High time resolution observations of millisecond pulsars with Fermi

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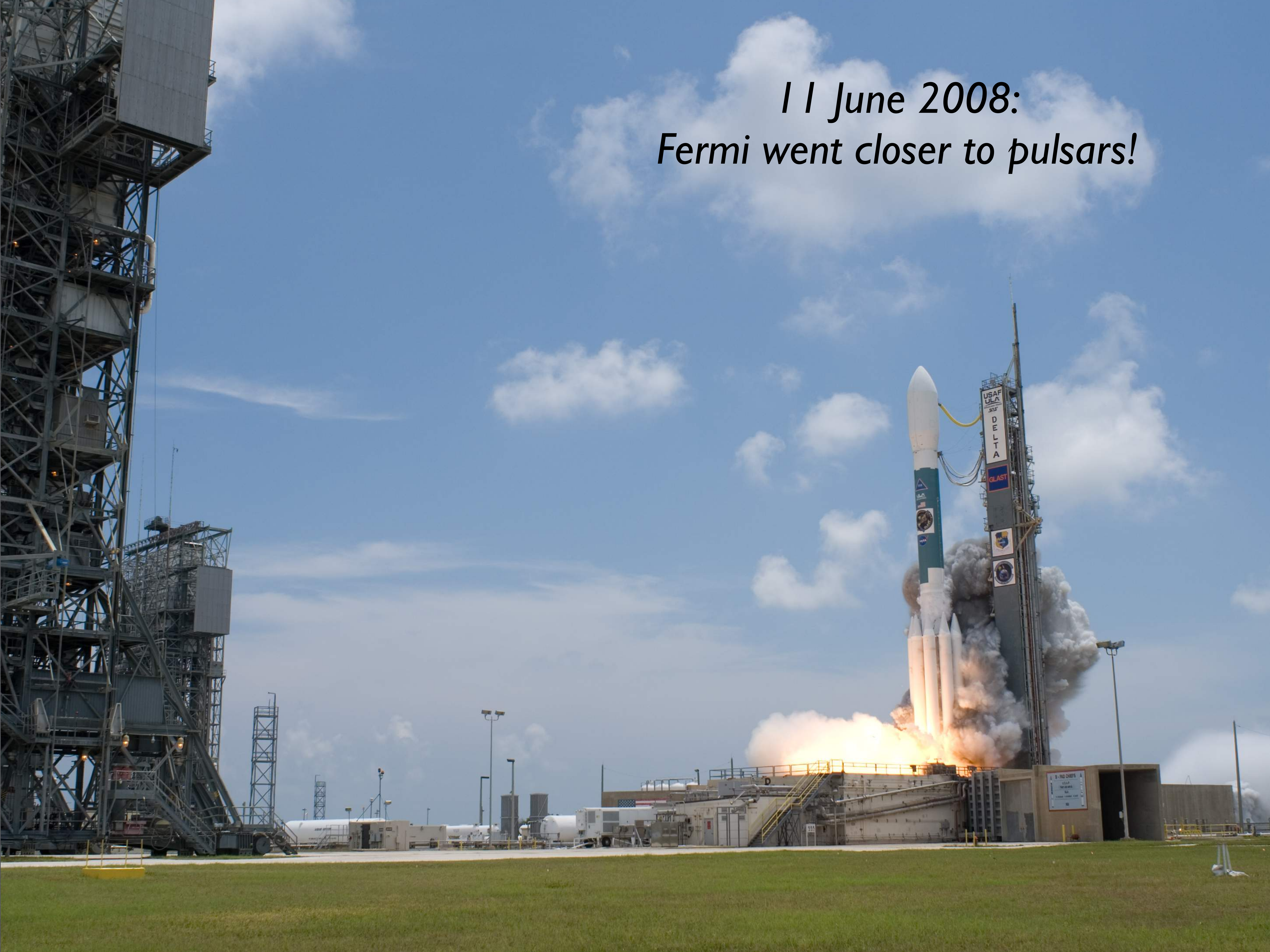
For the Fermi LAT Collaboration

HTRA IV - Άγιος Νικόλαος - *2010*

Outline

- ➡ The Fermi Large Area Telescope
- ➡ Fermi observations of pulsars
- ➡ High time resolution observations of millisecond pulsars
- ➡ A search for pulsars in Fermi unassociated sources


11 June 2008:
Fermi went closer to pulsars!
USAF
ULA
DELTA
GLAST

The Fermi Gamma-ray Space Telescope

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

Will operate during 5 to 10 years.

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

Area of 8000 cm^2 and 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).

Approx. 30 times more sensitive than EGRET.

Fermi observations of pulsars

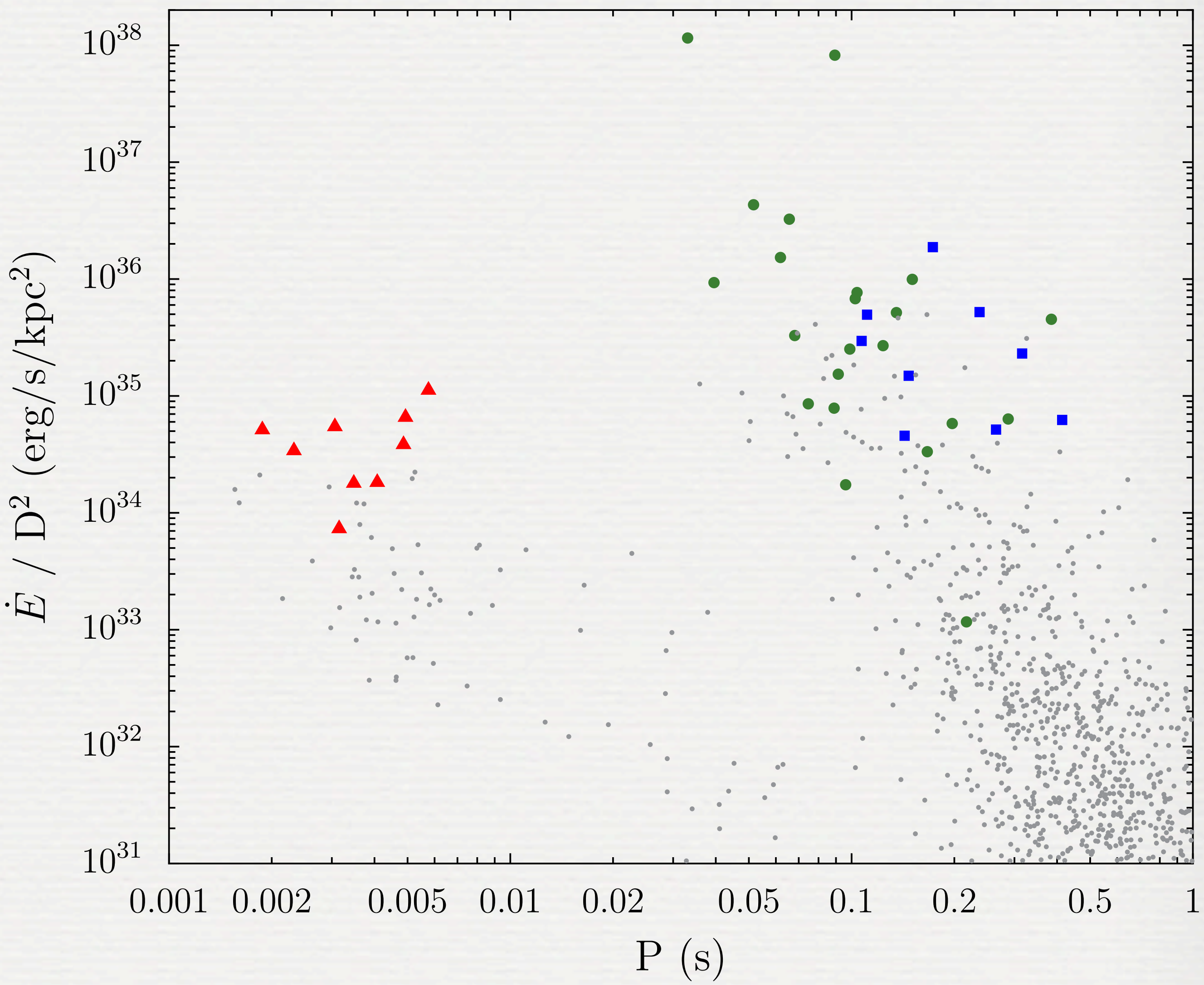
Since Fermi was launched, the LAT has detected:

- ✓ 24 previously unknown pulsars in a blind search of the gamma-ray data.
- ✓ 22 radio-loud and/or X-ray-loud normal pulsars.
- ✓ 11 radio-loud millisecond pulsars (MSPs).

+ new pulsars found at the position of Fermi unassociated sources in radio.

Major step forward in gamma-ray astronomy and pulsar science!

See talk by Patricia Caraveo on Thursday.



Spin-down flux vs rotational period for pulsars with known distances, as of Dec. 2009.

Numerous gamma-ray detections ever since, in particular for MSPs.

Observables of timing measurements

A number of observables are available through timing observations:

- Is there any pulsed emission?

(gamma-ray pulsar population)

- How structured is the gamma-ray emission profile?

(geometry of the gamma-ray emission)

- Where is the gamma-ray emission located, compared to lower energy?

(geometry of the emission as a function of the energy)

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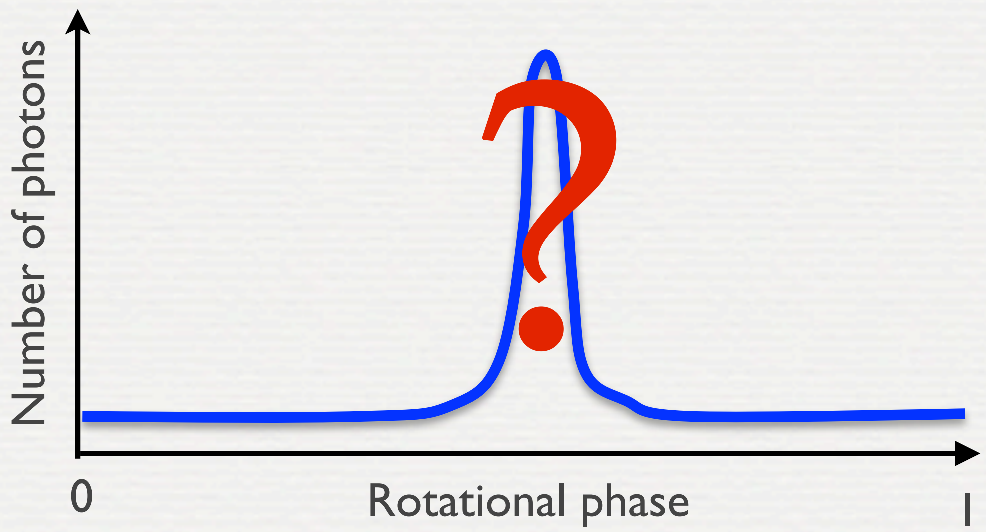

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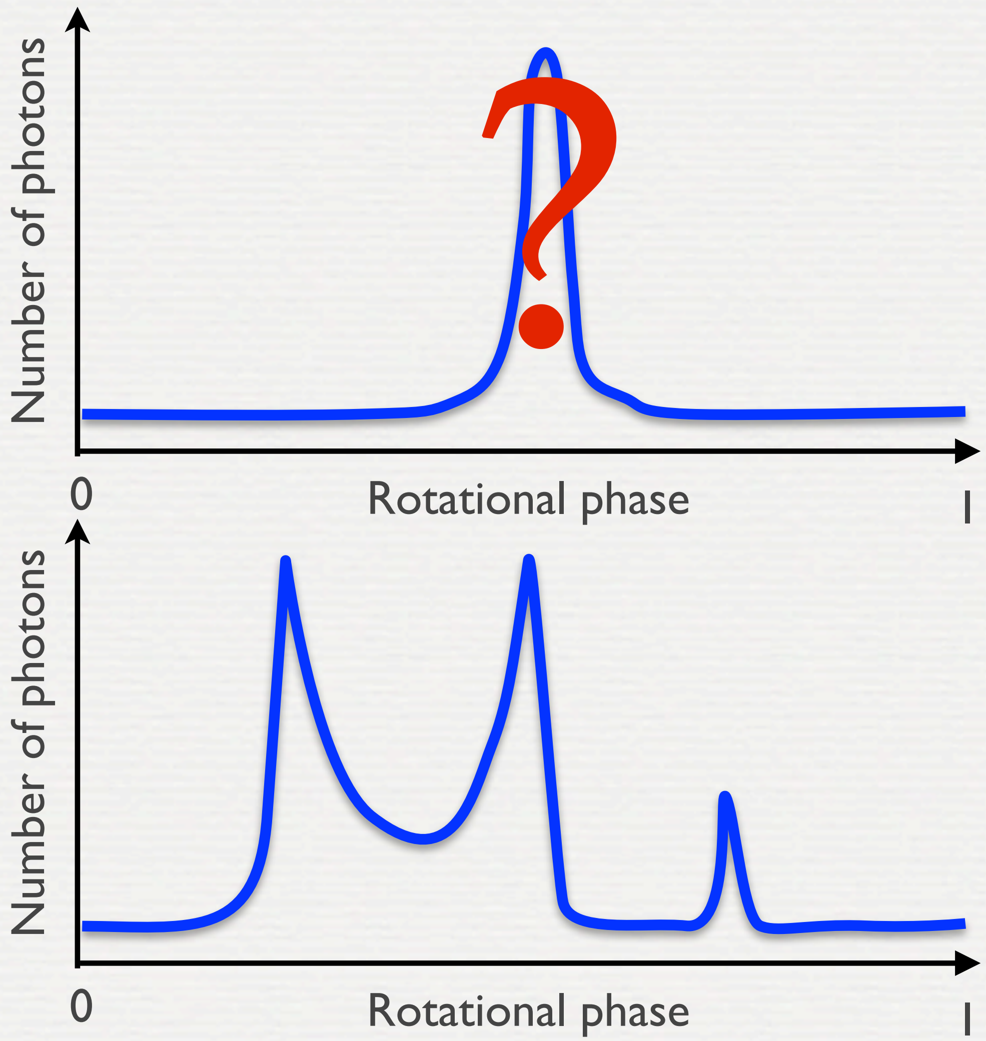

