Fermi-LAT Searches for gamma-ray pulsars

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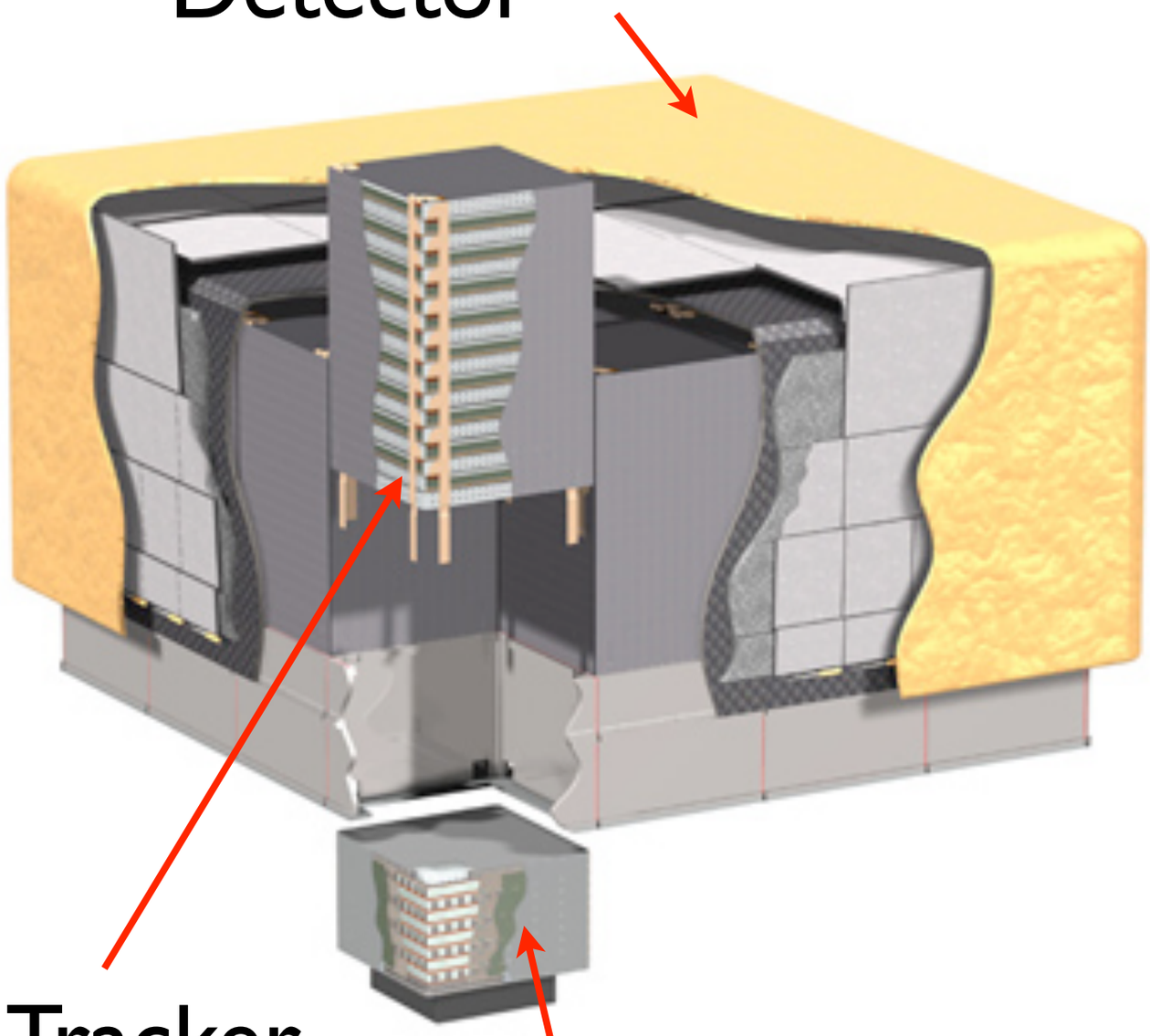
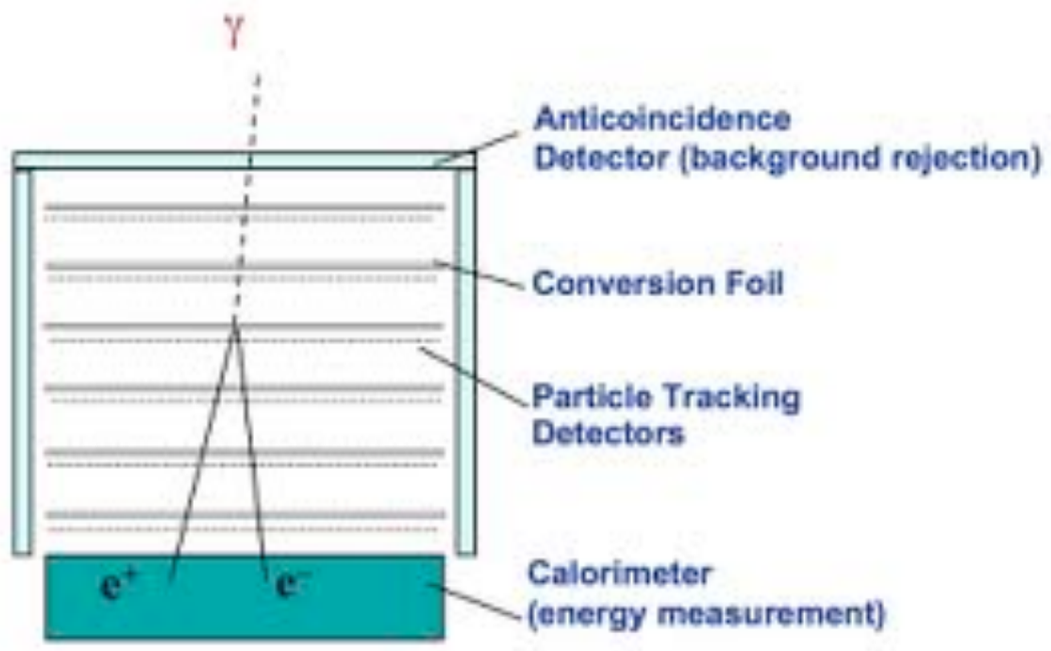
Outline

