Discovery of PSR J2339−0533, a redback millisecond pulsar powering the Fermi LAT bright source 0FGL J2339.8−0530

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Fermi Gamma-ray Space Telescope

Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

Recently completed 7 years of operations

Large area: 8000 cm^2 area (at 1 GeV)
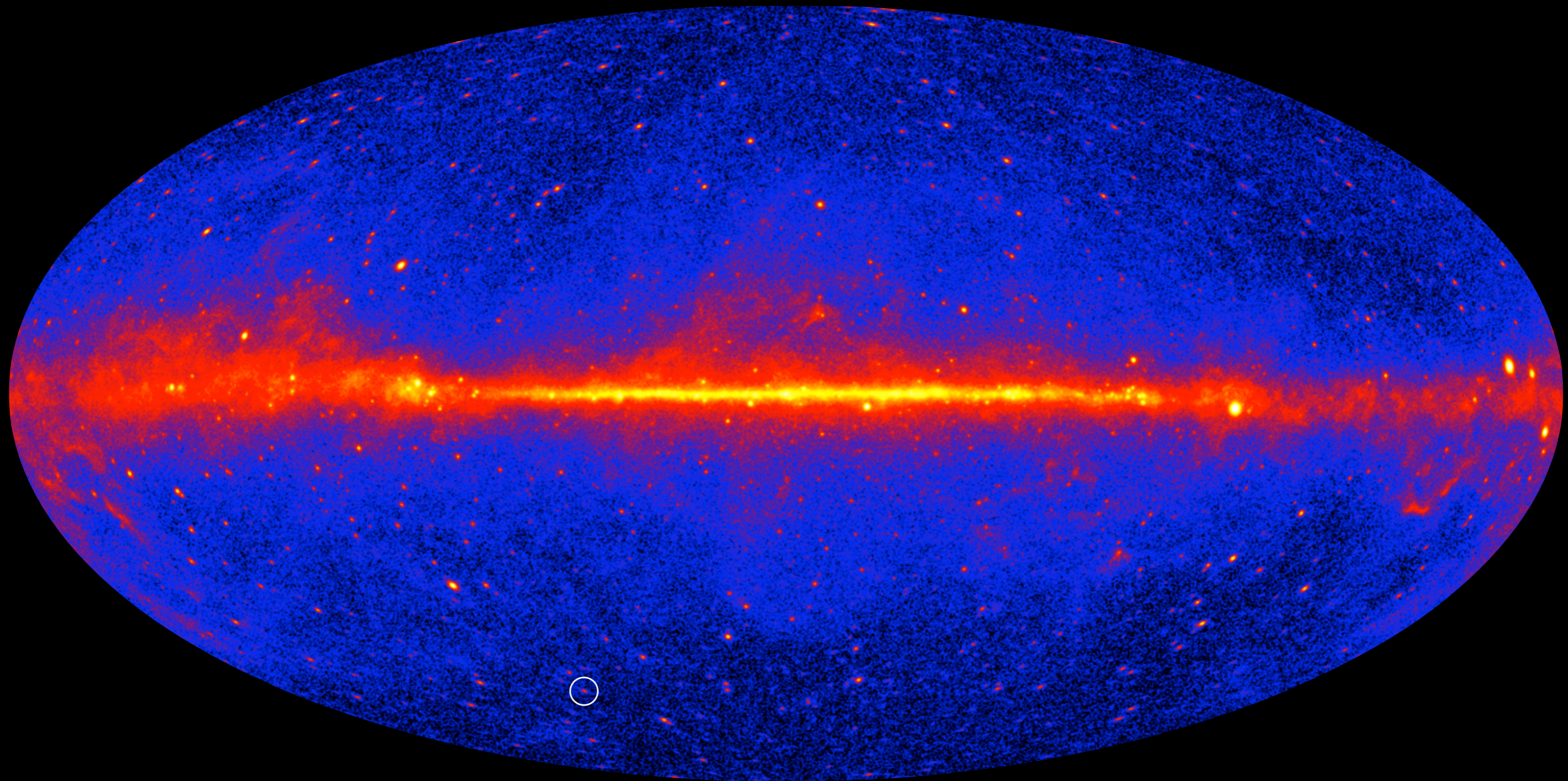
Broad band: 20 MeV to >300 GeV

Good localization: 0.6–0.8 deg radius PSF (1 GeV)
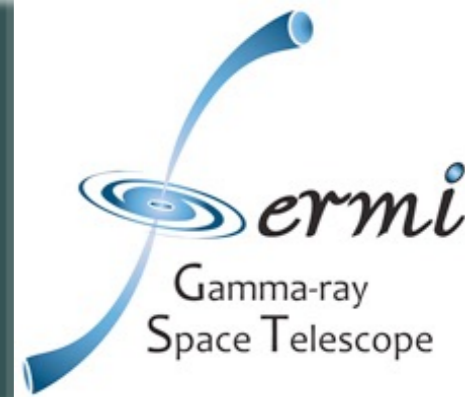
Continuous sky survey mode of operation with wide FOV

