New Radio Millisecond Pulsars in Fermi (formerly) Unassociated Sources

Scott Ransom (NRAO)

For the Fermi Pulsar Search Consortium (PSC)

Fermi Pulsars

- Currently 24 blind search pulsars (16 in Sci)
  - Young and/or nearby
- Currently 9 Millisecond PSRs (8 in Sci)
  - Confirmed 1 weak EGRET "detection"
- Integrated gamma-ray flux from globular cluster 47 Tuc likely from MSPs
- All pulsars have power-law spectra (steep) with exponential cut-off between 1-5 GeV
- Indicates emission from outer magnetosphere

Abdo et al, 2009, Science, 325, 840

Abdo et al, 2009, Science, 325, 845

Abdo et al, 2009, Science, 325, 848

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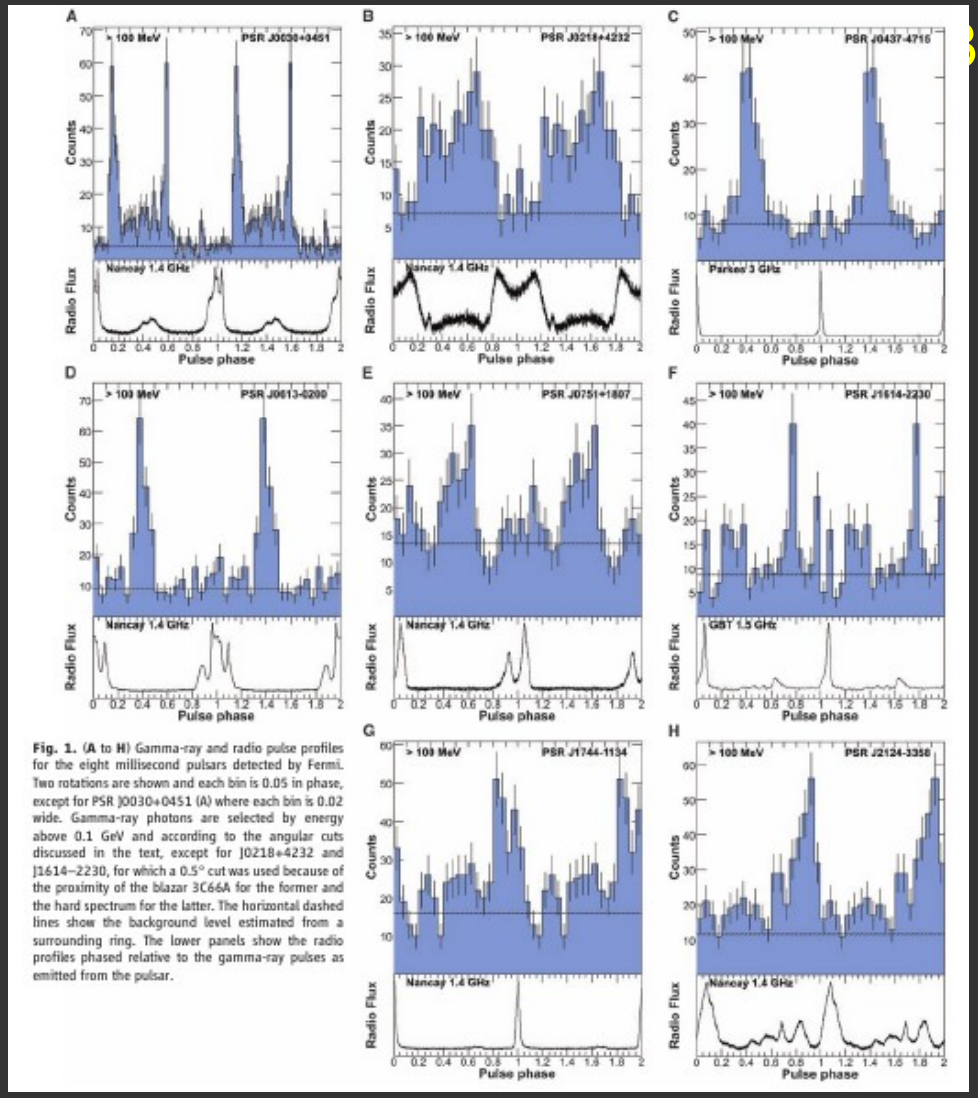
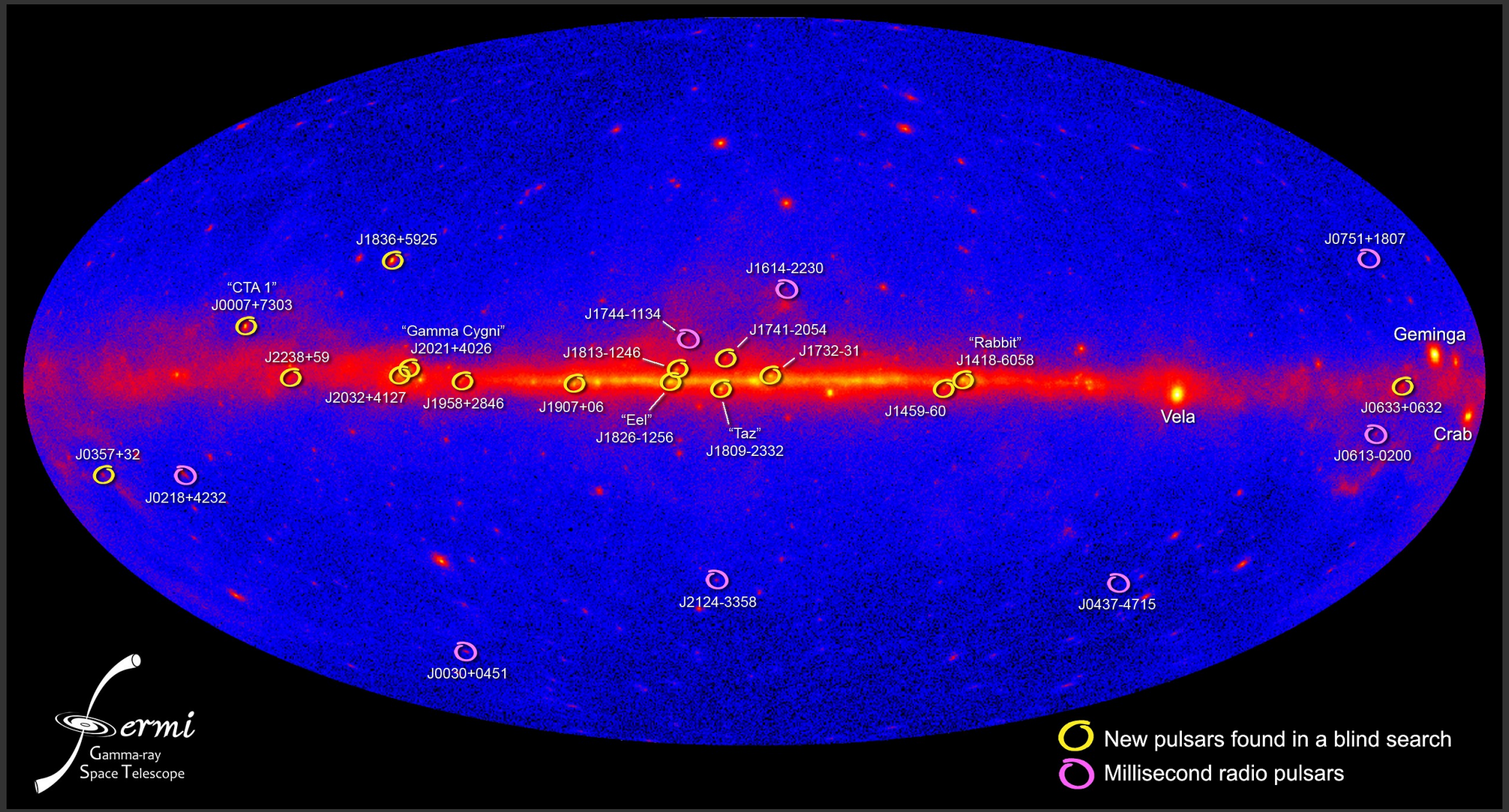