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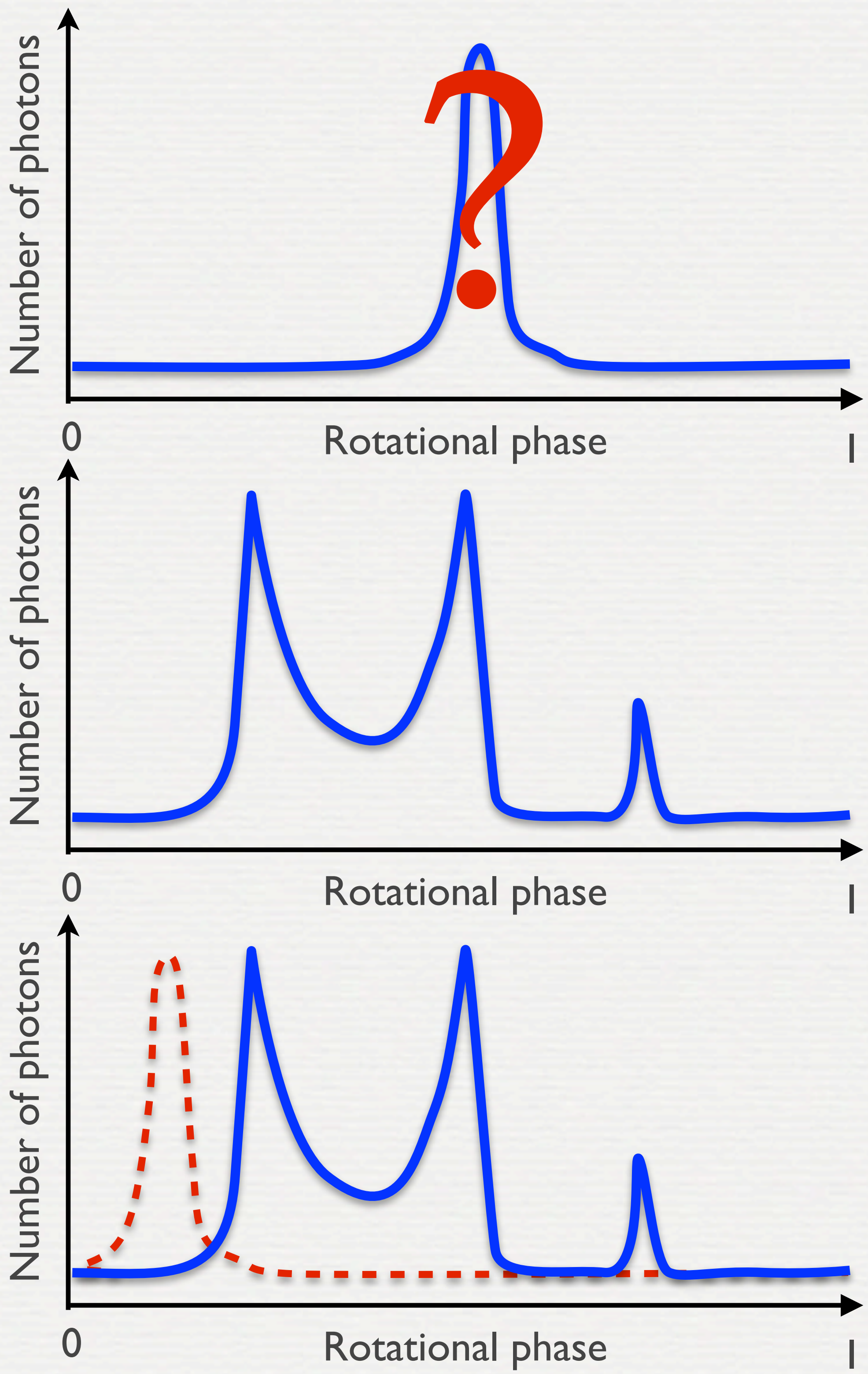