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

Five years of LAT survey data

Using LAT to Find Radio Pulsars

Gamma-ray
Space Telescope

2FGL Catalog (Nolan et al. 2012)

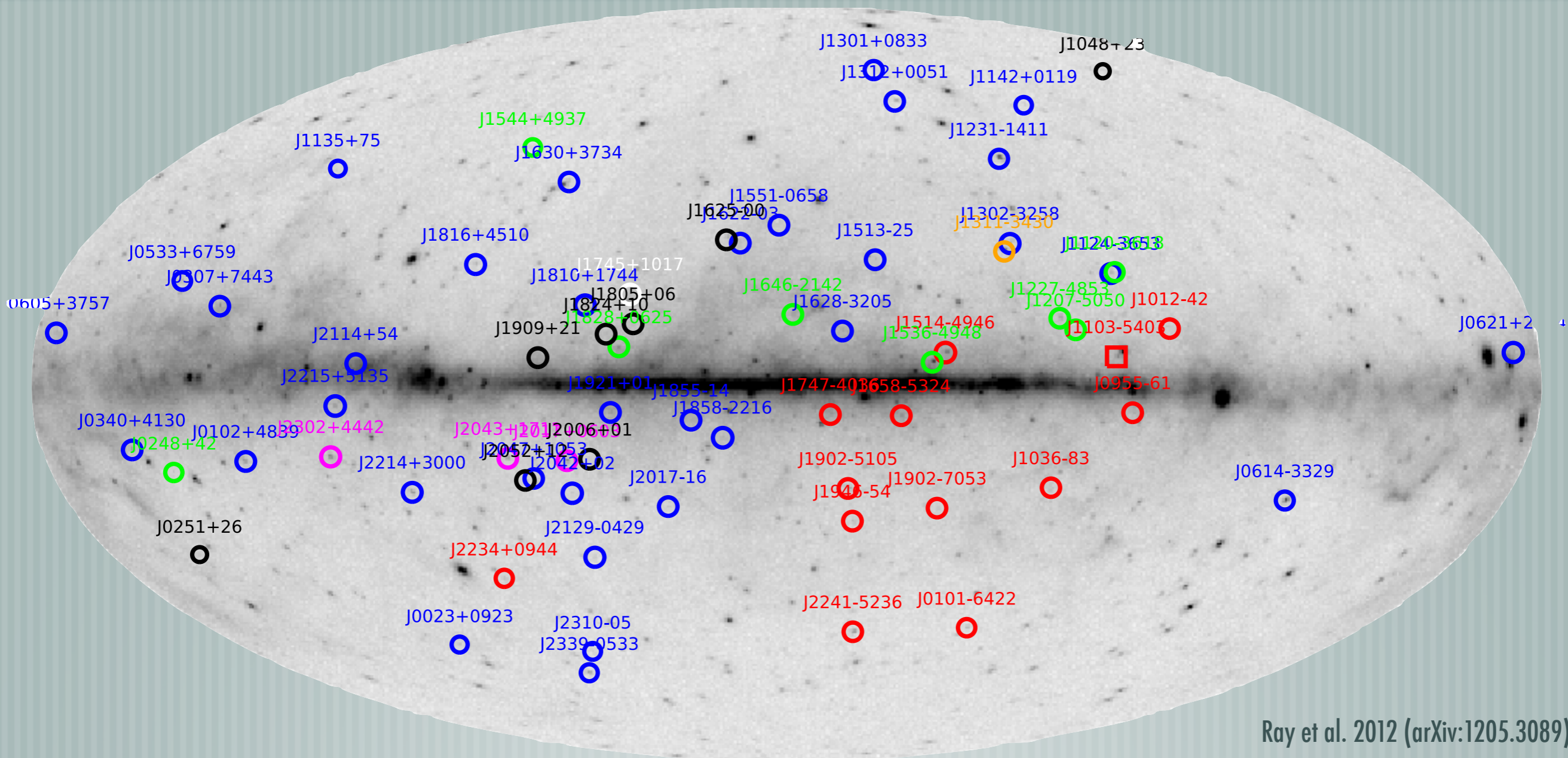- Out of 1873 sources, 575 unassociated with plausible counterparts at other wavelengths