- Introduction: The Fermi Large Area Telescope
- Pulsar searches in gamma rays (compared to radio)
- Searches for gamma-ray pulsars
  - Young pulsars
  - Millisecond pulsars
- Conclusions and Prospects

The Large Area Telescope (LAT)

Anti-coincidence Detector





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

LAT specifications

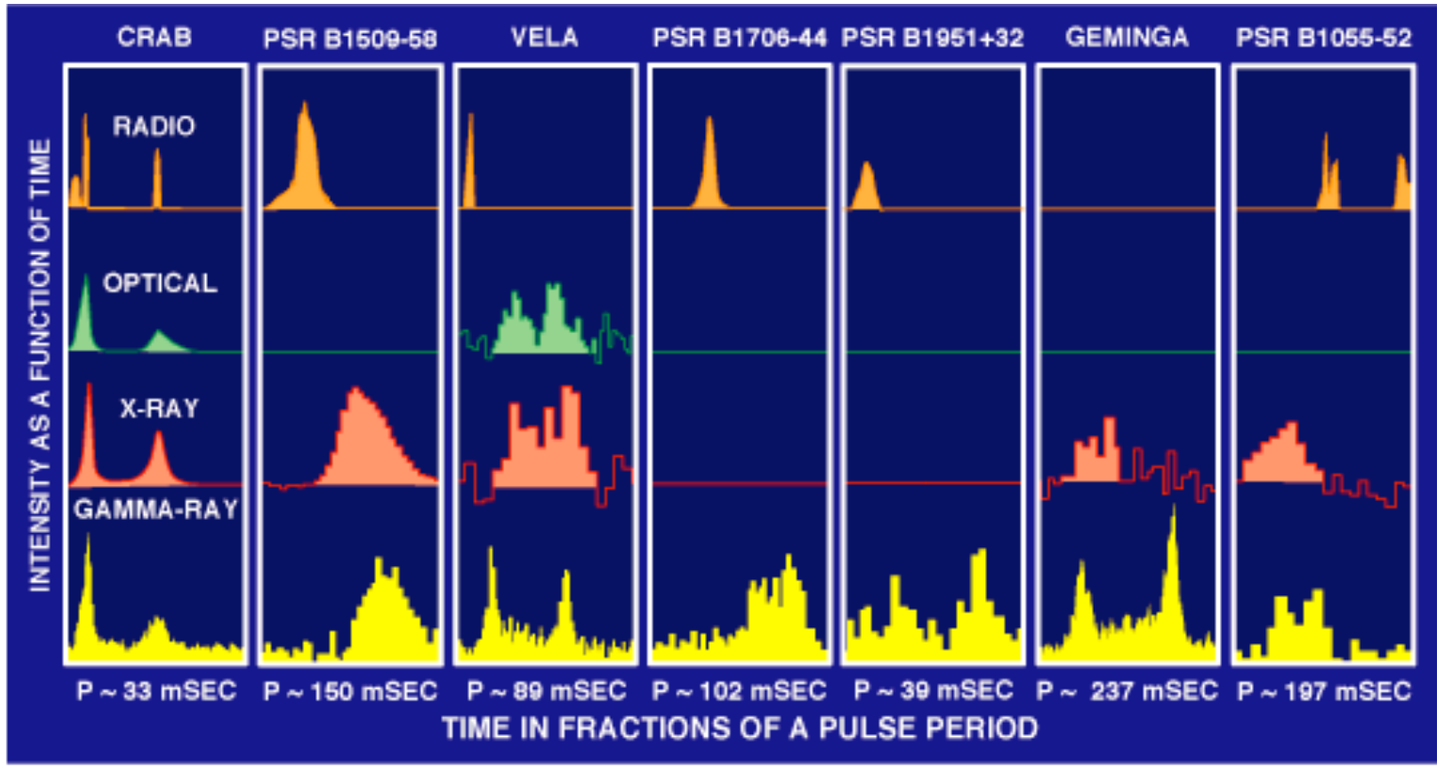
LAT Specifications & Performance

Quantity	LAT (Minimim Spec.)	EGRET
Energy Range	20 MeV - 300 GeV	20 MeV - 30 GeV
Peak Effective Area [1]	> 8000 cm^2	1500 cm^2
Field of View	> 2 sr	0.5 sr
Angular Resolution [2]	< 3.5° (100 MeV) < 0.15° (>10 GeV)	5.8° (100 MeV)
Energy Resolution [3]	< 10%	10%
Deadtime per Event	< 100 μs	100 ms
Source Location Determination [4]	< 0.5'	15'
Point Source Sensitivity [5]	< 6 x 10^{-9} cm^{-2} s^{-1}	~ 10^{-7} cm^{-2} s^{-1}

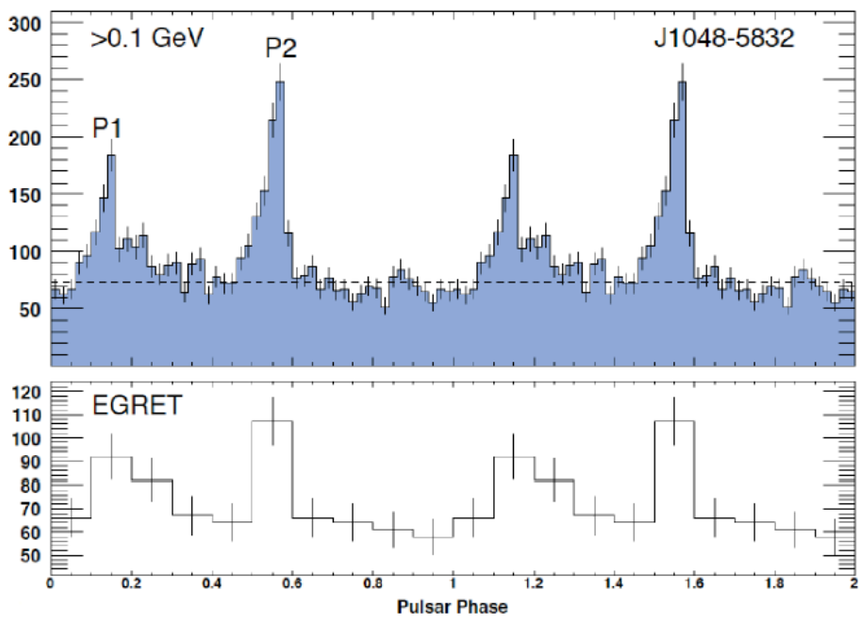
[1] After background rejection
[2] Single photon, 68% containment, on-axis
[3] 1-σ, on-axis
[4] 1-σ radius, flux 10^{-7} cm^{-2} s^{-1} (>100 MeV), high $|b|$
[5] > 100 MeV, at high $|b|$, for exposure of one-year all sky survey, photon spectral index -2