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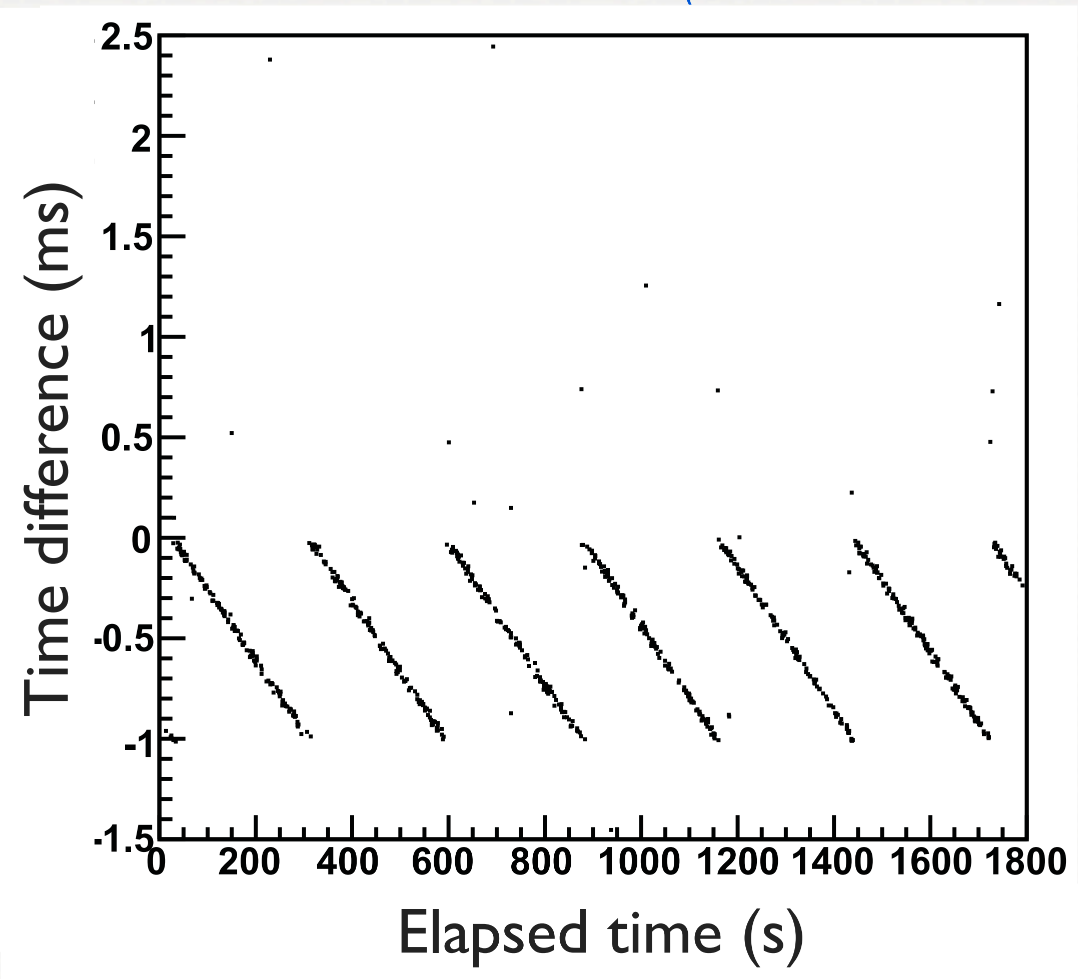
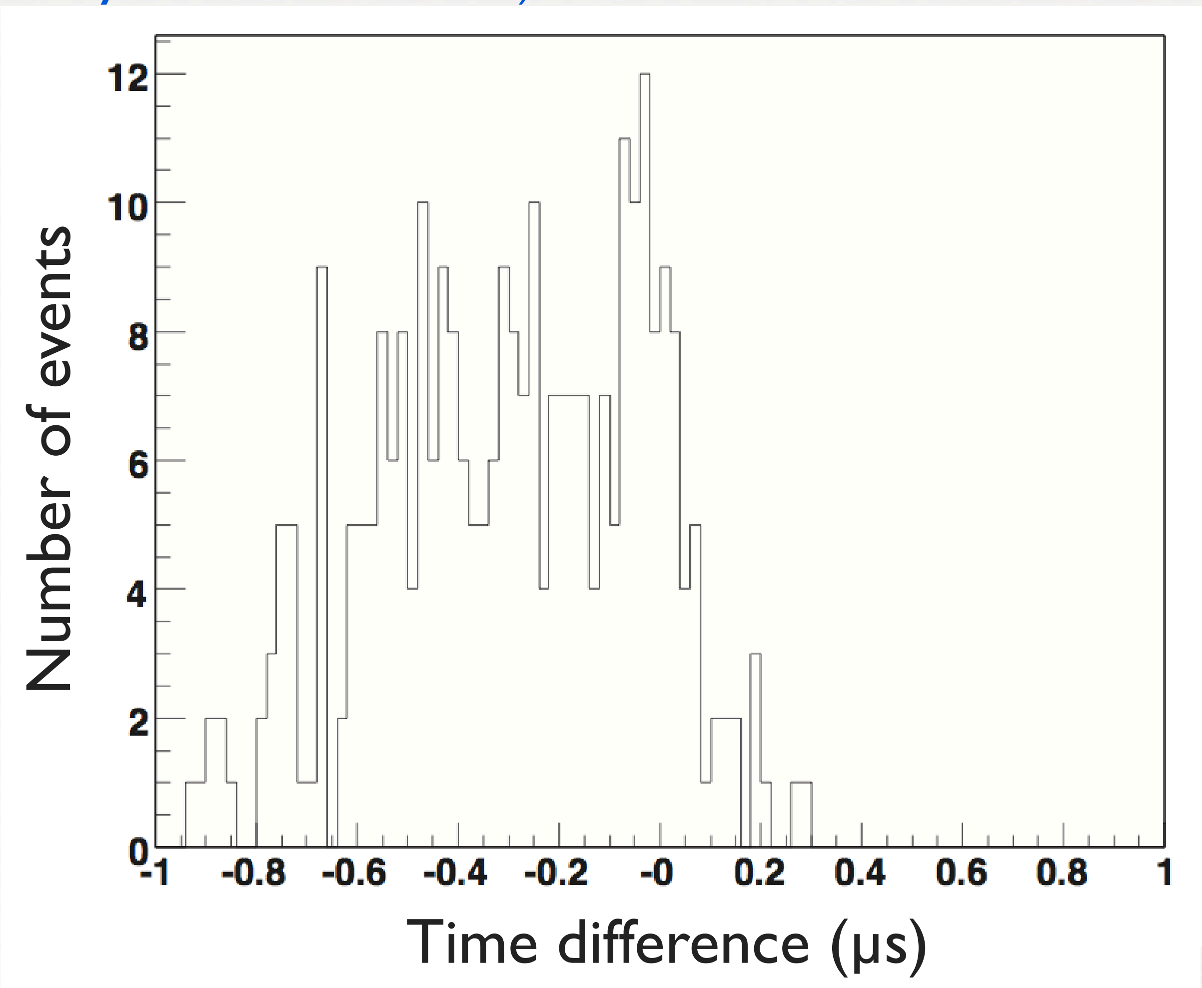
Photon time stamps

(Abdo et al., Astropart. Phys. 32, 192, 2009)



Difference between dates measured with the GPS on Fermi and a reference GPS, before correction.



Histogram of time differences after correction. Mean difference of 0.3 μs.

Pre-launch checks of Fermi's timing using atmospheric muons and a reference GPS (CELESTE experiment) revealed time stamping issues in the software.

After correction, ~1 μs precision on individual event dates.

Pulsar ephemerides

Lesson learned from EGRET: if gamma-ray MSPs exist, Fermi should see < 100-1000 ph/year.
In 1 year, a P = 5 ms pulsar does ~6.31 10^9 rotations! And more than 80% are in binaries!

For MSPs, <u>we have to do pulsar timing</u> in radio and/or X-rays and monitor the apparent period as a function of time.

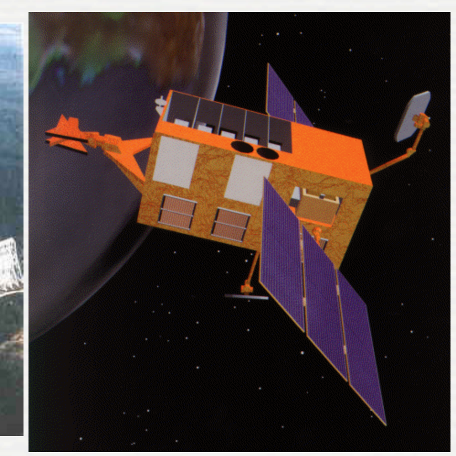
=> Pulsar timing campaign for Fermi: multi-wavelength monitoring of pulsars on a regular basis.
(Smith, Guillemot, Camilo et al., A&A 492, 923, 2008)


Parkes (Australia)


Jodrell Bank (England)


Green Bank (US)


Nançay (France)


RXTE

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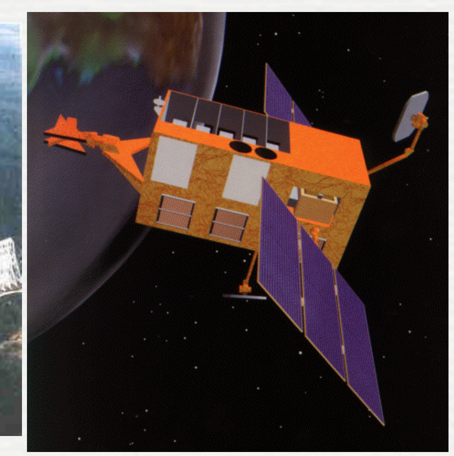


RXTE

Radio and/or X-ray «ephemerides»:

- Pulsar position in the sky and proper motion
- Rotational period as a function of time
- Binary motion (if any)
- Dispersion by interstellar matter

A population of gamma-ray MSPs

The LAT detected pulsed gamma-ray emission from J0030+0451. First firm detection of an MSP in gamma rays.