- Best targets are sources with low variability and "pulsar-like" spectra

- Used multiple techniques for ranking sources

More details on ranking of "pulsar-likeness":
Ackermann et al., ApJ 753, 83 (2012)
Lee et al., MNRAS 424, 2832 (2012)
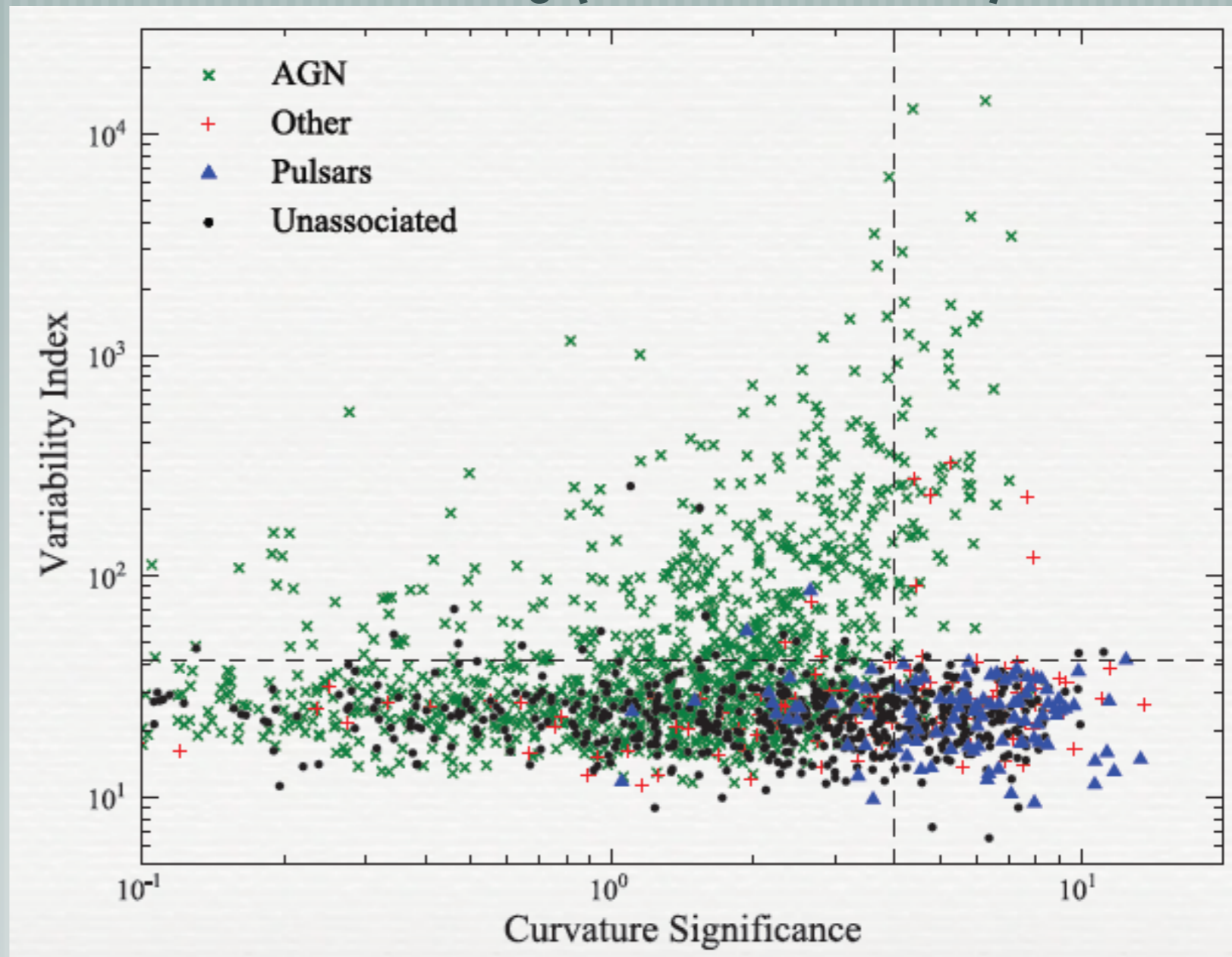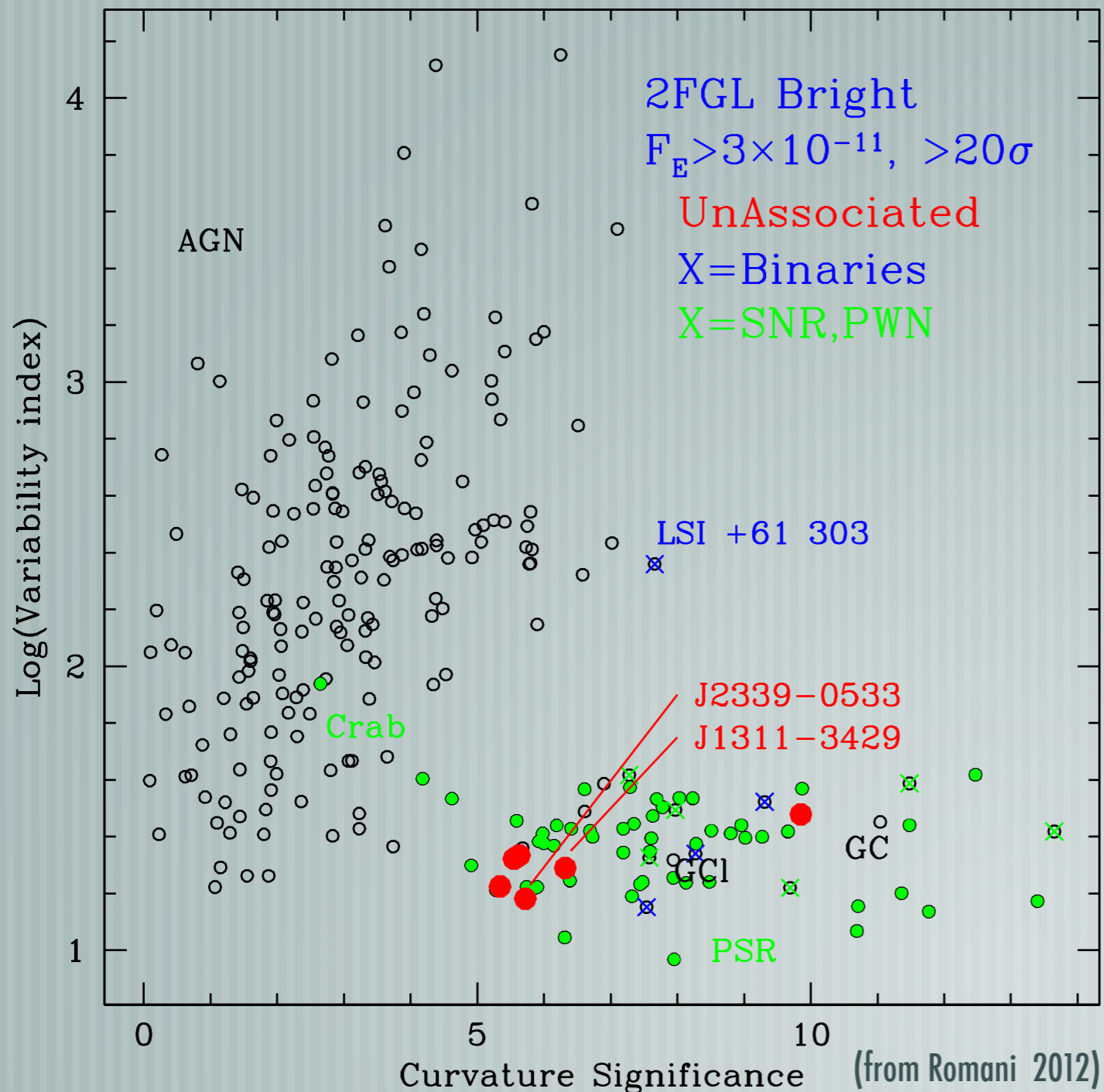
Success! 68 MSPs found!