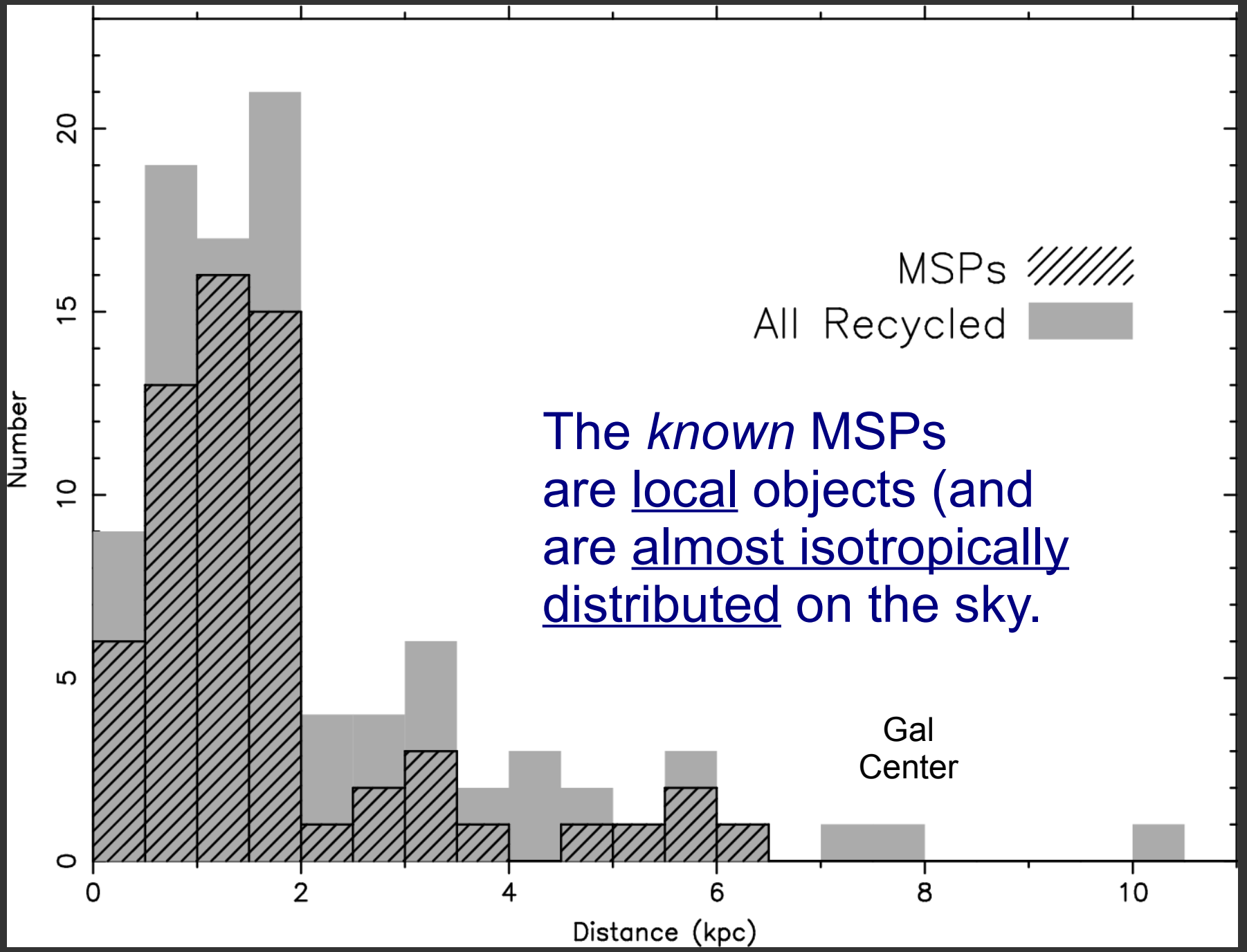
Fig. 1. (**A** to **H**) Gamma-ray and radio pulse profiles for the eight millisecond pulsars detected by Fermi. Two rotations are shown and each bin is 0.05 in phase, except for PSR J0030+0451 (A) where each bin is 0.02 wide. Gamma-ray photons are selected by energy above 0.1 GeV and according to the angular cuts discussed in the text, except for J0218+4232 and J1614−2230, for which a 0.5° cut was used because of the proximity of the blazar 3C66A for the former and the hard spectrum for the latter. The horizontal dashed lines show the background level estimated from a surrounding ring. The lower panels show the radio profiles phased relative to the gamma-ray pulses as emitted from the pulsar.

Fermi Pulsars

Young pulsars in the plane, millisecond pulsars at high Galactic latitude.



Recycled PSR Distances

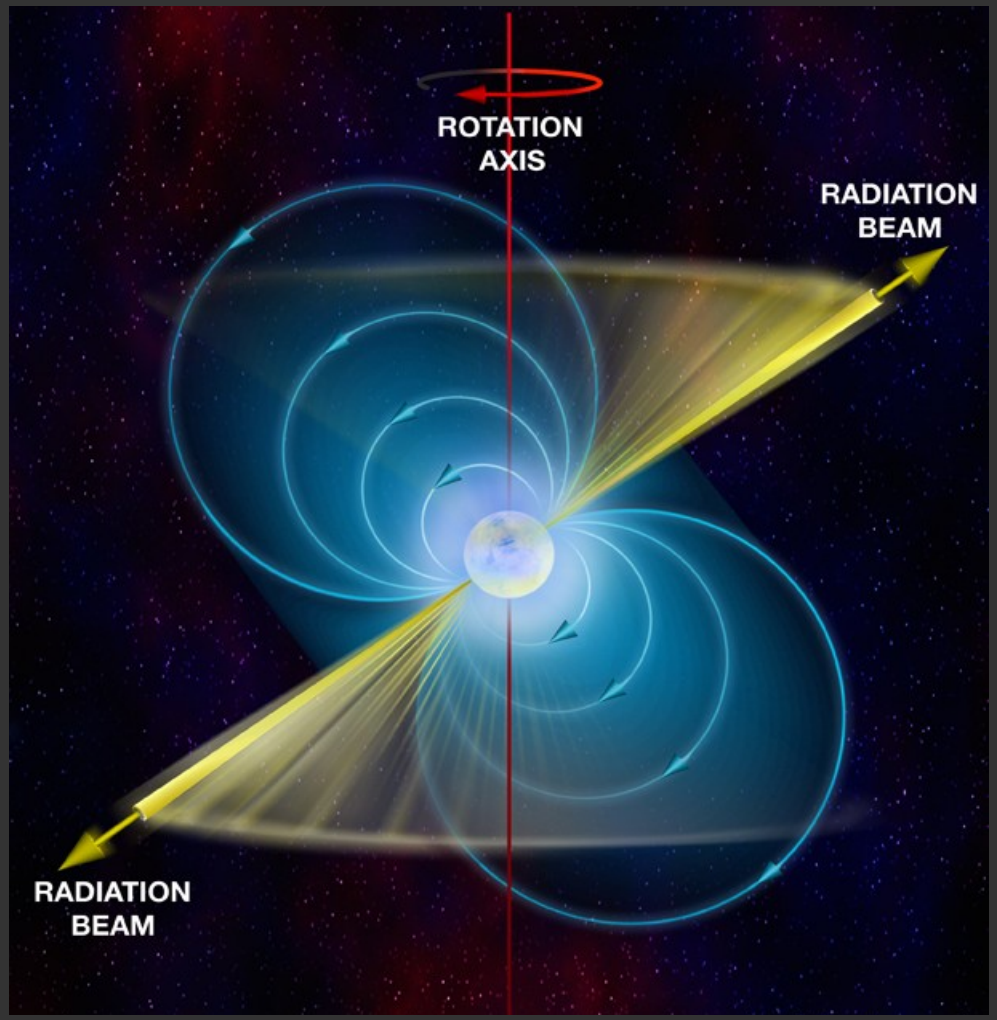


Fermi Pulsar Search Consortium (PSC)

- **Purpose**: To organize deep radio searches of the blind search pulsars and unassociated LAT sources
- **Fermi LAT Members**: Paul Ray, Smith, Harding, Thompson, Saz Parkinson, Ziegler, Abdo, Wood, Romani, Kramer (Effelsberg), Johnston (Parkes), Theureau, Cognard (Nançay)
- **External Members on MOU**:
  - GBT: Camilo, Ransom, Roberts
  - Arecibo: Freire
  - Jodrell Bank: Stappers
  - Parkes: Keith, Weltevrede

Why search for pulsars?