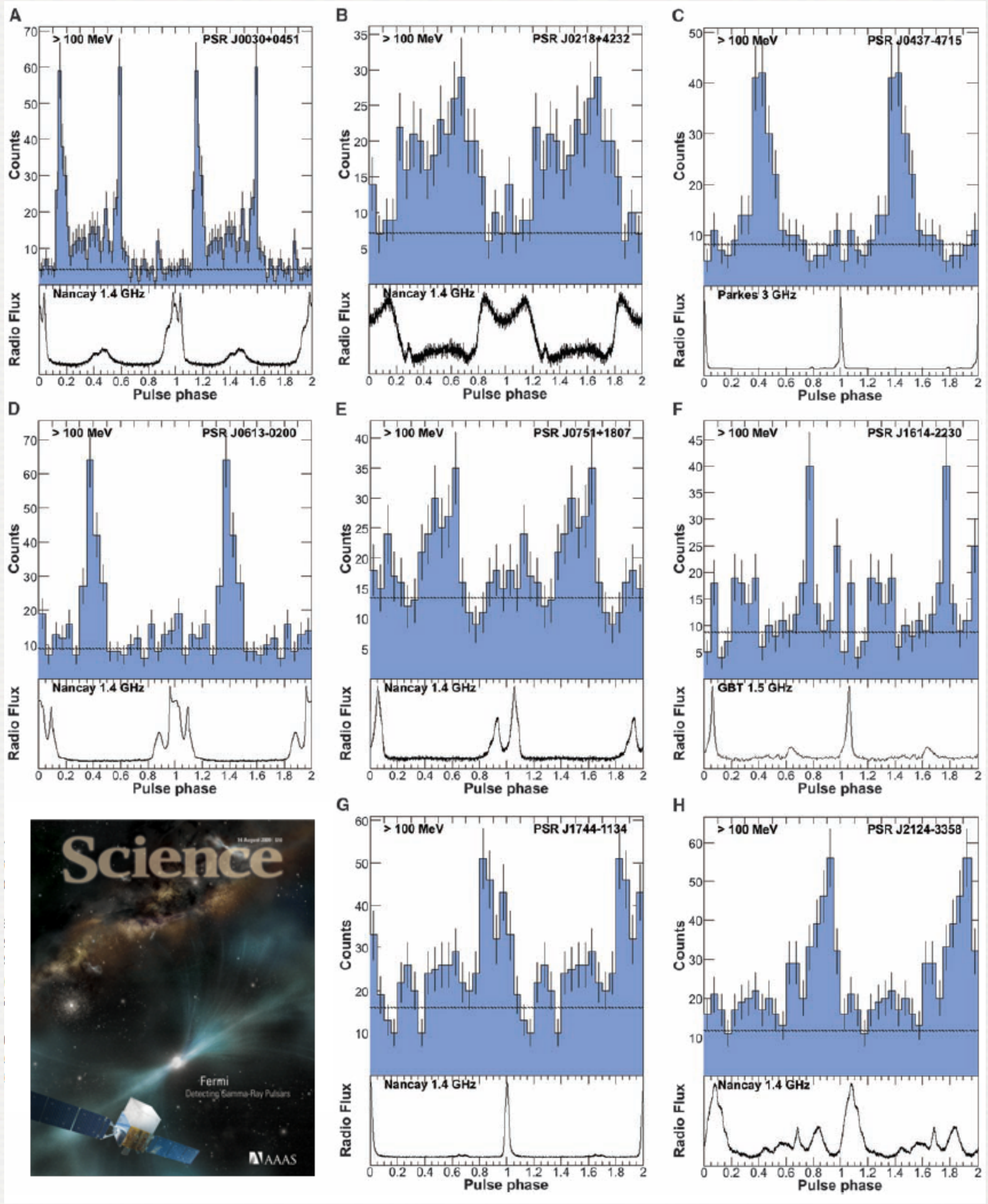
(Abdo et al., ApJ 699, 1171, 2009)

After 9 months of data taking, the LAT had detected 8 gamma-ray MSPs.

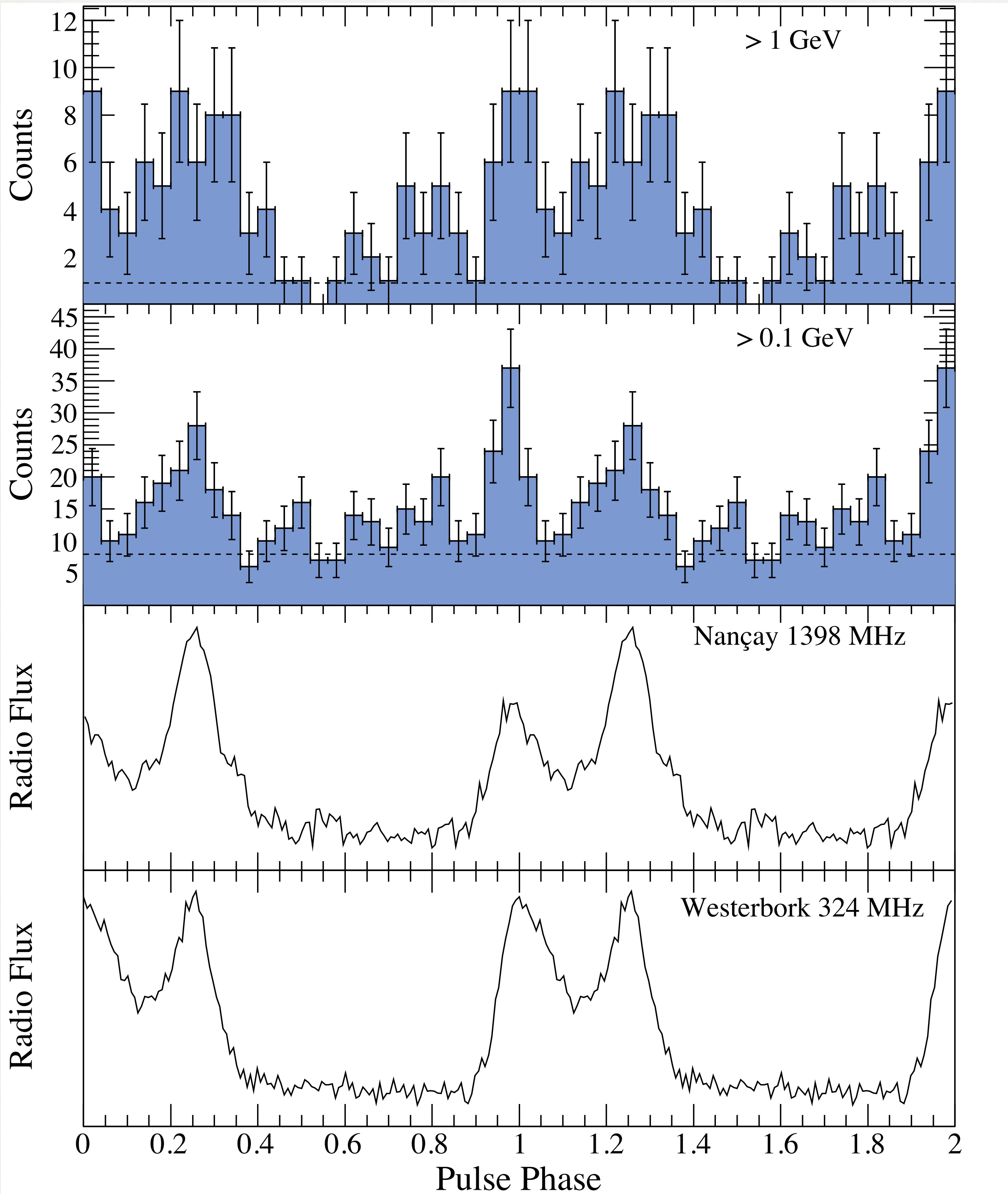
(Abdo et al., Science 325, 848, 2009)

MSPs are powerful particle accelerators!