Ray et al. 2012 (arXiv:1205.3089)

Fermi Pulsar Search Consortium (PSC) searches with
GBT, Parkes, Nançay, Effelsberg, GMRT, and Arecibo

Digging Deeper: X-ray and Optical Studies

At time of 2FGL, 6 remaining UNIDs out of 250 bright sources, all pulsar-like

2FGL Bright
$F_E > 3 \times 10^{-11}$, $> 20\sigma$
UnAssociated
X=Binaries
X=SNR,PWN

AGN

LSI +61 303

J2339−0533
J1311−3429

Crab

GCl   GC

PSR

Log(Variability index)

Curvature Significance   (from Romani 2012)

- Bright unassociated sources subjected to deep X-ray, optical and radio imaging observations to look for likely counterparts

- Could any be radio-quiet MSPs?

- 5/6 now identified

  - **J2339-0533, this talk**

  - J1311-3430 optical, blind search, radio MSP

  - J1227-4853 transitional MSP

  - J1653.6-0158 optical orbit MSP

  - J1906.5+0720 blind search PSR

  - J1702.5-5654 still **UNID**

Study of 0FGL J2339.8−0530

Kong et al. discovered variable X-ray and optical source

Romani & Shaw added optical spectroscopy and solved the orbit

T$_{eff}$ varies from 3000 to 6000 K

Clearly a binary MSP in a 4.6 hour orbit. Modeling suggested a black widow type system with low mass (< 0.1 Msun) companion

Precise optical position + orbital period and phase led to a major search for gamma-ray pulsations from a radio quiet MSP