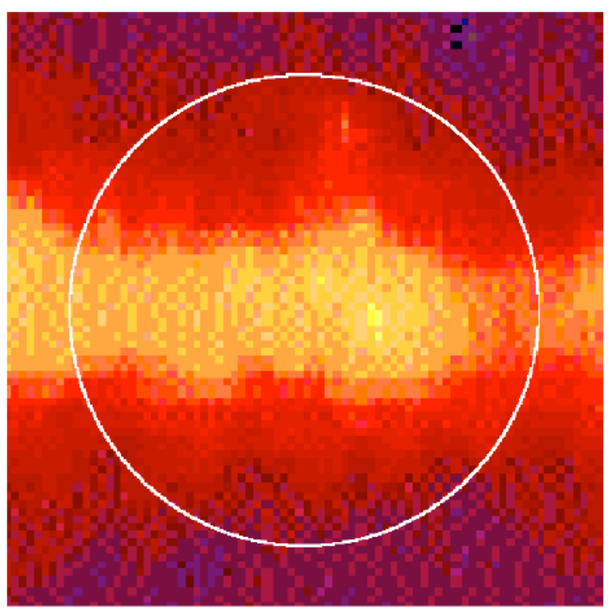
http://fermi.gsfc.nasa.gov/ssc/

LAT vs EGRET

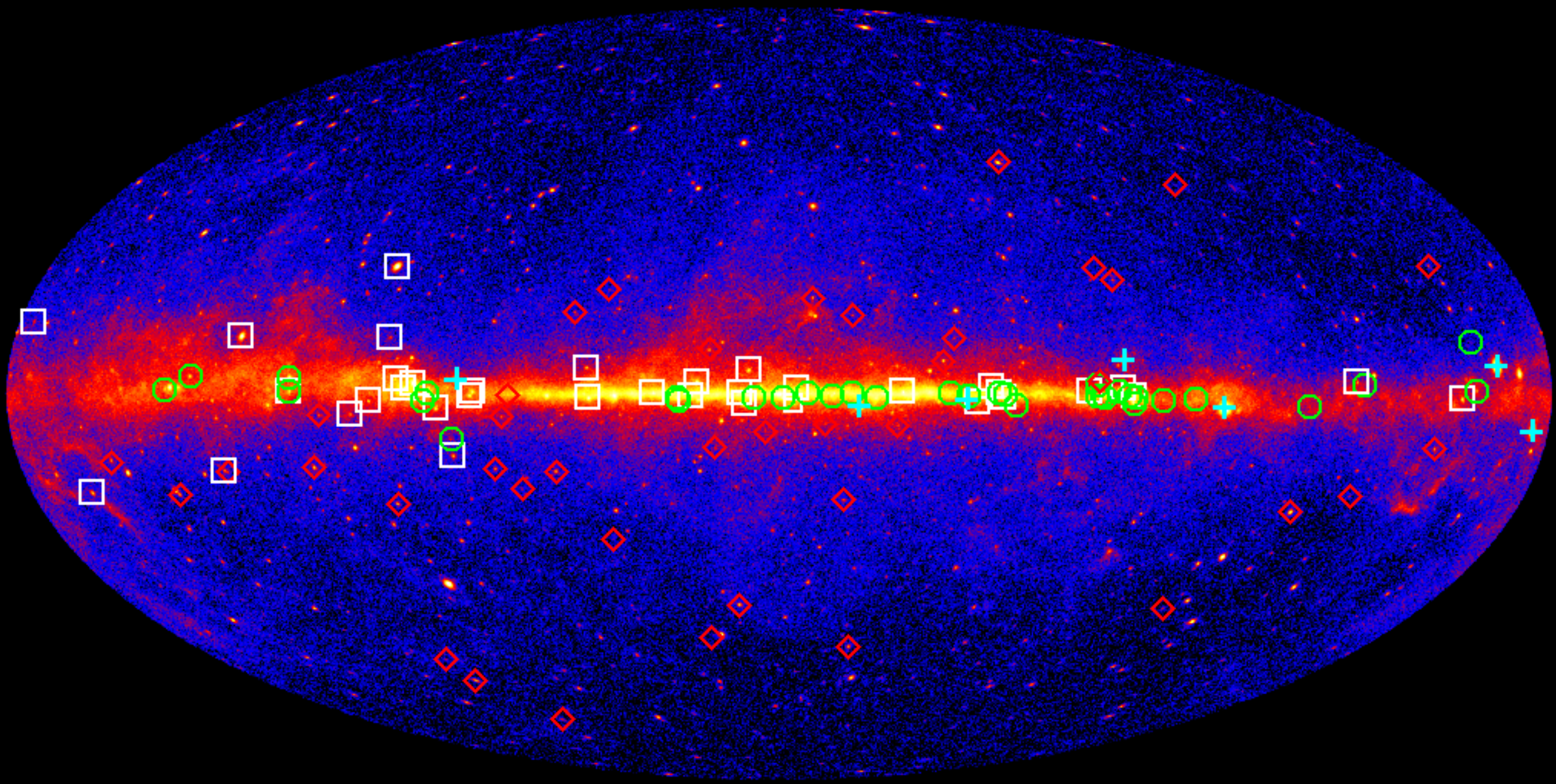


- > 200 million "source" class events by the LAT in first 4 years (~1.5 million EGRET photons in 9 yrs)





117 gamma-ray pulsars!



41 young radio- and X-ray-selected (green circles, cyan crosses)