Peak separations and radio lags are similar to those of normal pulsars.



Radio/gamma-aligned MSPs!



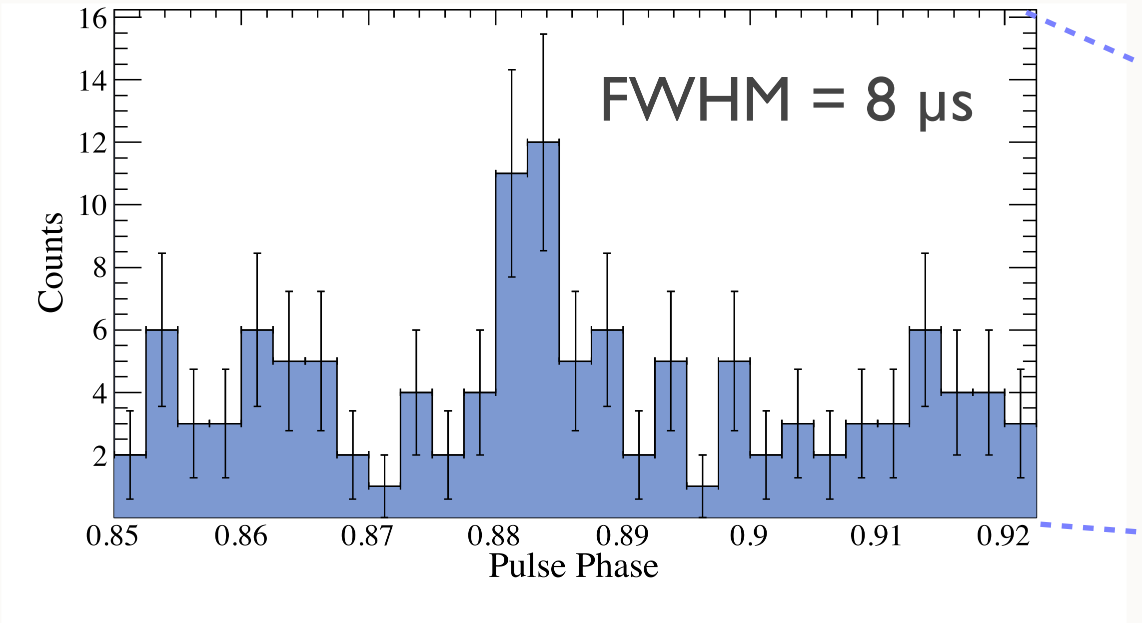
J0034-0534: ninth MSP detected in gamma rays with radio ephemerides.

First MSP with radio/gamma-ray alignment, phenomenon seen only in the Crab pulsar previously.

The alignment suggests that radio and gamma-ray emission regions are co-located.

(Abdo et al., ApJ 712, 957)

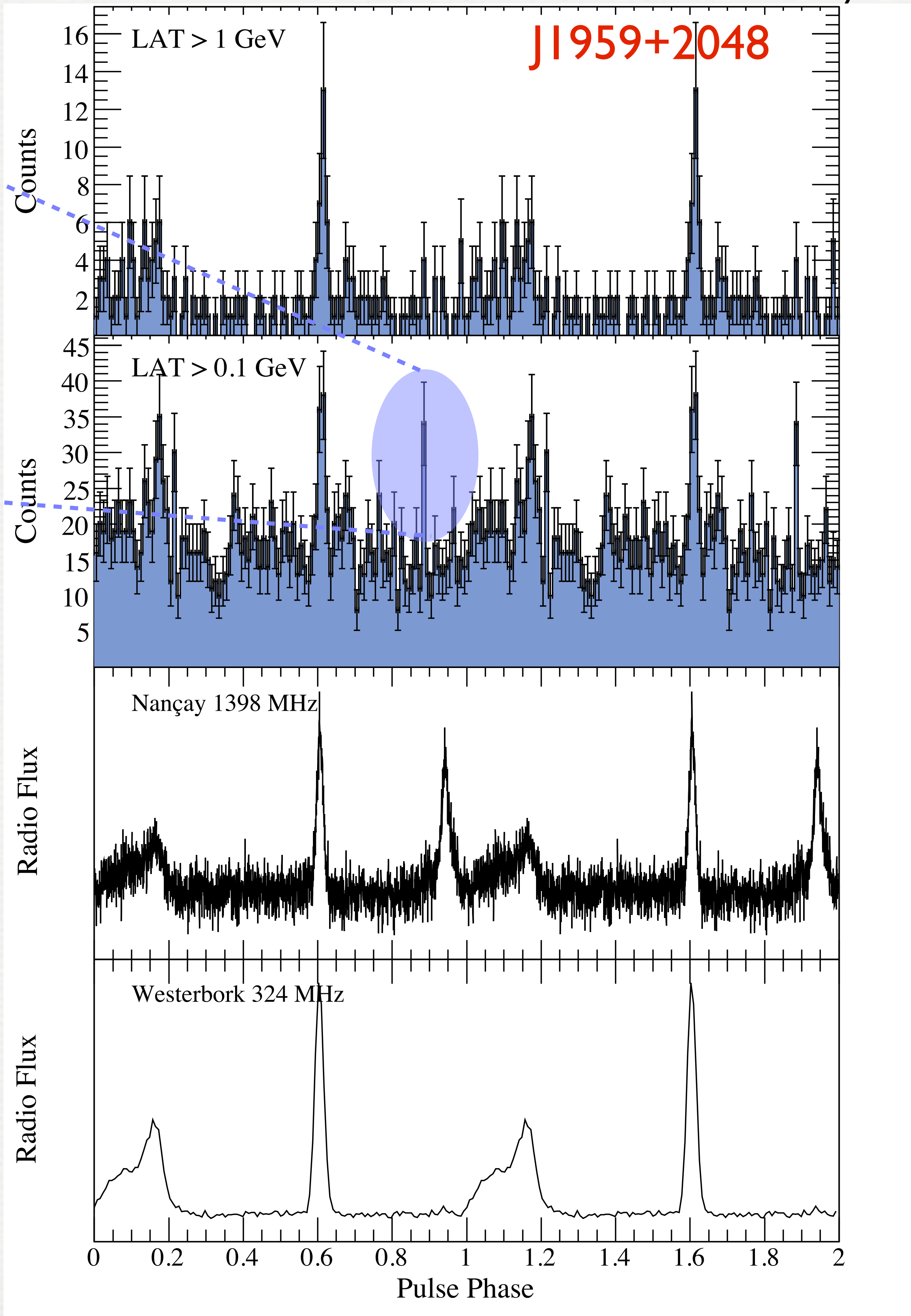
PSR J1959+2048



PSRs J1939+2134 & J1959+2048: 2 latest detections of MSPs with radio ephemerides *(Abdo et al., in prep)*.