No gamma-ray pulsations found...
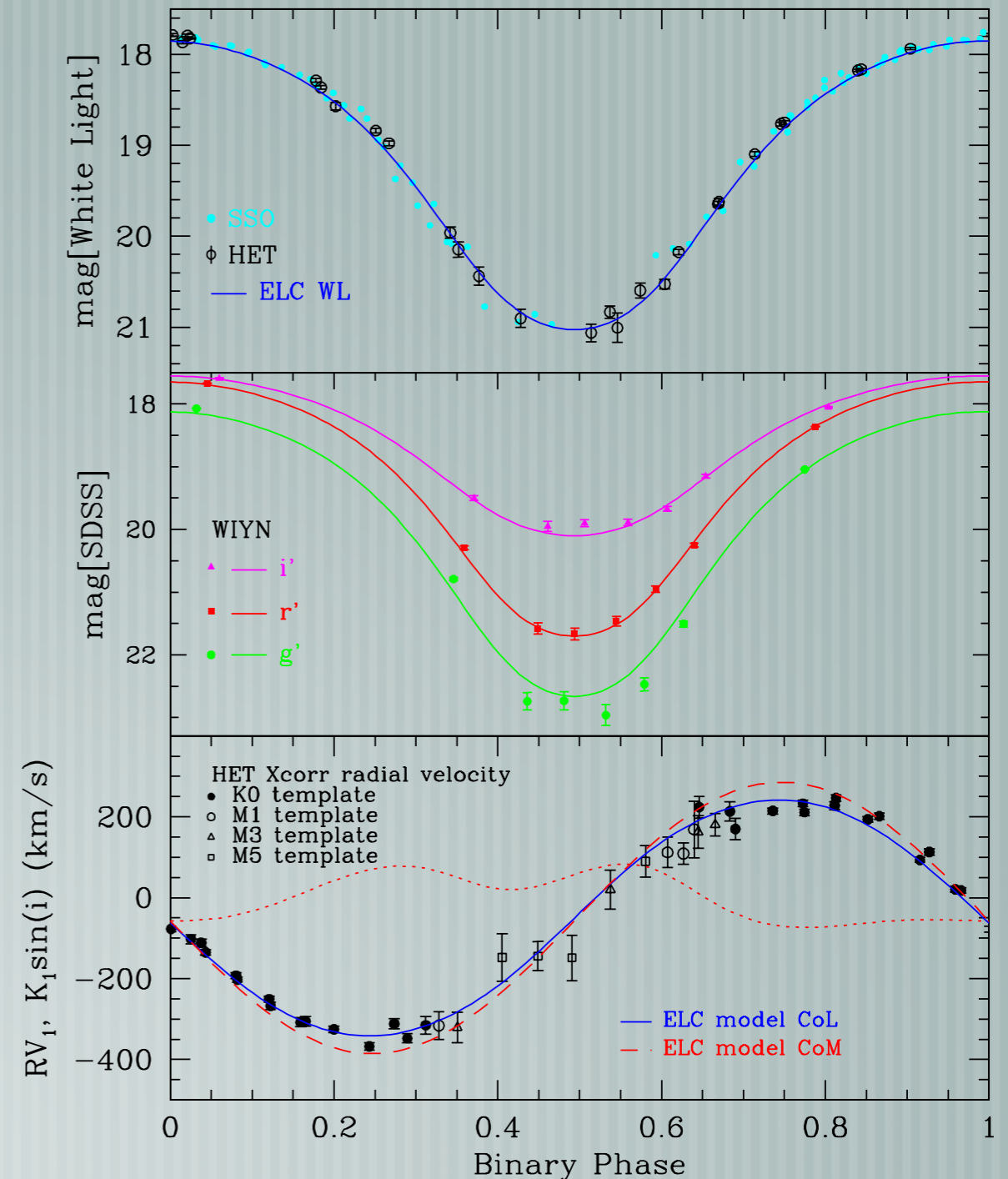
(Romani & Shaw 2011)

J2339−0533 Radio Pulsations Discovered

After several unsuccessful tries, 2.88 ms pulsations discovered in 1.6 hr GBT observation at 820 MHz
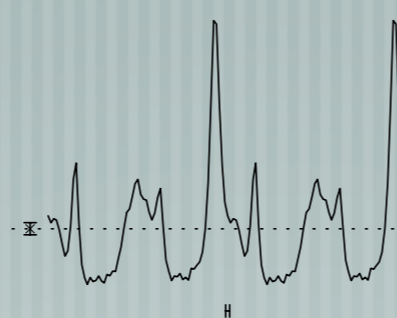
DM 8.72 gives D=450 pc

Measured semimajor axis 0.611 lt-s, larger than expected

$M_C > 0.26\ M_\odot$

Redback, not black widow

Often not visible, highly variable `weather' in the system


2 Pulses of Best Profile

Candidate: PSR_2339−0533
Telescope: GBT
$Epoch_{topo}$ = 55792.19046296296
$Epoch_{bary}$ = N/A
T_{sample} = 6.144e−05
Data Folded = 99532800
Data Avg = 4.814e+04
Data StdDev = 334.9
Profile Bins = 64
Profile Avg = 7.486e+10
Profile StdDev = 4.176e+05