- Radio and γ-rays come from different parts of magnetosphere
  - Constrain emission
  - See work by Romani, Harding, Gonthier, etc
- Dispersion Measure gives a distance
- Radio timing typically much more accurate
- Some pulsars we can't find in γ-rays

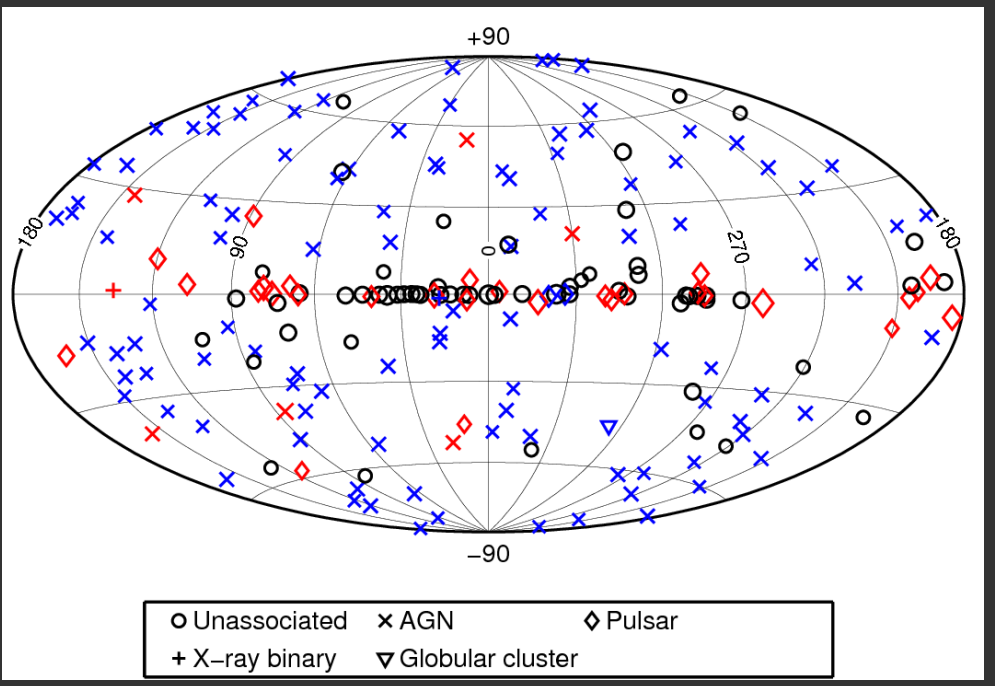


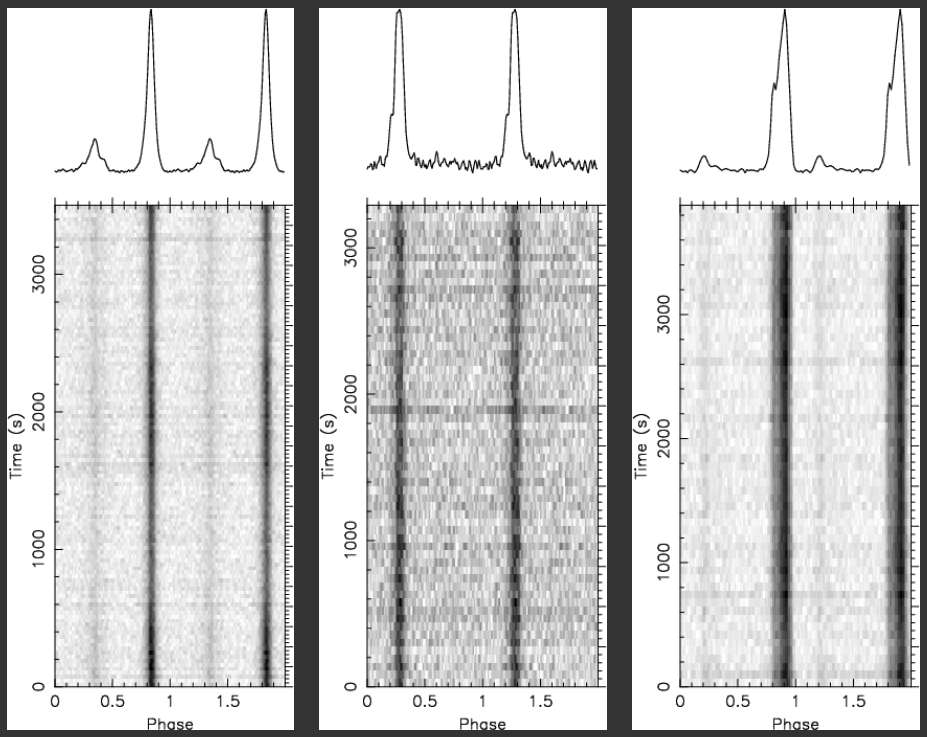
Searches for γ-ray PSRs in EGRET srcs were not very successful. Exceptions:
PSR J2229+6114 (Halpern et al 2001)
PSR J2021+3651 (Roberts et al 2002)

Radio Searches of Fermi Bright Sources

- Used NRAO's Green Bank Telescope to observe 27 bright gamma-ray sources
- Quickly found 3 bright binary MSPs! Big surprise!

Abdo et al, 2009, ApJS, 183, 46





0FGL J2214.8+3002 is PSR J2214+30

3.12 ms spin

10 hr orbit

13 Mjup min companion

~1.5 kpc (DM)

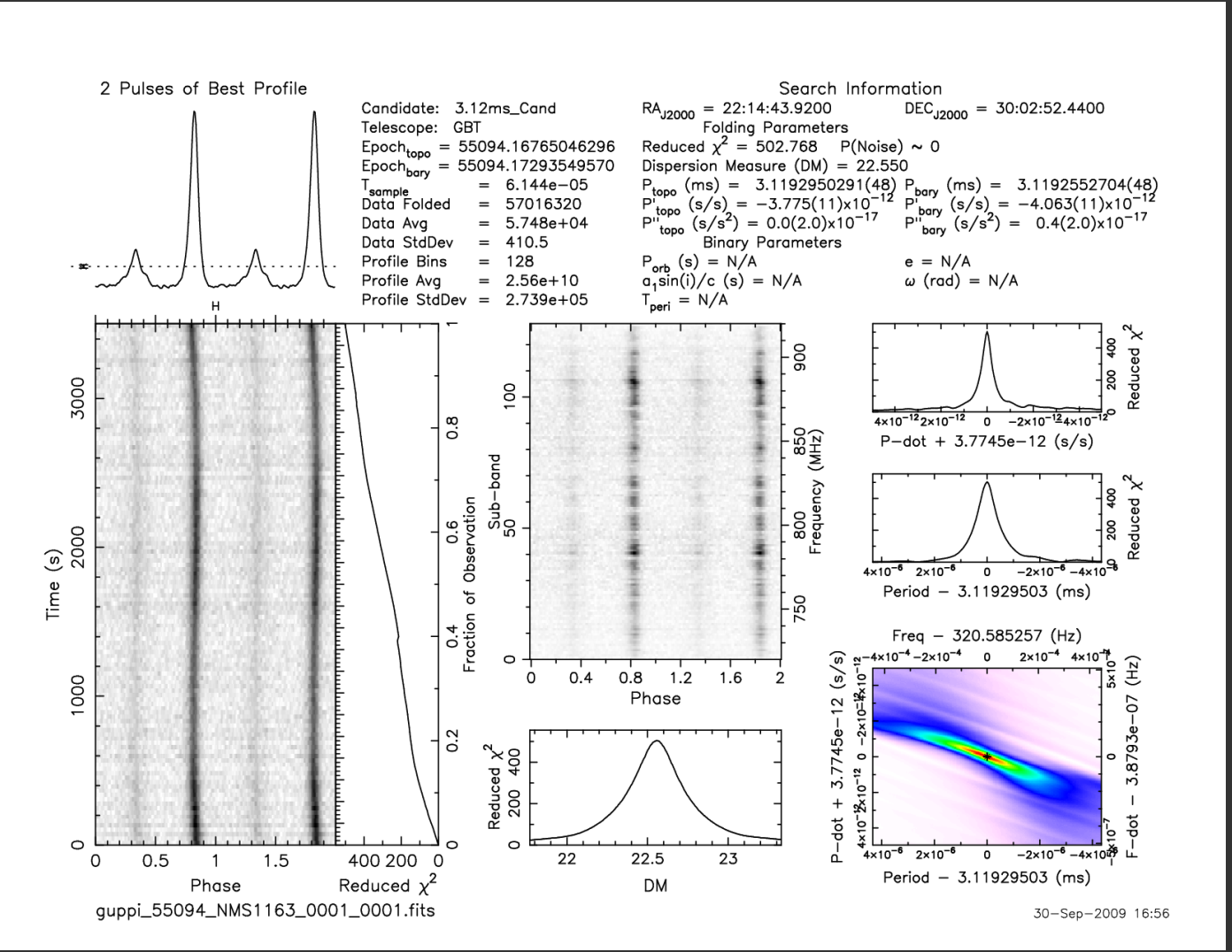
X-ray point sources...

Very bright

Scintillation

Arecibo visible!

"Black-Widow", NANOGrav MSP?