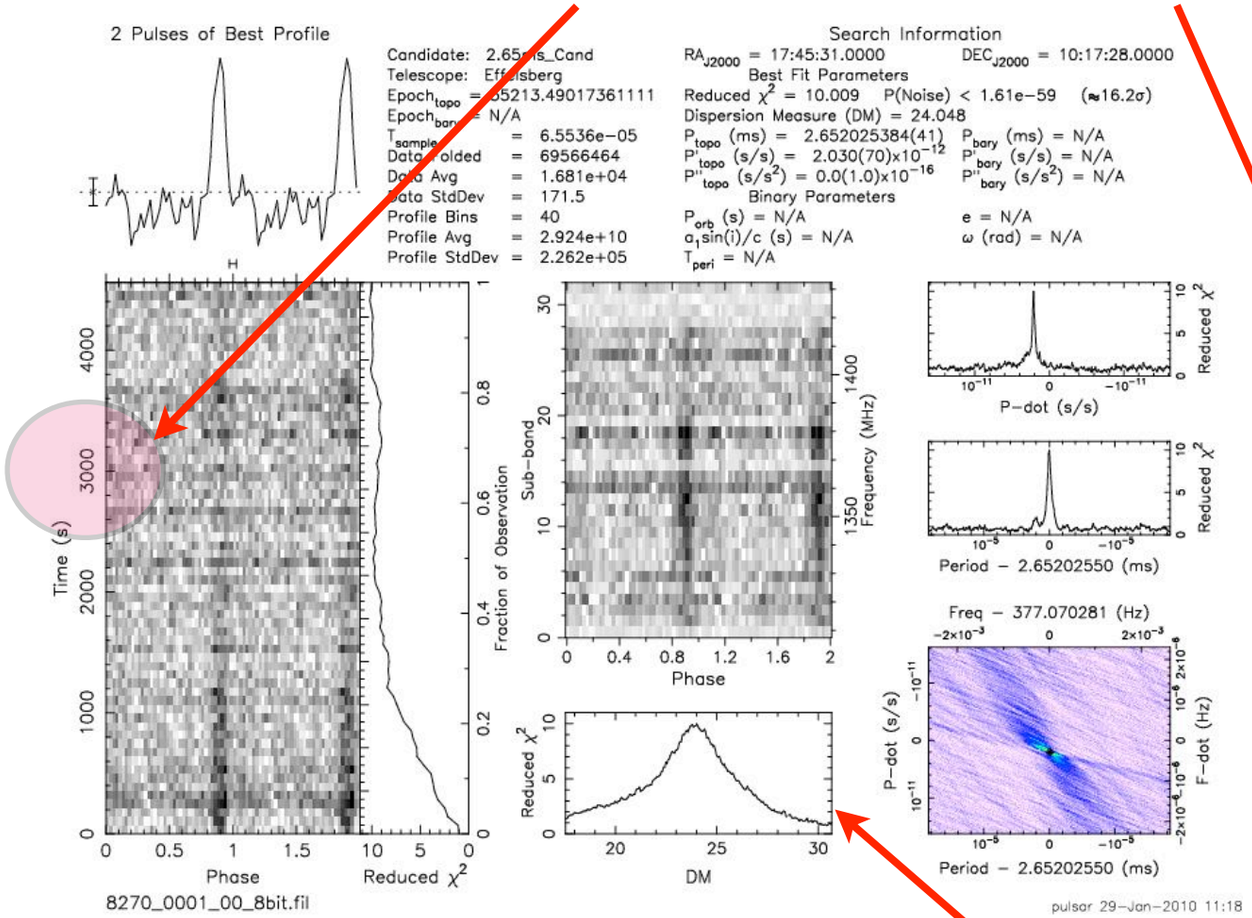
36 young gamma-selected (white squares)

40 radio-selected MSPs (red diamonds)