Search Information
RA_{J2000} = 23:39:38.7120 DEC_{J2000} = −05:33:05.7600
Folding Parameters
Reduced χ^2 = 88.085   P(Noise) ~ 0
Dispersion Measure (DM; pc/cm^3) = 8.720
P_{topo} (ms) = 2.8834785136(76) P_{bary} (ms) = N/A
P'_{topo} (s/s) = 0.0(9.6)x10^{-15} P'_{bary} (s/s) = N/A
P''_{topo} (s/s²) = 0.0(1.0)x10^{-17} P''_{bary} (s/s²) = N/A
Binary Parameters
P_{orb} (s) = N/A   e = N/A
$a_1 sin(i)/c$ (s) = N/A ω (rad) = N/A
T_{peri} = N/A
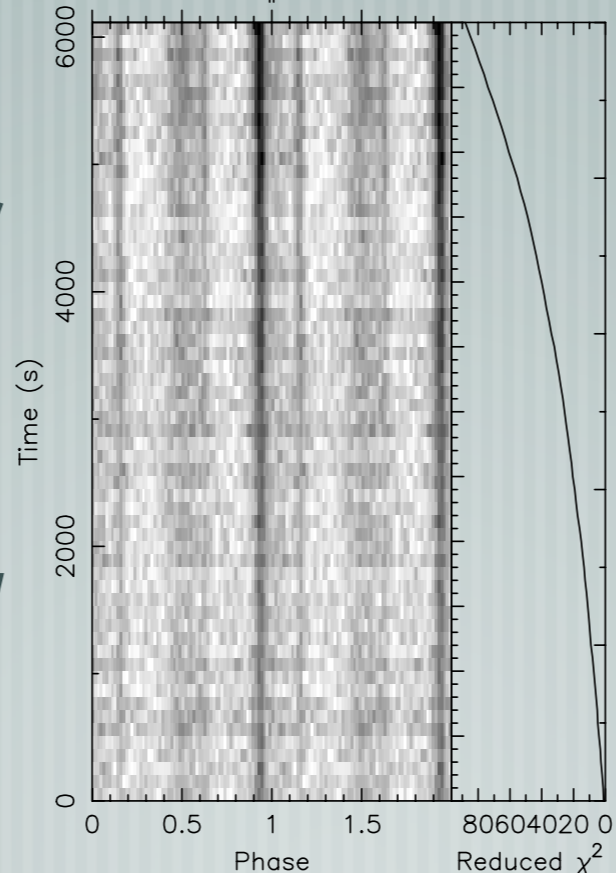
guppi_55792_J2339−0533_0002_0001.fits
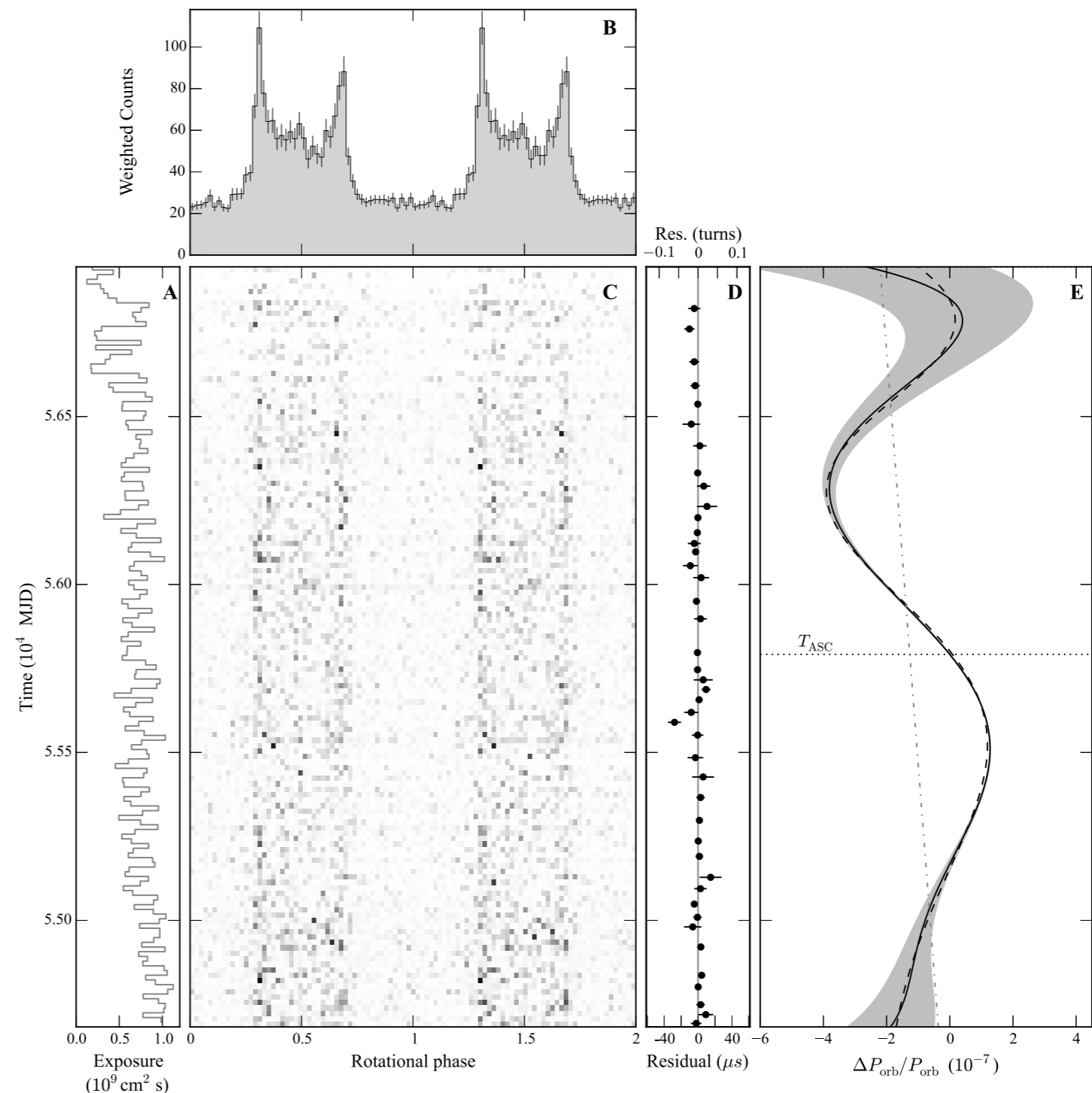
paulr 21−Oct−2012 20:08
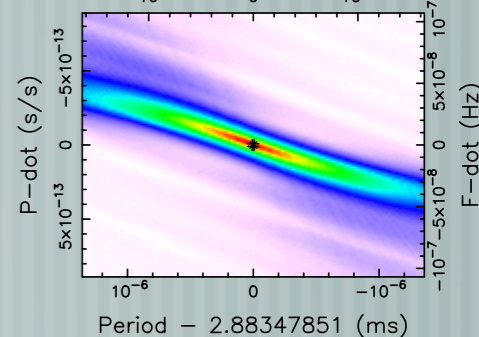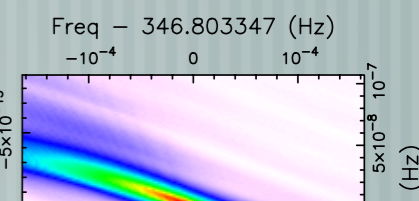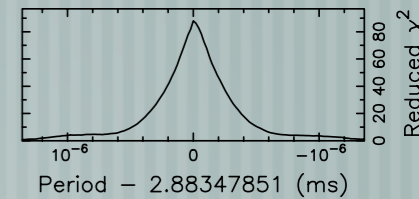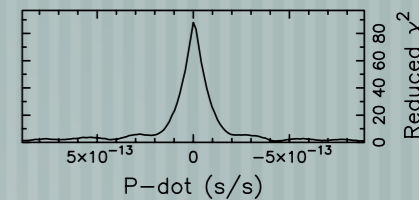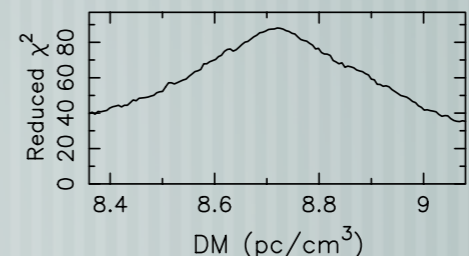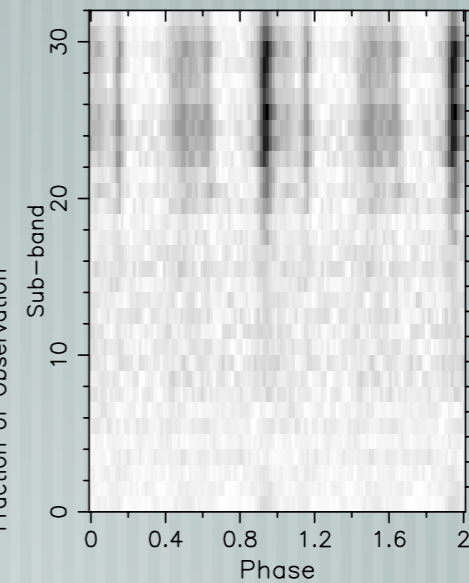
(Ray et al. 2015, in prep)