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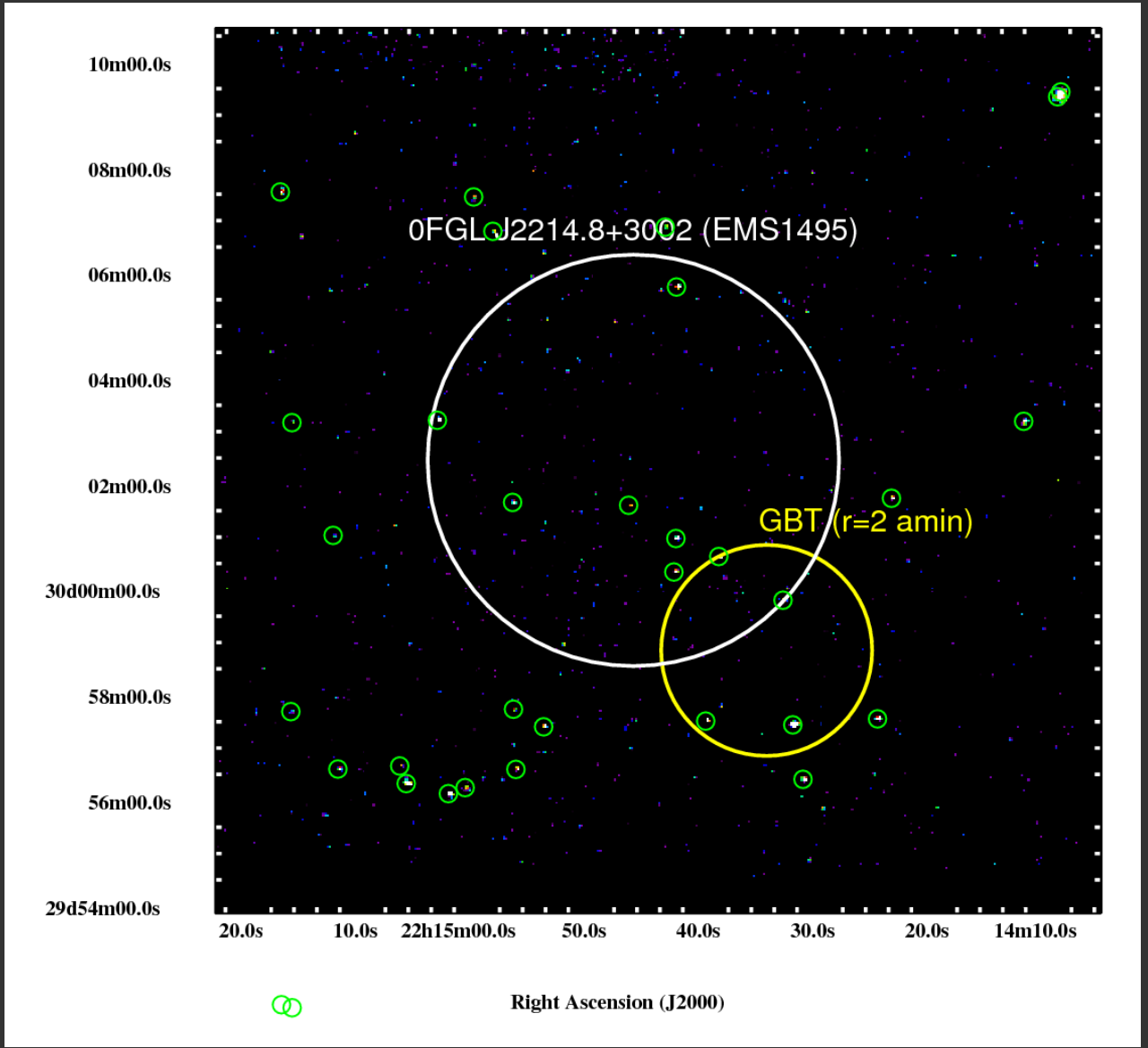


Chandra ACIS

0FGL J1231.5-1410 is PSR J1231-14

3.68 ms spin

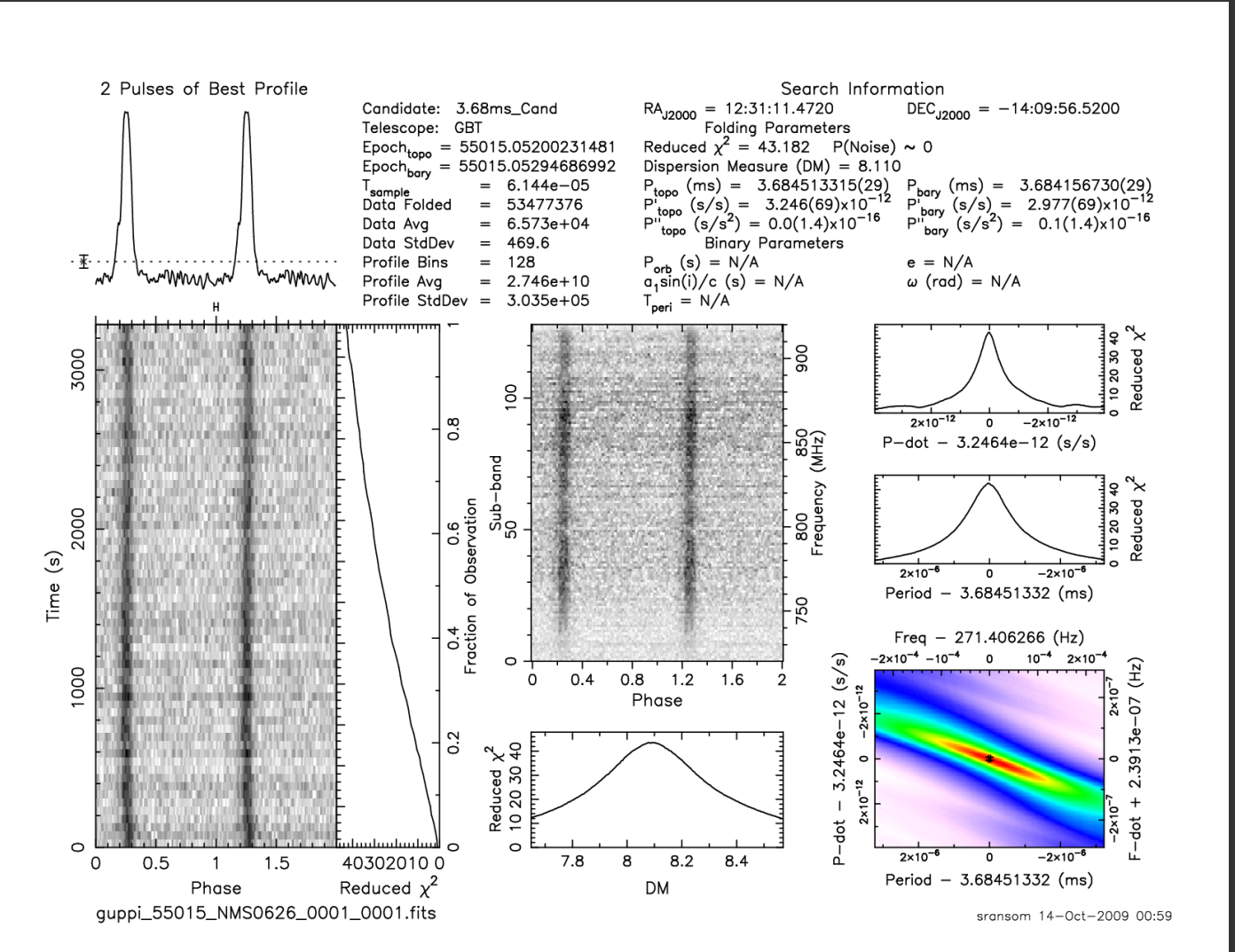
1.86 day orbit

0.2 Msun min companion

~400 pc (DM)

Good X-ray point source... (thanks to Michael Wolff)

"Normal" Binary MSP (and close)