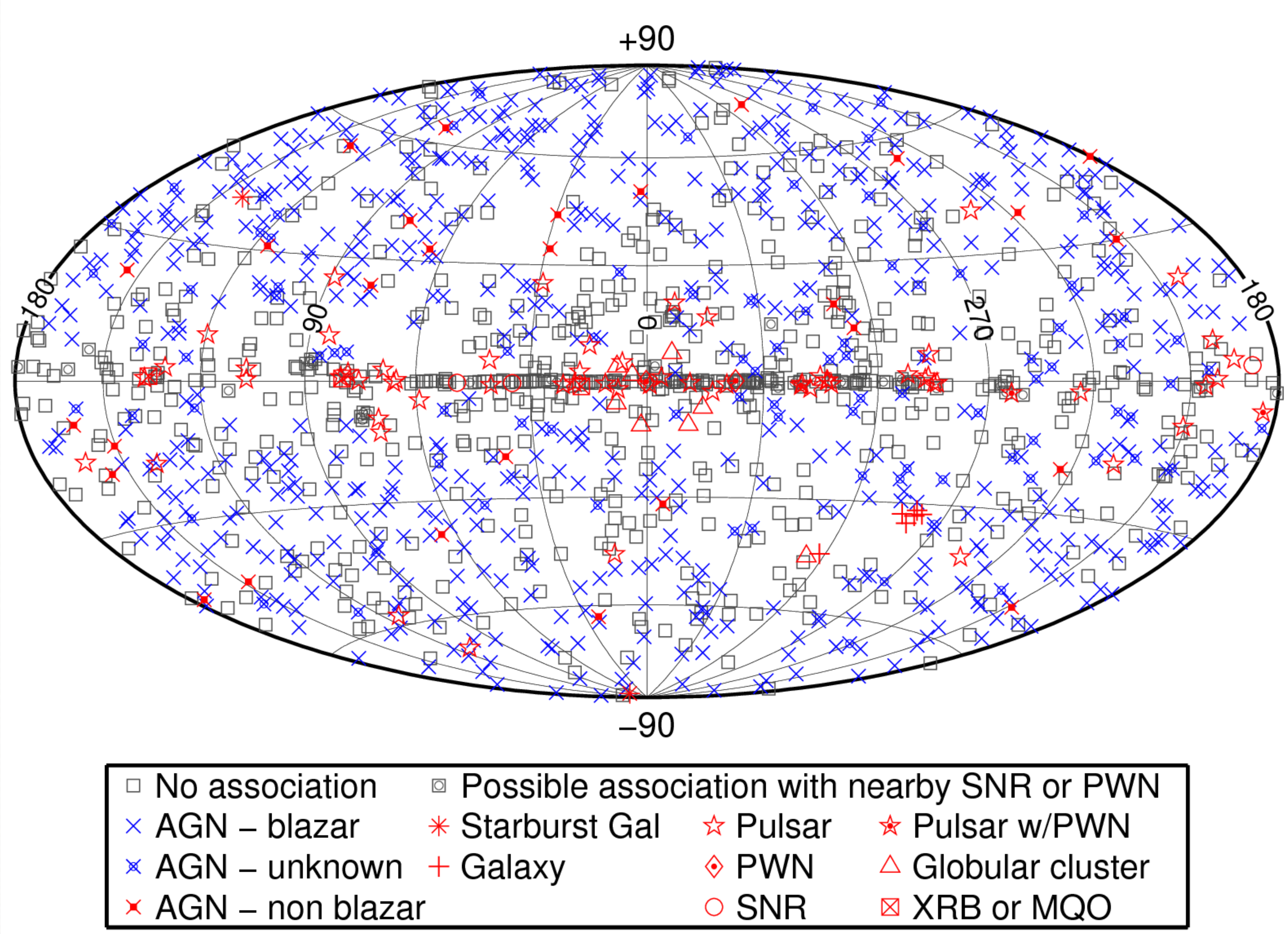
Both radio/gamma-ray aligned! Supports co-located radio and gamma-ray emission.

< 10 μs features observed!



L. Guillemot, HTRA IV, 05/05/10

The Fermi LAT First Source Catalog

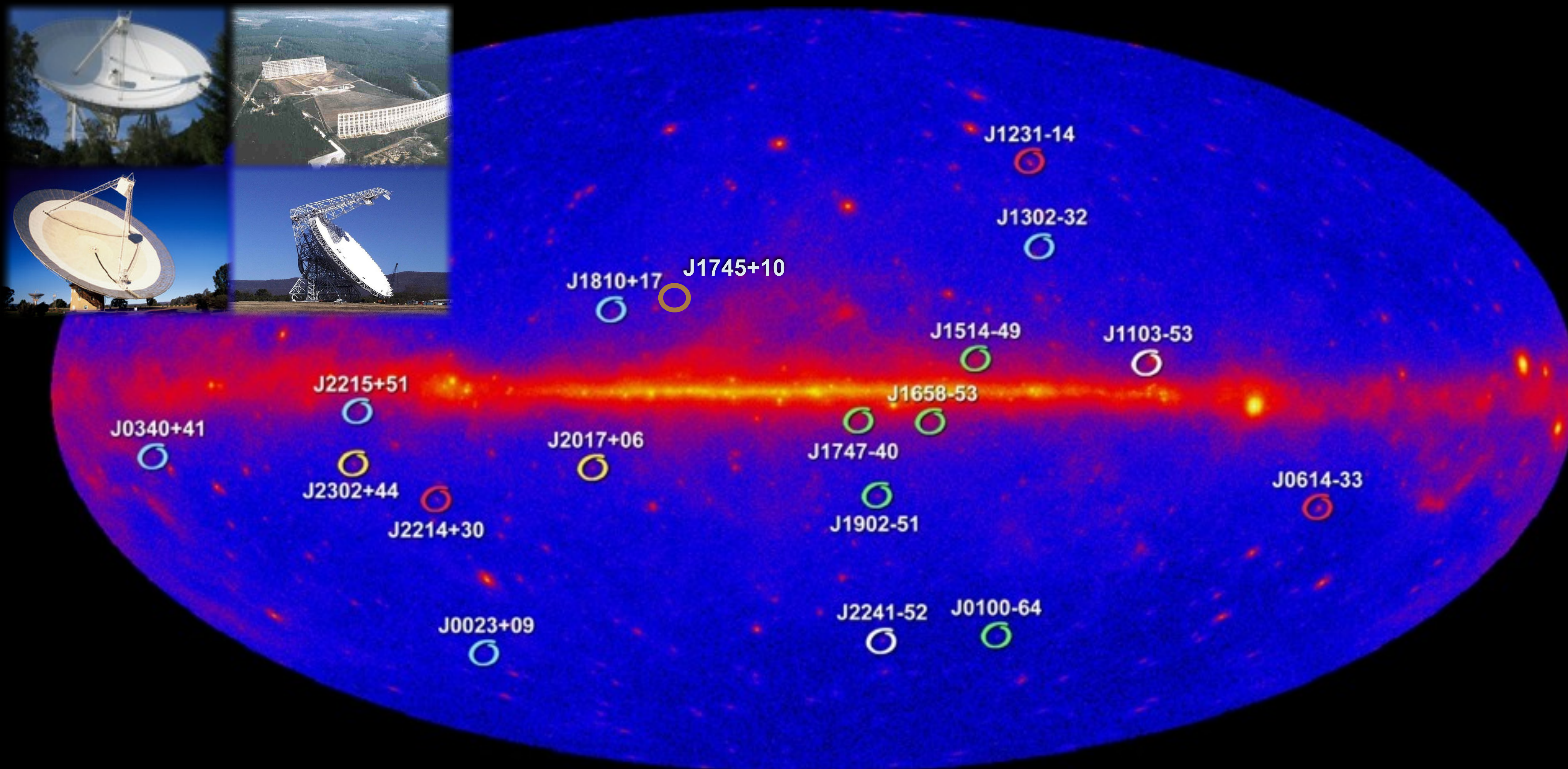


Released Jan 14, 2010. See http://fermi.gsfc.nasa.gov.ssc/ and arXiv:1002.2280.

