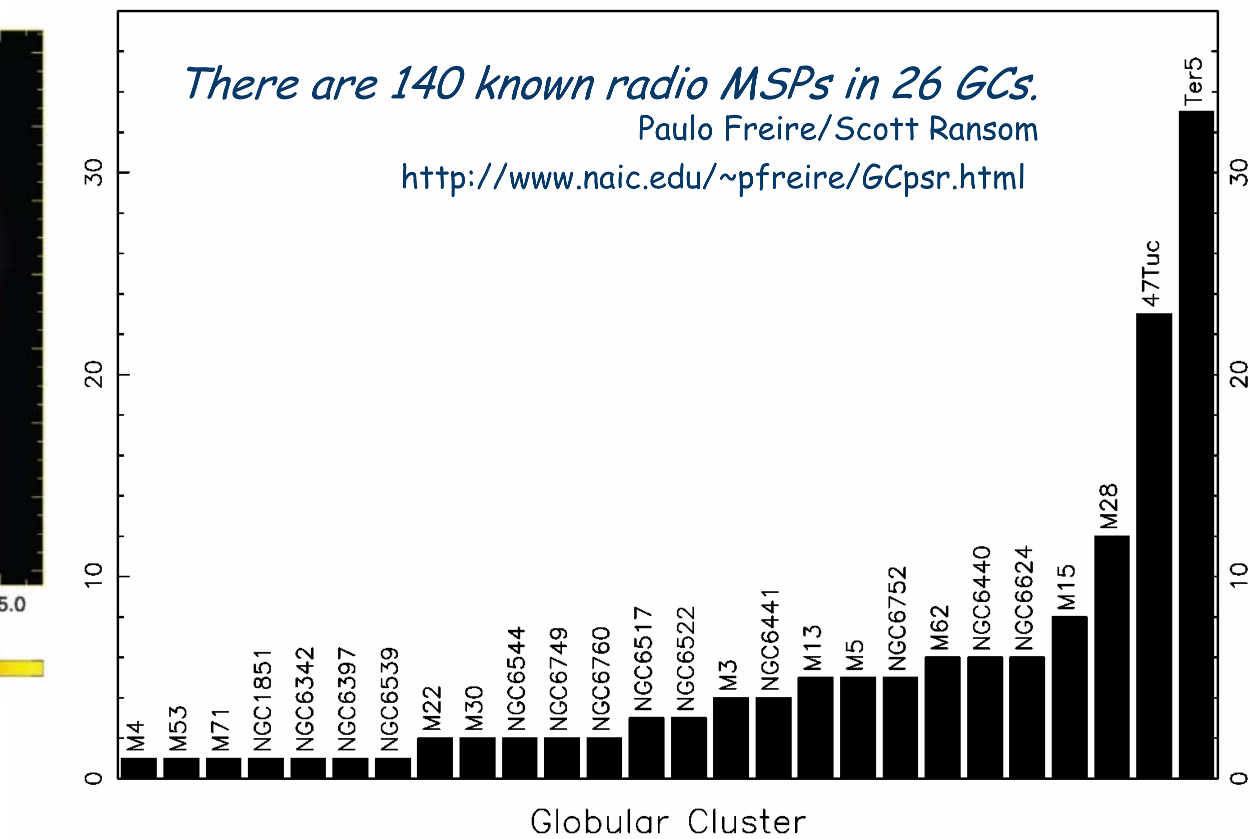
8 Millisecond pulsars

Abdo et al 2009 Science 325 848

- **5 are in binary orbits**
- **Similar lightcurves and spectra as in the young pulsars**
- **These MSP suggest the same emission mechanism as the young pulsars**