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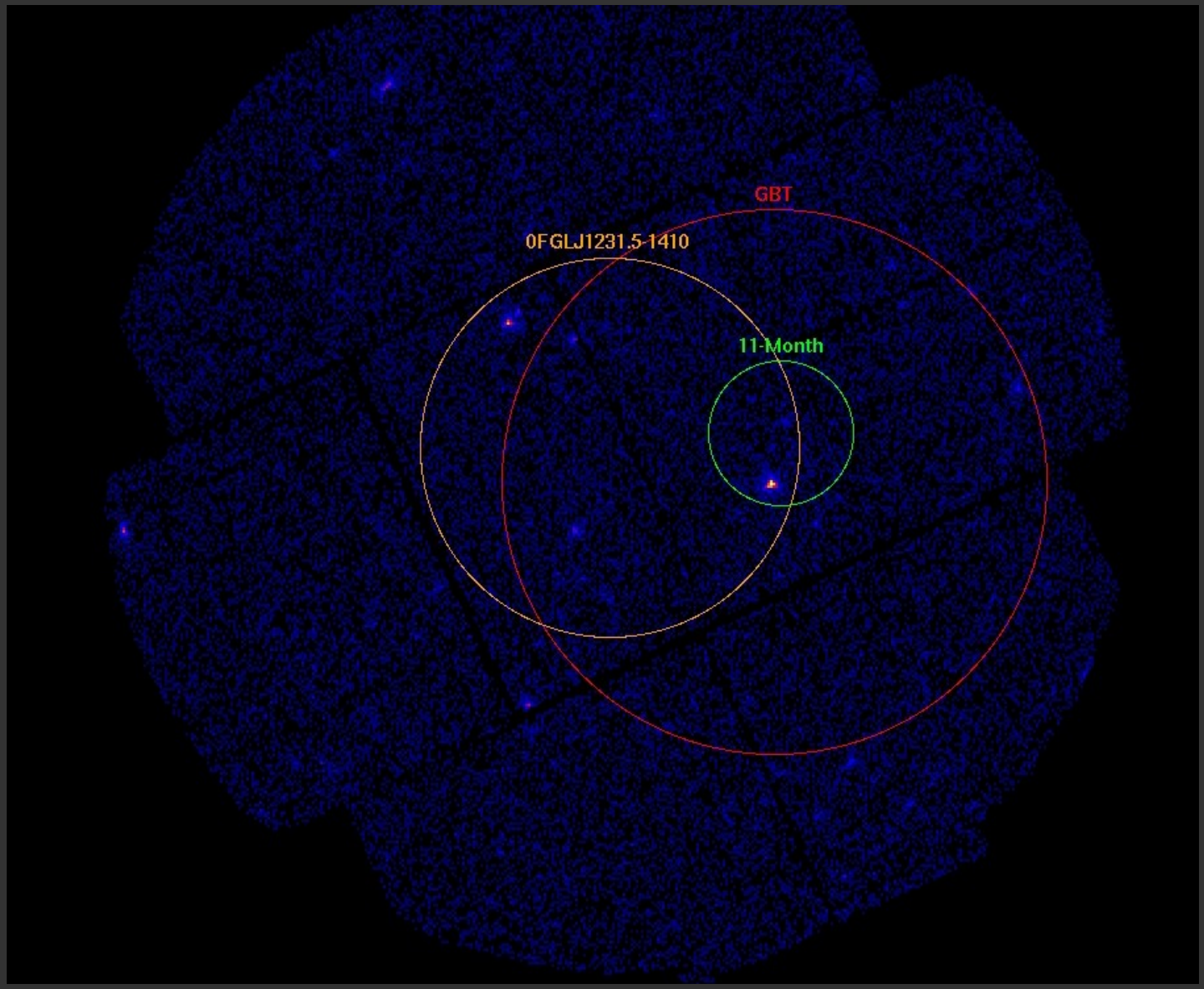
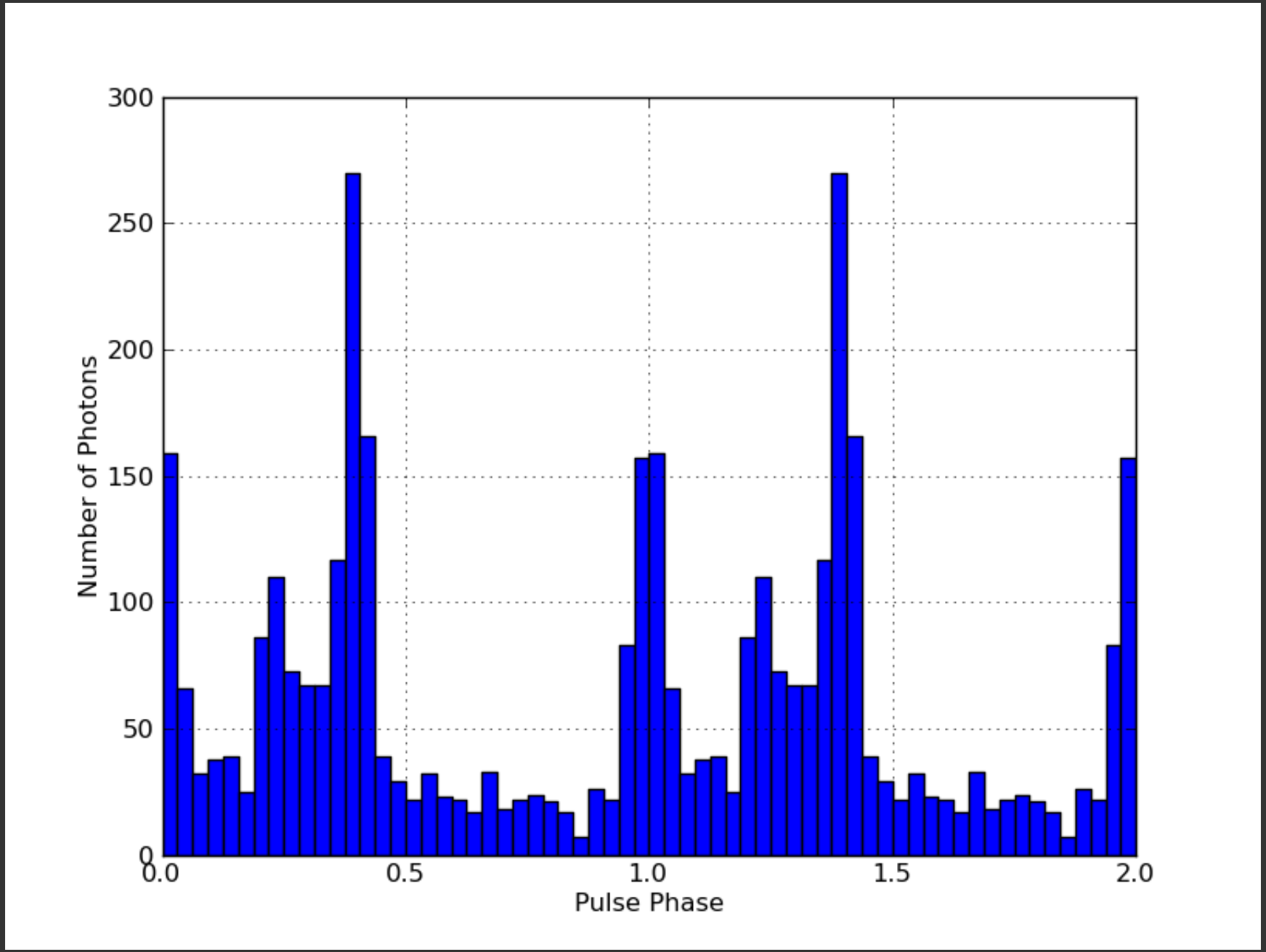


XMM-Newton (MOS)

PSR J1231-14 Gamma-Ray Pulsations!