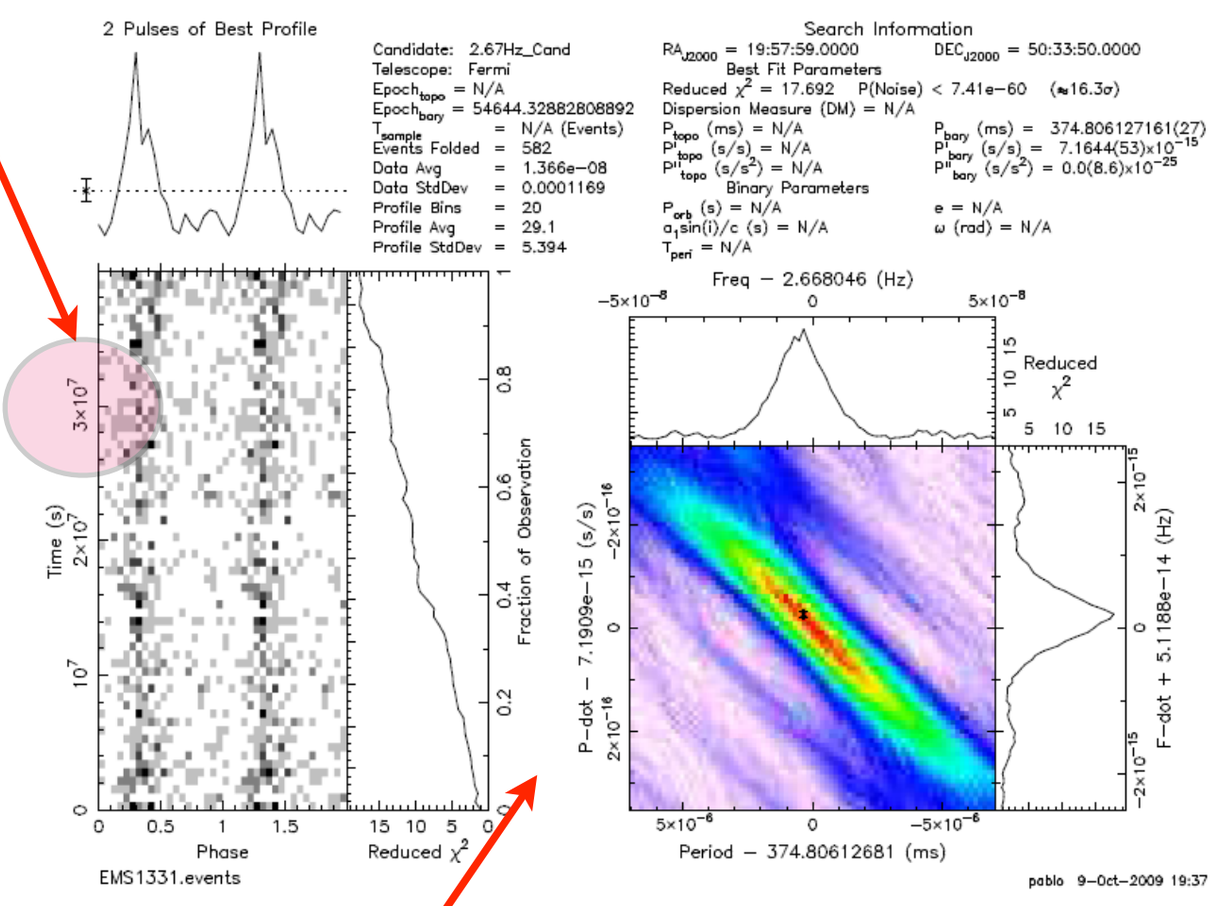
See talk by Lucas Guillemot

Searches in Gamma rays vs radio

Longer data spans (10,000x longer!)