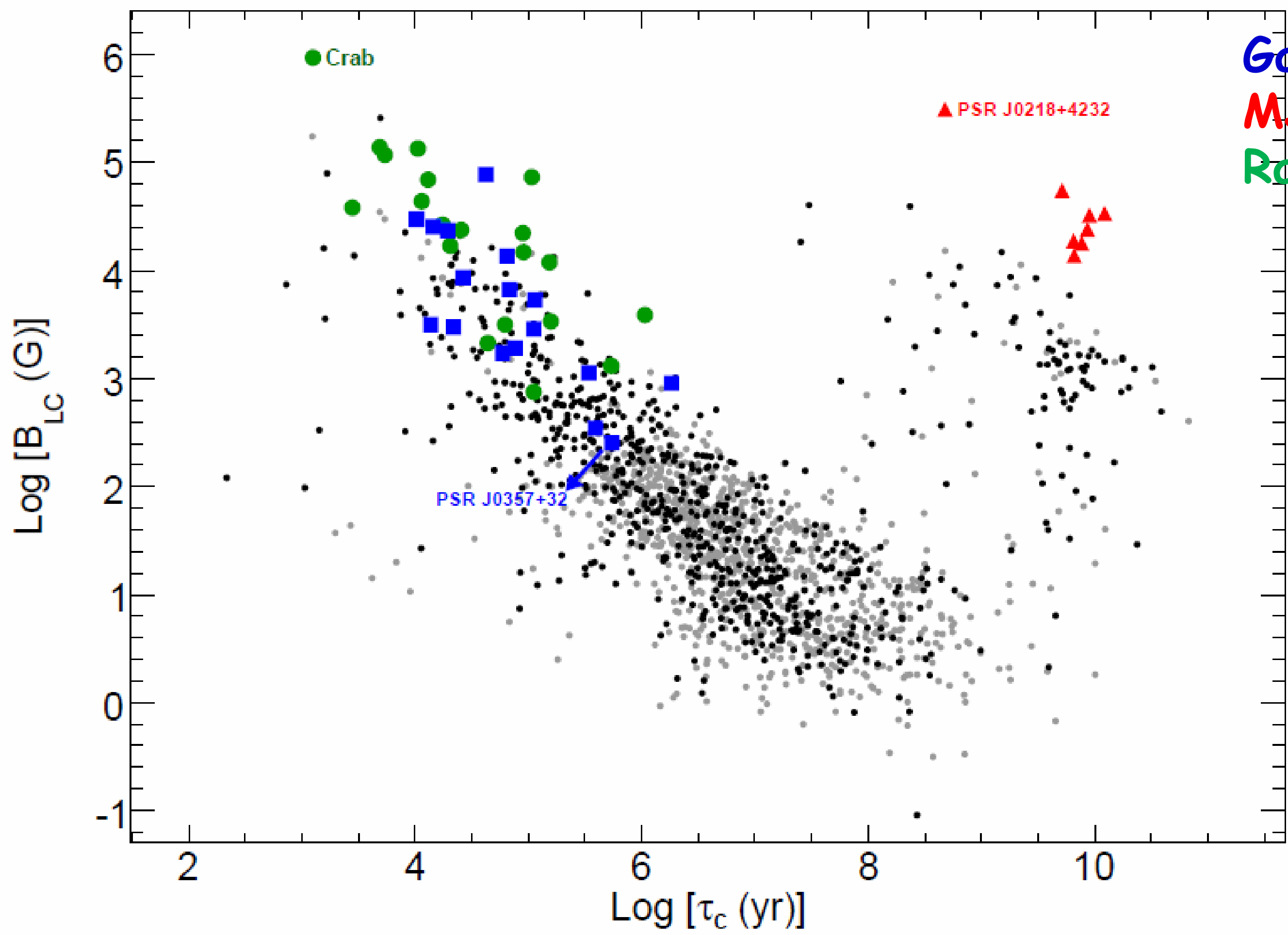
MSP in globular clusters?