0FGL J0614.3-3330 is PSR J0614-33

- 3.15 ms spin
- 53 day orbit
- 0.33 Msun min companion
- ~2 kpc (DM)
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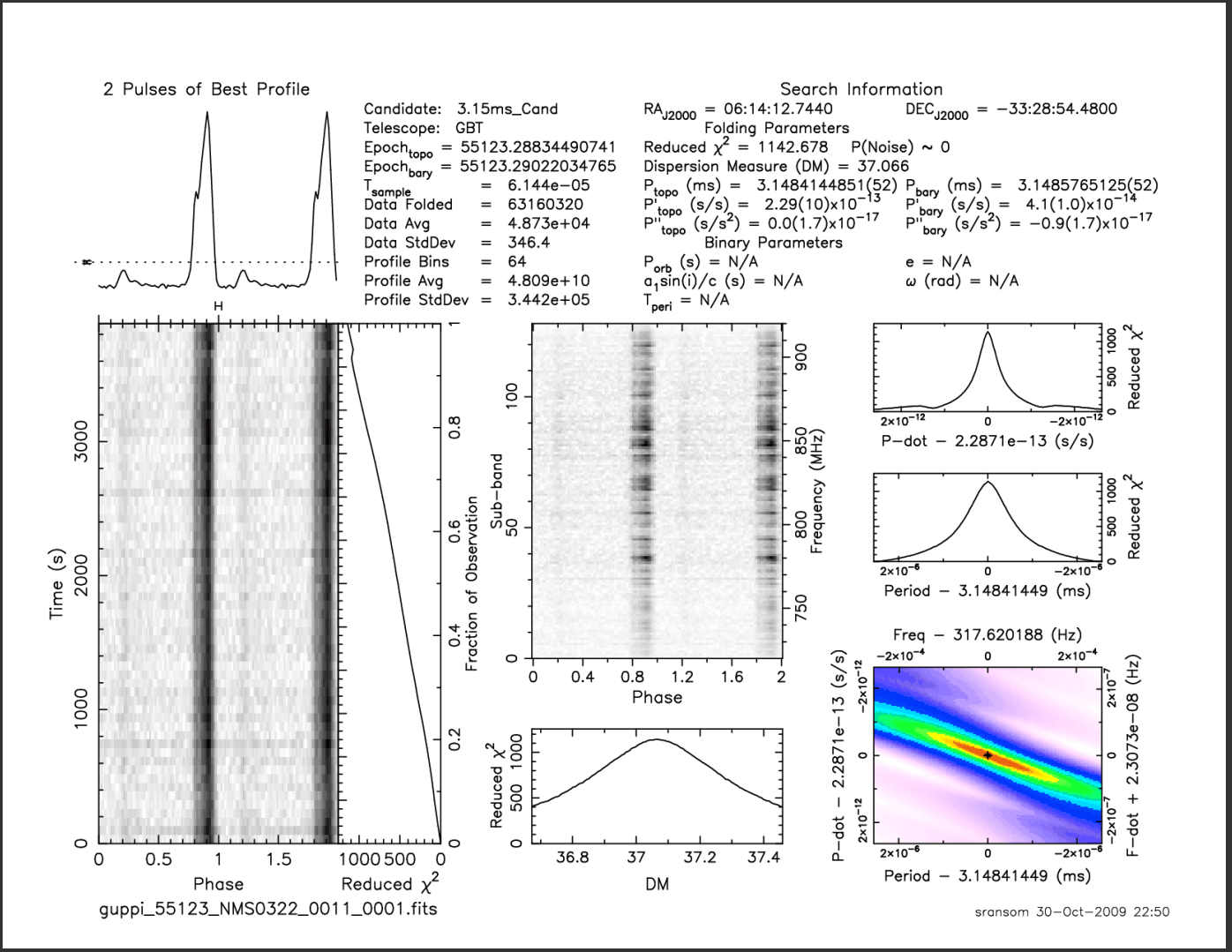
- Very bright
- Scintillation

“Normal” Binary MSP



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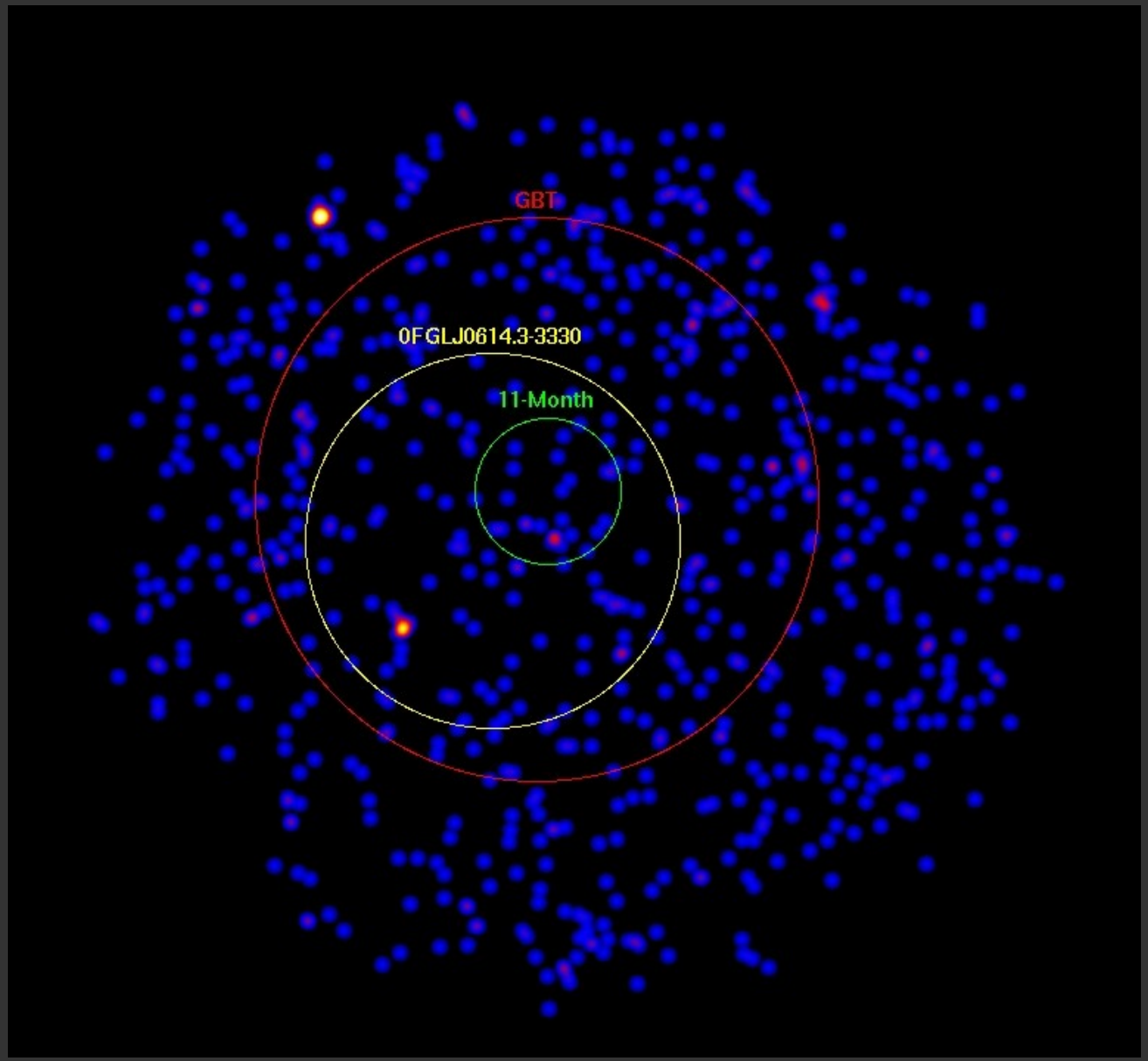