PSR J1745+1017 (Credit: Ewan Barr)



PSR J1957+5033

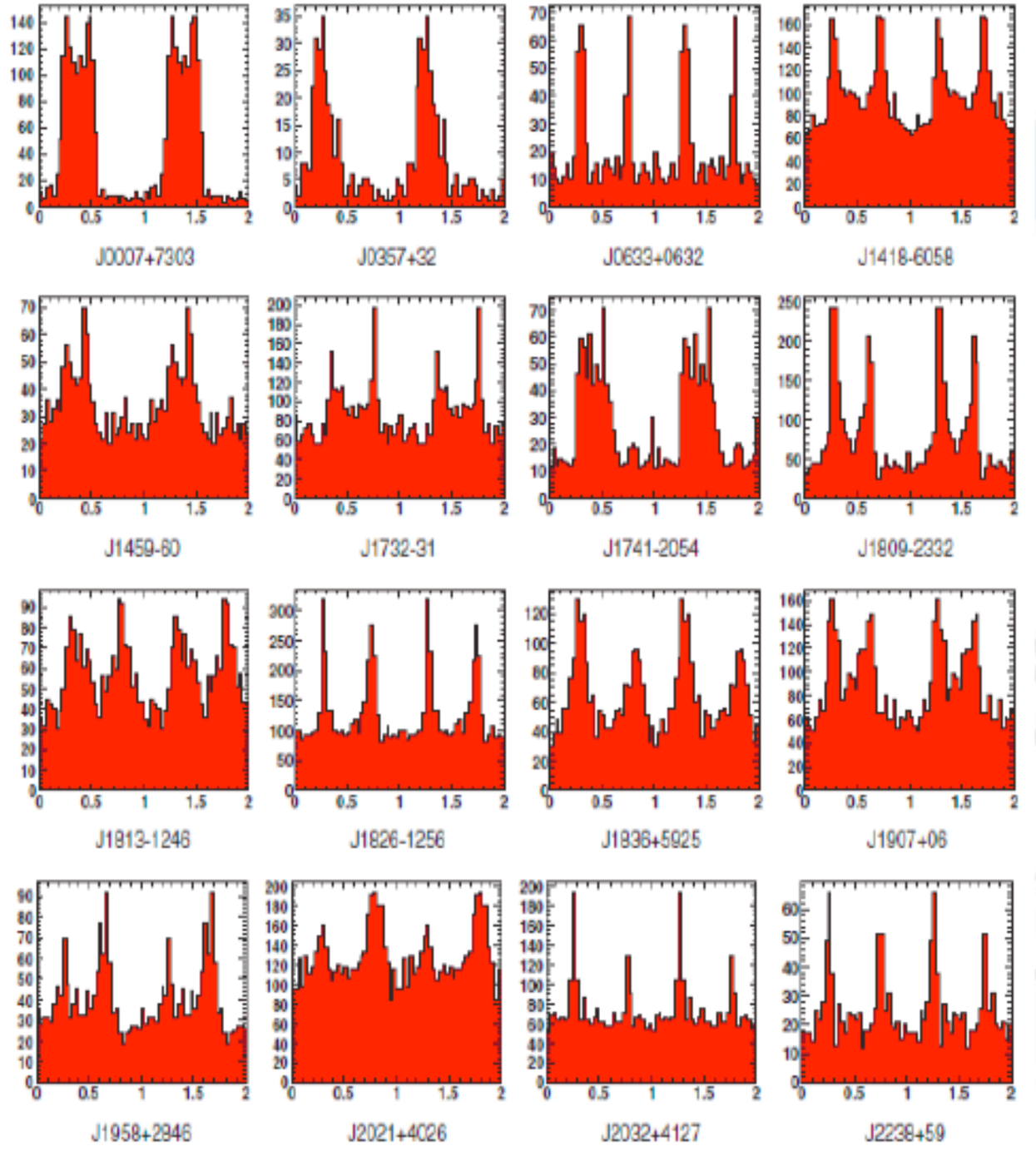
No DM

Gamma rays vs radio

- Worse flux sensitivity in gamma rays
- Short vs Long data sets
- All-sky survey mode vs pointed
- No DM in gamma rays
- Different biases