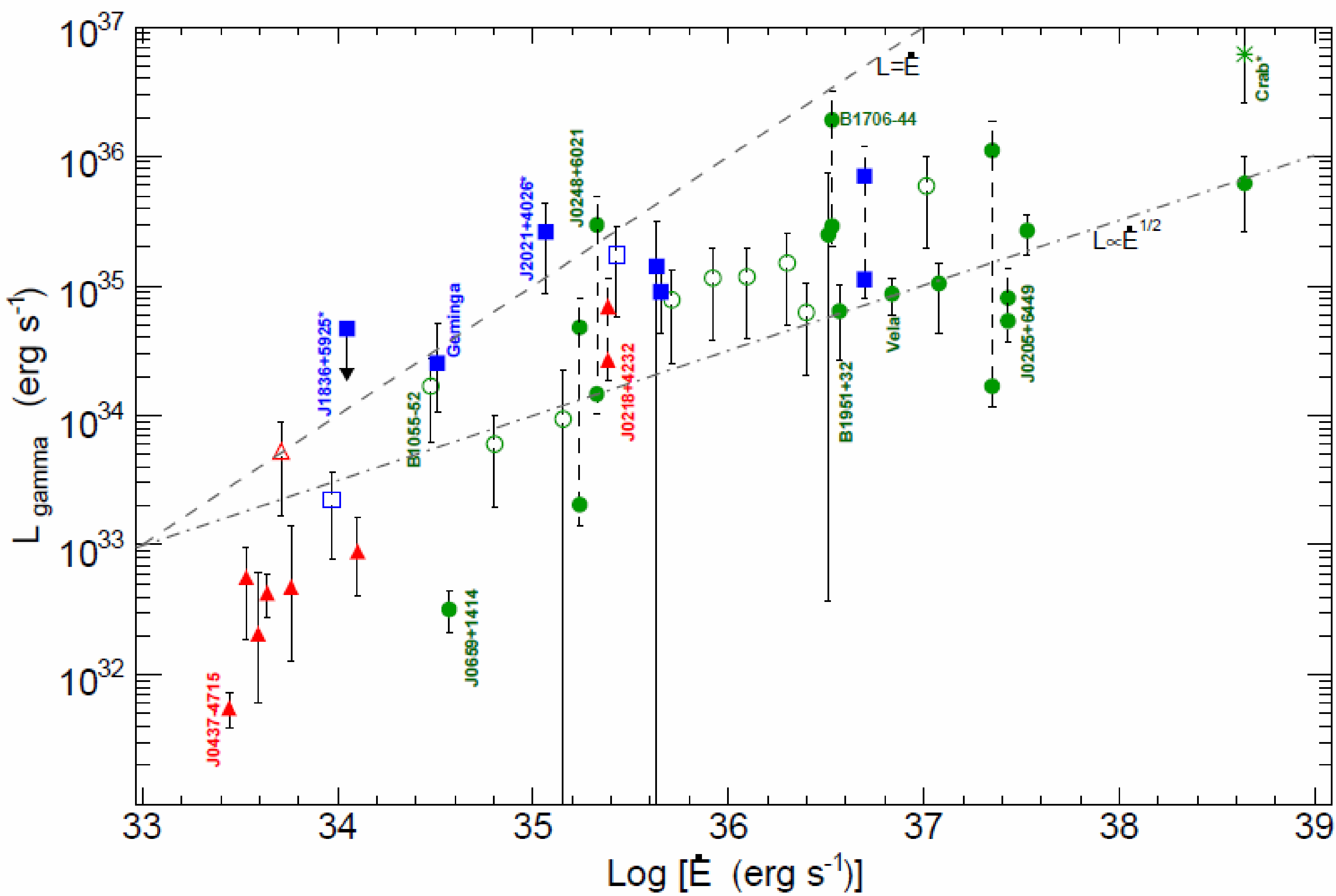
- Detection of 47 Tuc as a steady g-ray source *(Science325,845)*
- Consistent with ~50 MSPs.
- Pulsed searches ongoing.