Swift XRT

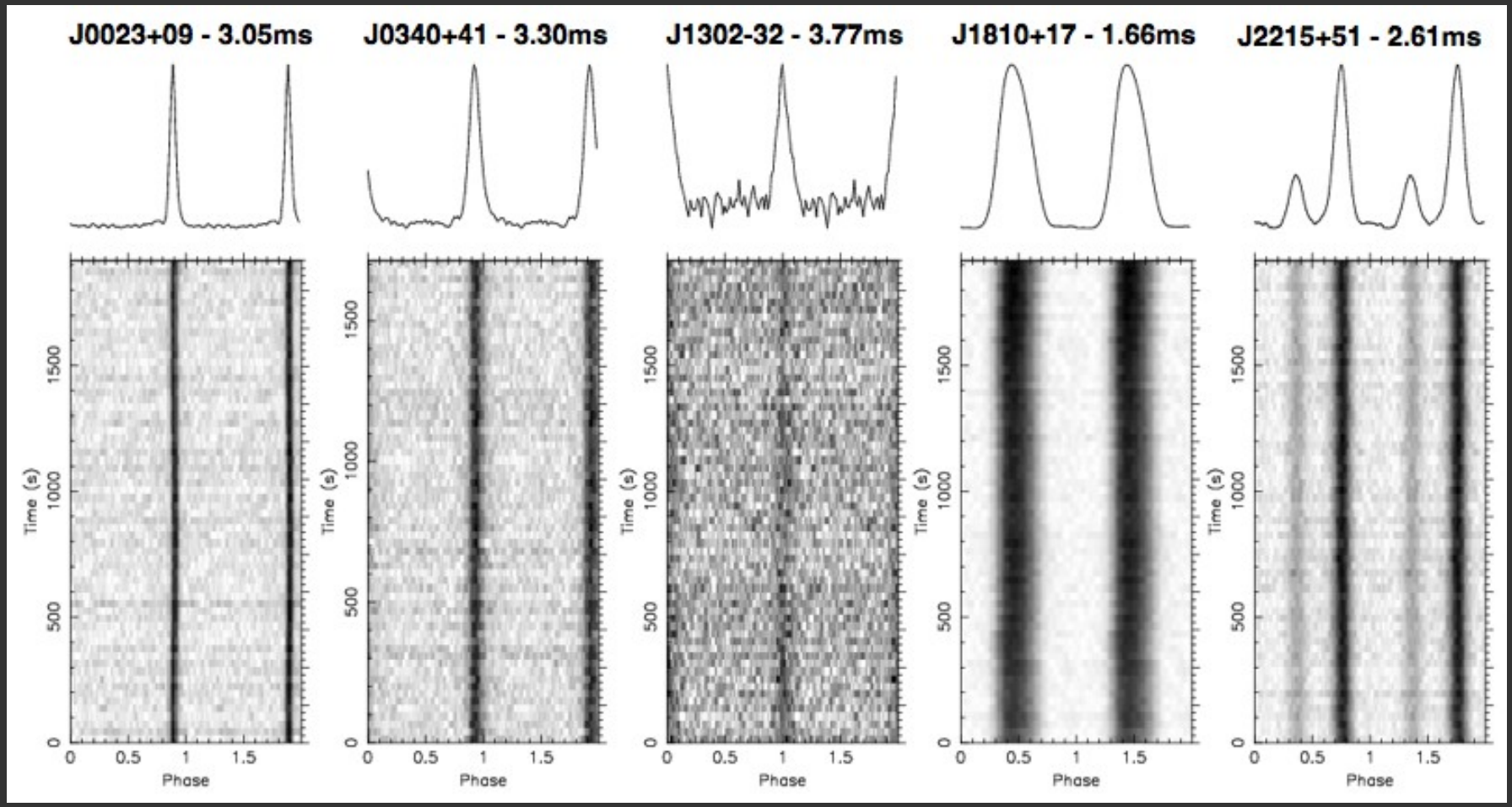
Other GBT Searches

- Approx 50 sources:
  - No associations
  - Dec > -40deg
  - More than ~5 deg out of Galactic plane
  - Sources selected based on “PSR-like” spectra (by Matthew Kerr)
- ~25 hrs of GBT time
  - Used 11-month posns
  - Very CPU intensive!

PIs M. Roberts (Eureka) and M. Mclaughlin (WVU)

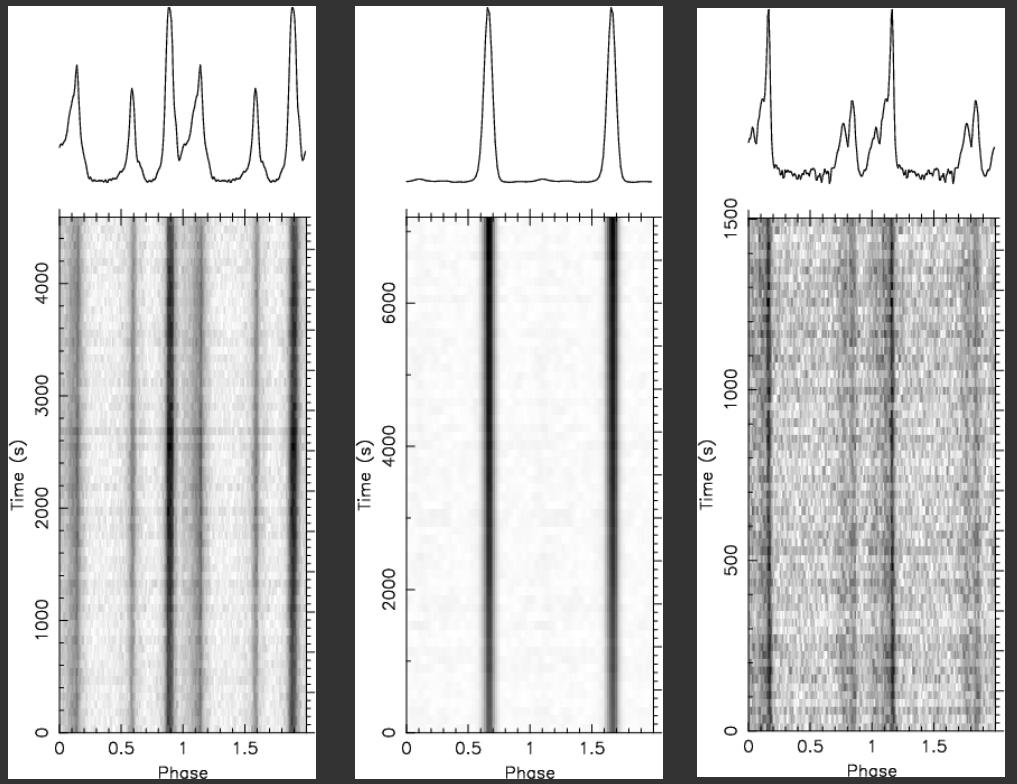
Roberts et al results

- Only first 2 min of each observation searched
- 5 new MSPs!
- 4 binaries (2 Black-Widows, 1 eclipsing)



Other Searches

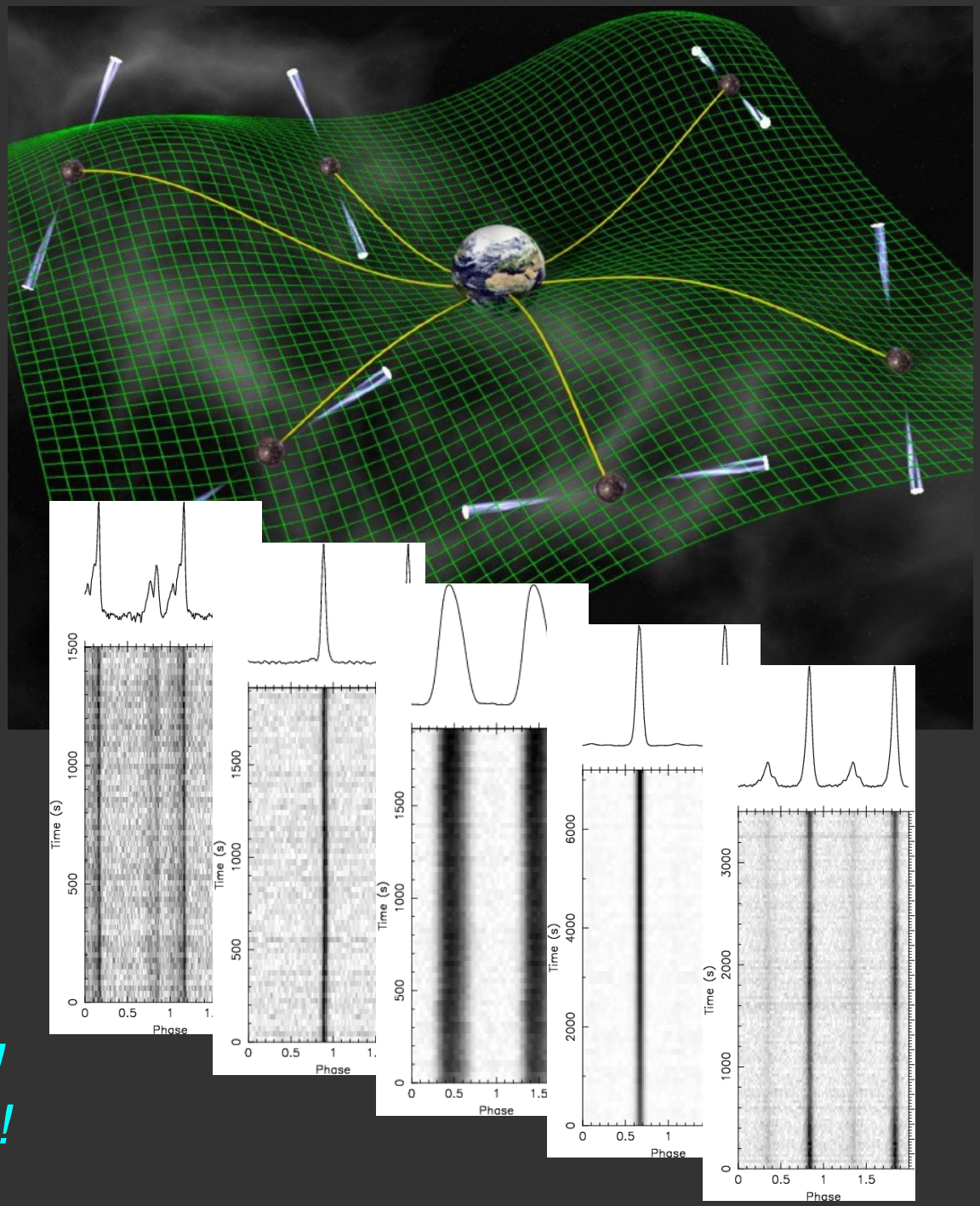
- Nancay:
  - I. Cognard: 2 binary MSPs
- Parkes:
  - M. Keith: 2 binary MSPs (1 bright)
  - F. Camilo: 4 binary, 1 isolated MSP
- Effelsberg, GBT, and Arecibo searches ongoing