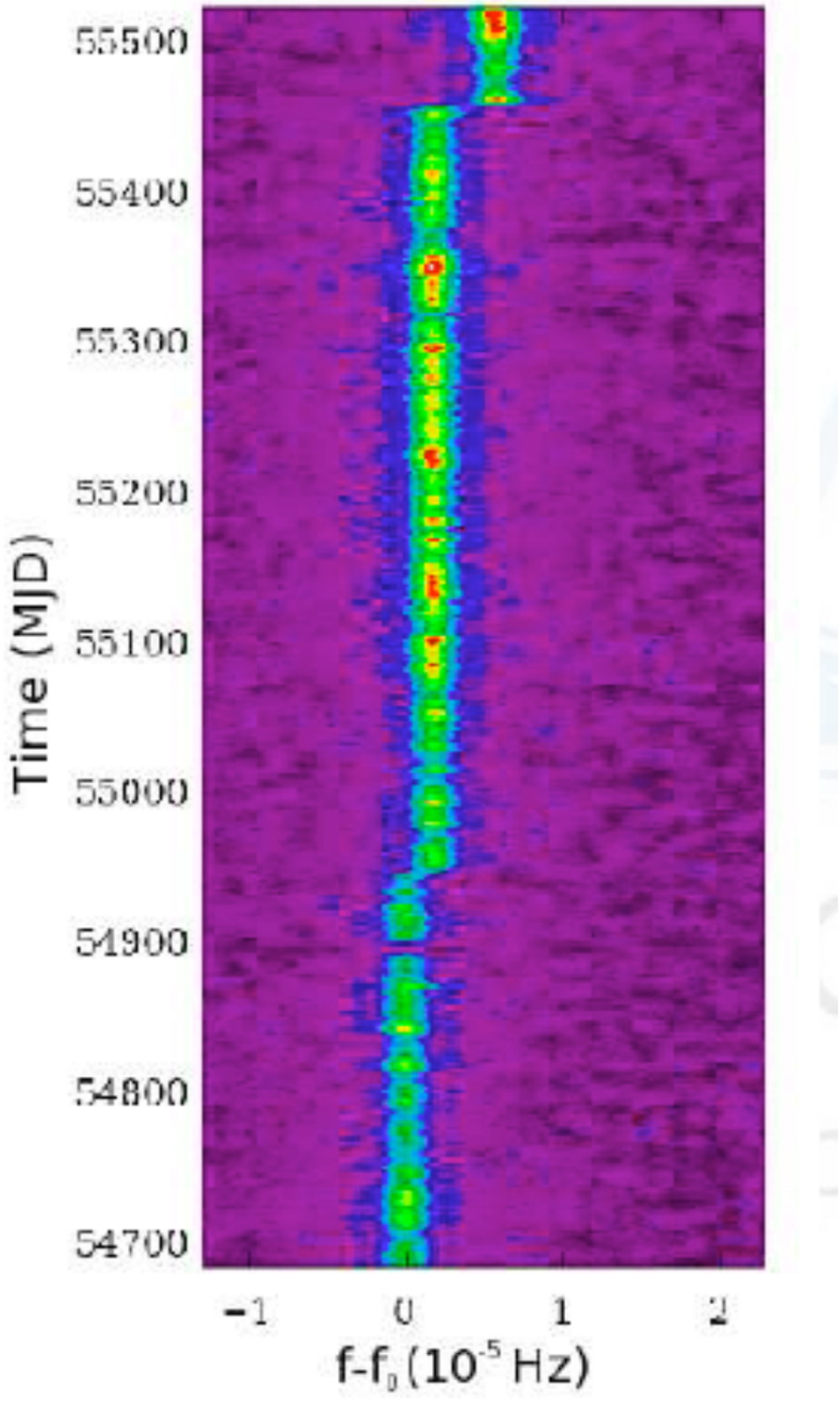
Early LAT discoveries

- Many associated with EGRET Unid sources and SNRs
- Mostly undetected in radio (or very faint)
- Young to middle-aged (2-20 Hz, < 2×10^6 yr) and energetic



Abdo et al. , Science, 325, 840 (2009)
Saz Parkinson et al., ApJ, 725, 571 (2010)

Glitches



- Young, energetic pulsars like those found in LAT blind searches are noisy and prone to glitches
- Long observation periods risk spanning multiple glitches (e.g. CTA1, shown on the left)
- Latest pulsar discovered (PSR J1838-0537) was originally only found in ~ half the data set, due to large glitch . Pletsch et al., ApJL, 755, 20 (2012)

Effect of a position offset

An error of ϵ in the source location results in an error of δf in the frequency observed: $\delta \mathrm{f} = \frac{v}{c} \epsilon f \sin\theta$.
Since θ (angle between the Earth's orbital velocity and the source direction) is also changing ($\dot{\theta} = 2 \times 10^{-7}$ rad s^{-1}), this also induces an error in $\delta \dot{f} = \frac{v}{c} \epsilon f \dot{\theta} \cos\theta + O(\dot{\theta}^2)$.