1451 sources in 11 months of data, 631 have no association (ie, no known counterpart).

Unknown pulsars must be powering some of these unassociated sources!

New MSPs in Fermi unassociated 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

Prospects from the new discoveries

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

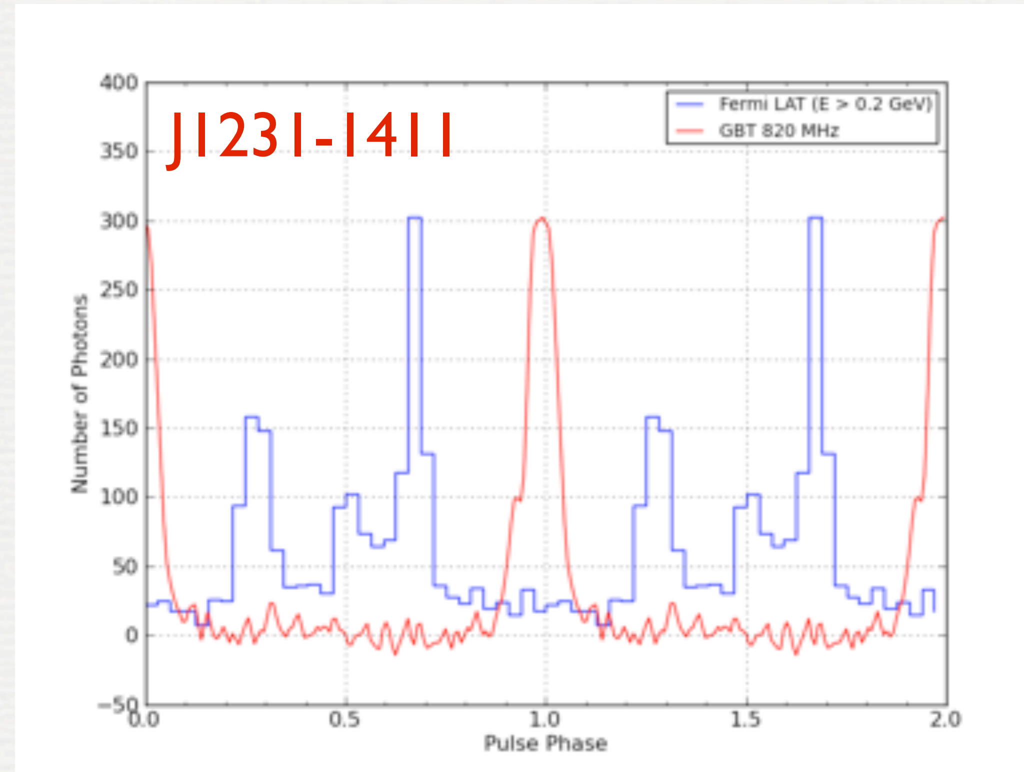
Better understanding of the underlying population of neutron stars.

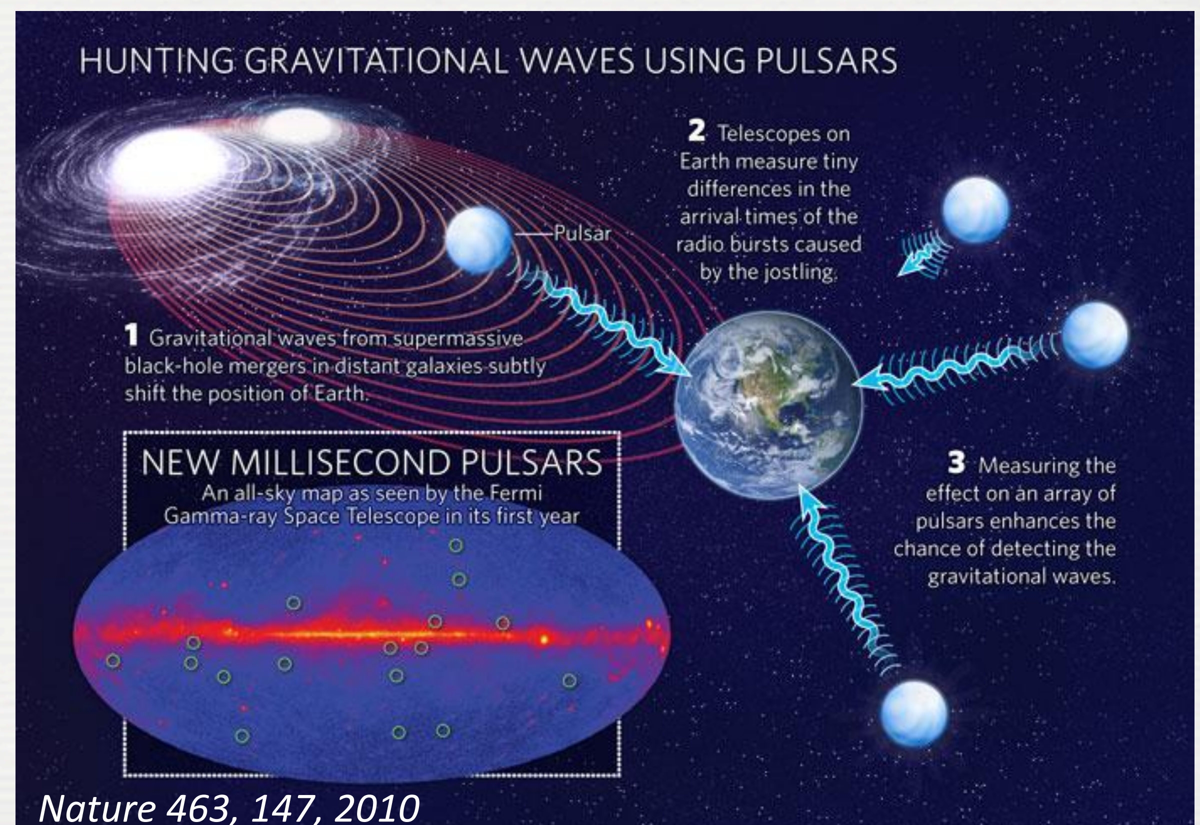
Most probably gamma-ray pulsars. Several pulsed detections already.

Radio timing of MSPs allows:

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

(Jenet et al., ApJL 625, 123, 2005)





Nature 463, 147, 2010

Conclusions

Detection of a population of gamma-ray MSPs (16 pulsed detections currently).

Pulsar science depends heavily on timing accuracy.

- Fermi's time stamps checked and corrected before launch. Accuracy < 1 μs.
- Multi-wavelength monitoring of the rotational period for pulsars with known radio or X-ray emission.

We are seeing < 10 μs features in some MSPs light curves.

➡ Detailed mapping of the high-energy emission from MSPs.

➡ Measurement of radio/gamma-ray lag. Geometry of the emission as a function of the energy.

Fermi detections are helping improve population synthesis of MSPs in the Galaxy and models of emission in pulsar magnetospheres.

Thank you for your attention!