Gravitational Wave Detection with a Pulsar Timing Array

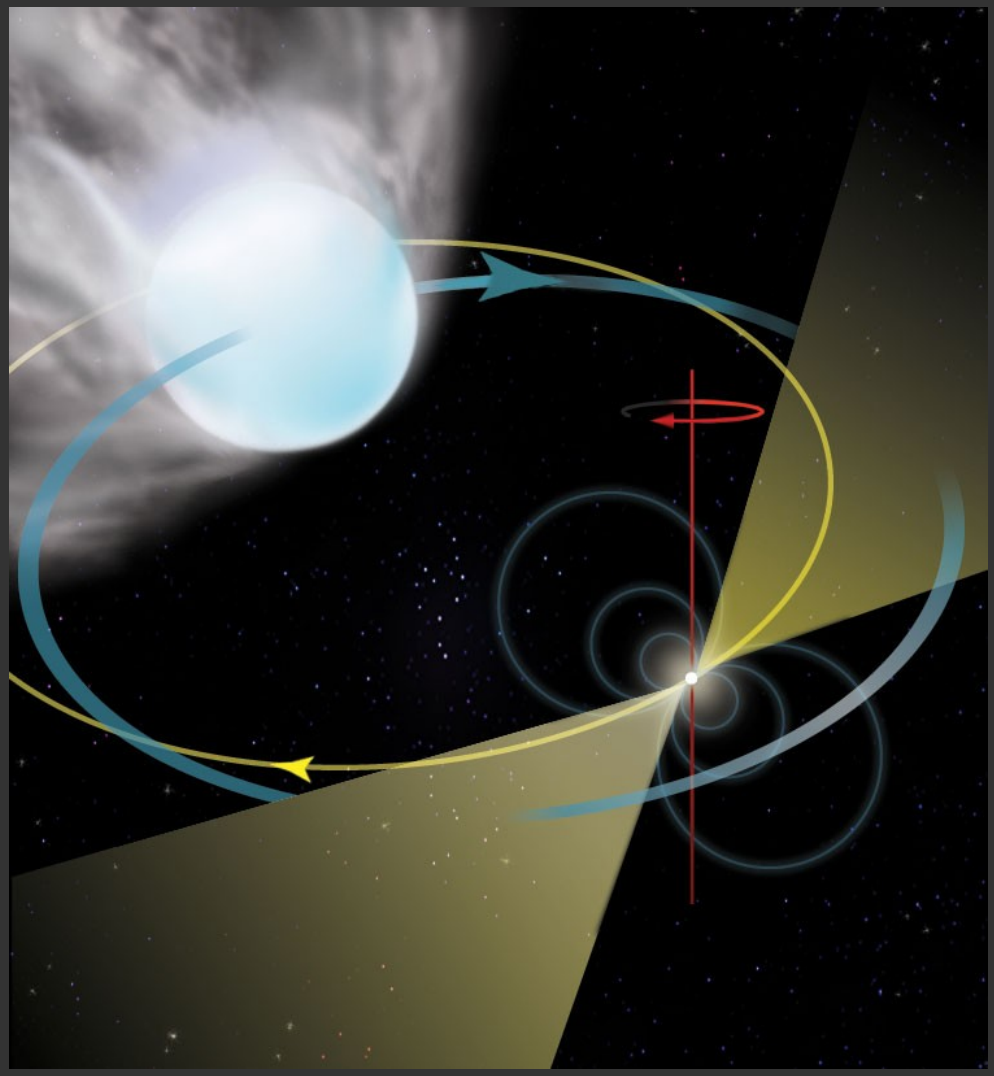
- Need good MSPs
- Significance scales directly with the number of MSPs being timed. Lack of good MSPs is currently the biggest limitation
- Must time the pulsars for 5-10 years at a precision of 0.1-0.2 micro-sec!
- North American (NANOGrav), European (EPTA), and Australian (PPTA) efforts

Several of the new MSPs are fast, bright, and sharp! Several visible by Arecibo!



At least *four* new "Black-Widow" Systems

- Have short period orbits (3-10 hr) with very low-mass companions (10-80 Jupiter Masses) which are being ablated by the MSPs
- Previously only 3 of these known in the Galatic disk!
- Another "nearly" black-widow shows eclipses of radio waves
  - Bad for timing, but good for evolution studies

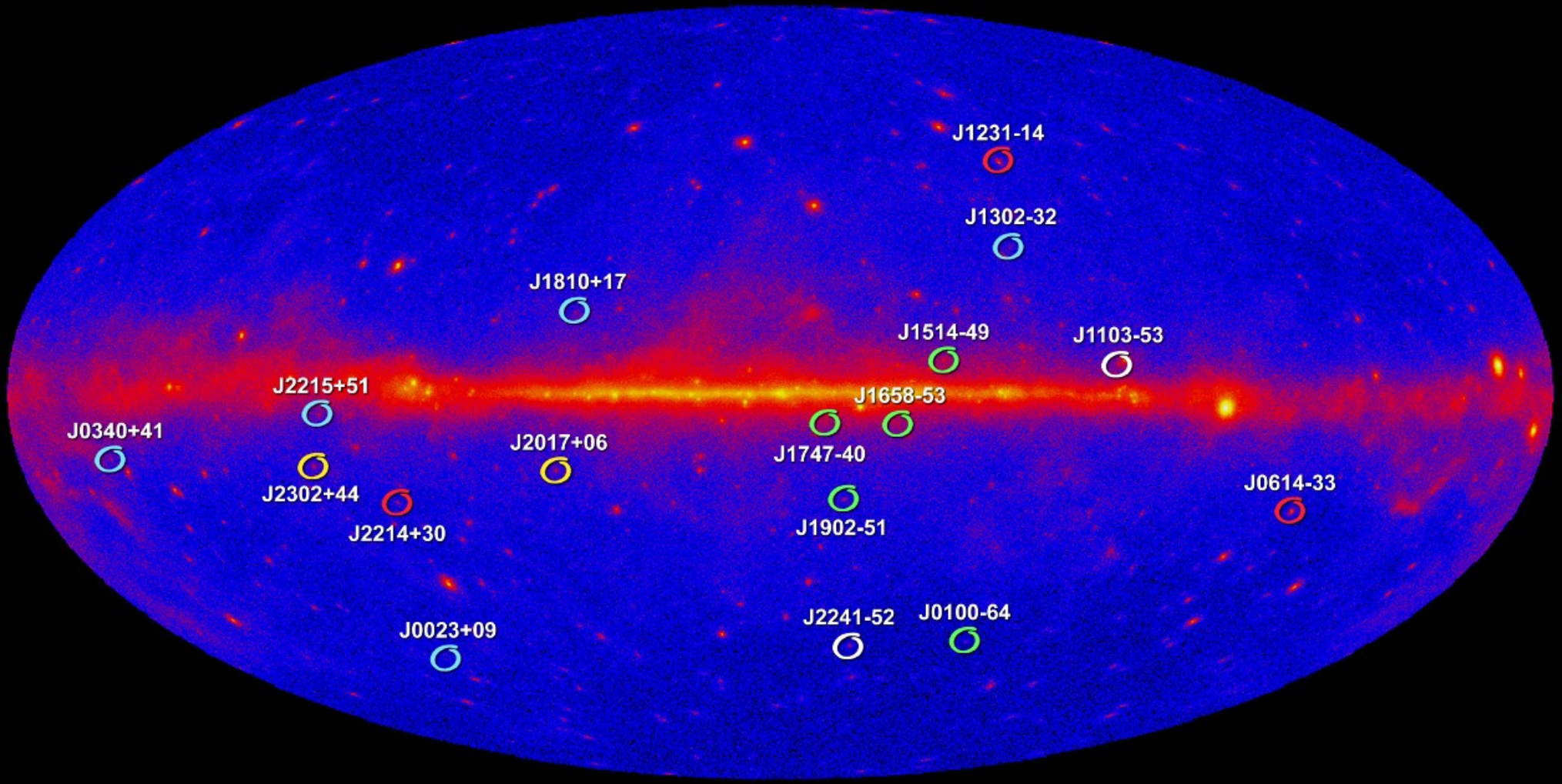


Why are these systems copious gamma-ray emitters?

Conclusions

- A large fraction of high-Galactic latitude sources searched so far (~20-30%?) have bright radio MSPs!
- Possibly important at 10-20% level for Gamma-ray Bkgd (i.e. Faucher-Giguere & Loeb 2010)
- More gamma-ray pulsations coming soon? (longer-term radio timing required)
- This is a brand new (and much simpler) way to find valuable Millisecond pulsar systems for:
  - Basic physics tests (e.g. Neutron Star physics)
  - Direct gravitational wave detection (e.g. *NANOGrav*)
- Still many more sources to search...
- γ-ray and radio luminosities of MSPs uncorrelated(?)
- γ-ray and radio both likely have wide fan-beams

New Millisecond Radio Pulsars Found in Fermi LAT 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 Radio Telescope

Led by Mike Keith (ATNF) using Parkes Observatory

Fermi Gamma-ray Space Telescope