LAT Detection and Timing

Limited search around radio orbital parameters quickly found LAT pulsations in this bright source

Missed previously because optical data suggested much lighter companion (thus a smaller orbit)

Holger Pletch et al. (2015) timed it with LAT data, determining F1, proper motion, and orbital period variability (req. 6 derivatives)
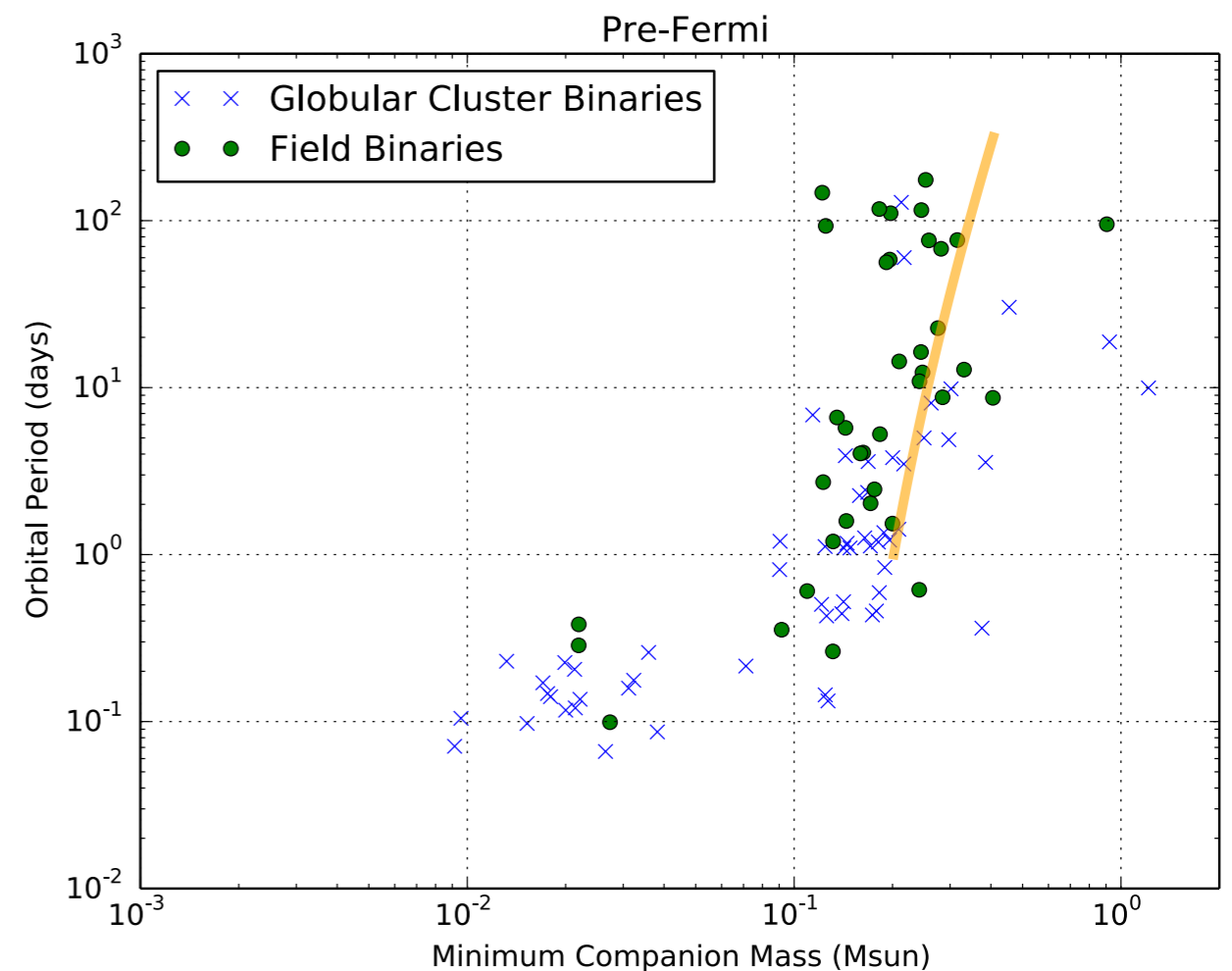
Summary

- Optical and X-ray studies of LAT unassociated sources is a very promising avenue to continue to explore

    - New Pass8 sources lists in development

- So far, no radio quiet MSP has been discovered, but some of them are very hard to see in radio because of material in the system

- J2339-0533 is a nearby `redback' binary MSP system that can be well studied in radio, gamma-ray, X-ray and optical

Pre-Fermi plot of Orbital Period (days) versus Minimum Companion Mass (Msun), showing Globular Cluster Binaries (x) and Field Binaries (filled circles).

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