We got 46 PSRs!!!
Let's put them together

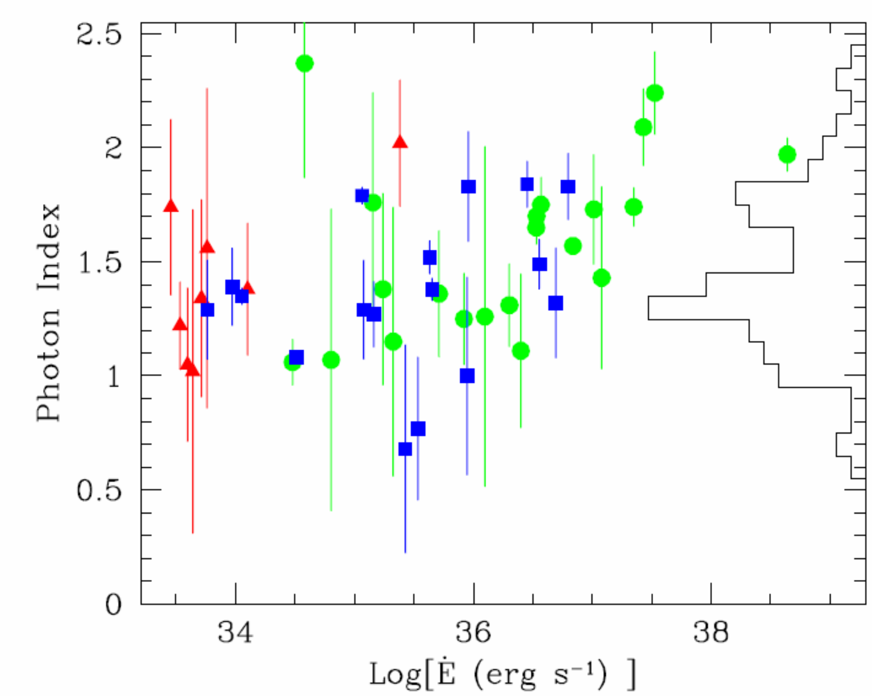


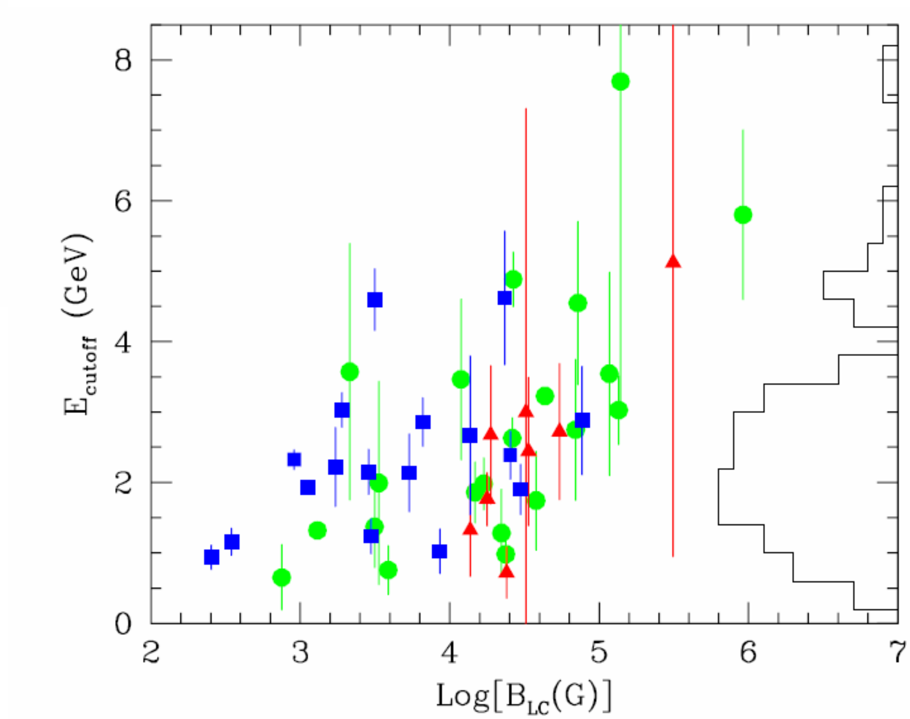
Gamma selected
MSP
Radio Loud

Luminosity vs Energy Loss



Spectral parameters





Conclusions

- Discovery of new radio-loud gamma-ray pulsars thanks to the contemporaneous ephemerides (*e.g.* J1028-5819,J0205+6449, J1048-5832…)
- New search technique for finding pulsars in blind search: new 16 pulsars discovered
- Identification of 3EG galactic sources
- MSP in gamma-rays now discovered
- For the brightest pulsars a phase resolves analysis is in progress
- LAT performances in terms of timing and energy resolution is given a great help in the understanding of the emission mechanism

The game is not OVER …

keep enjoying !!!