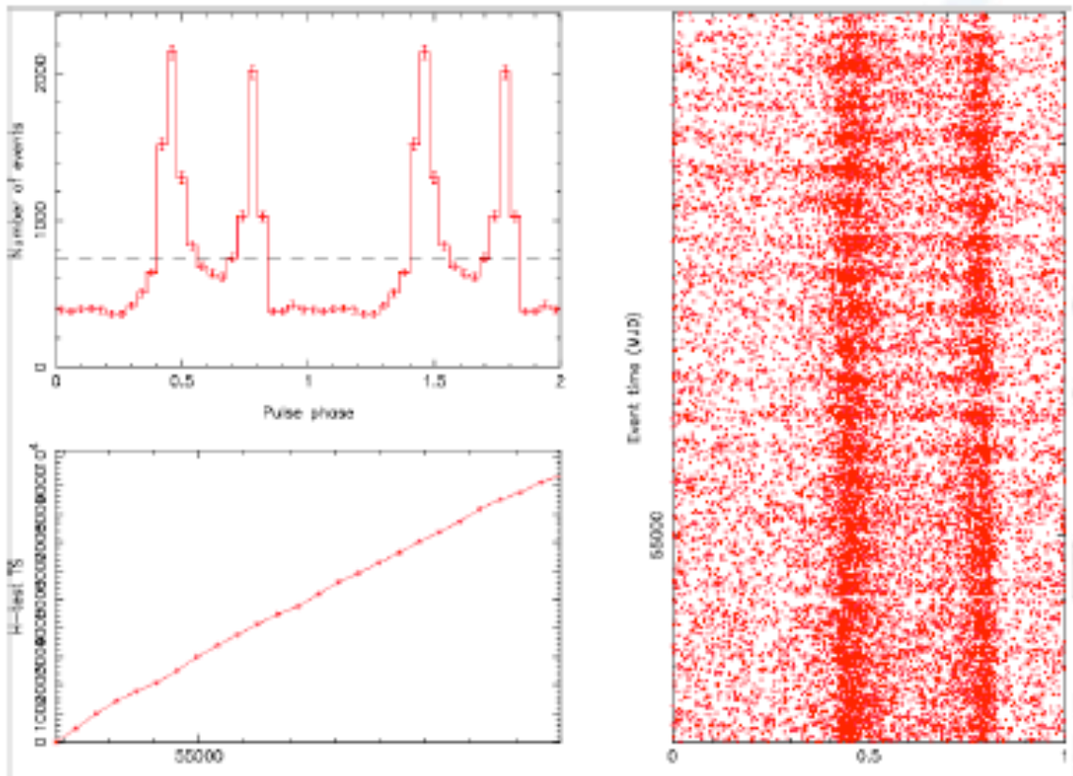


Figure: PSR J1809-2332: Correct position – Max H-test=9340

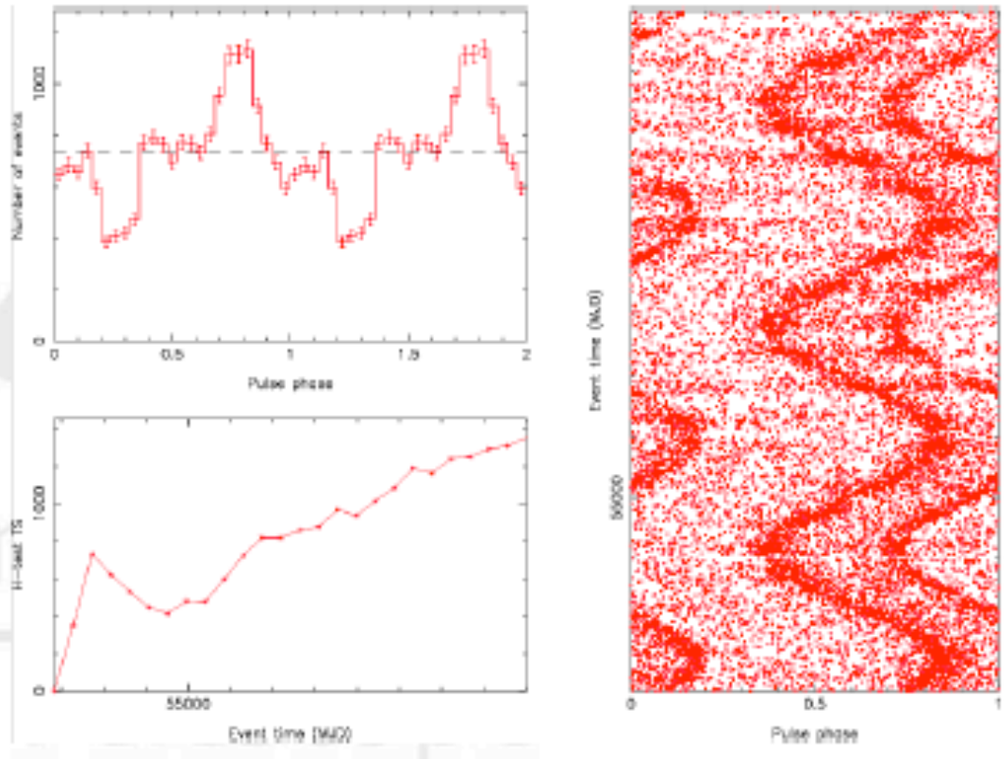
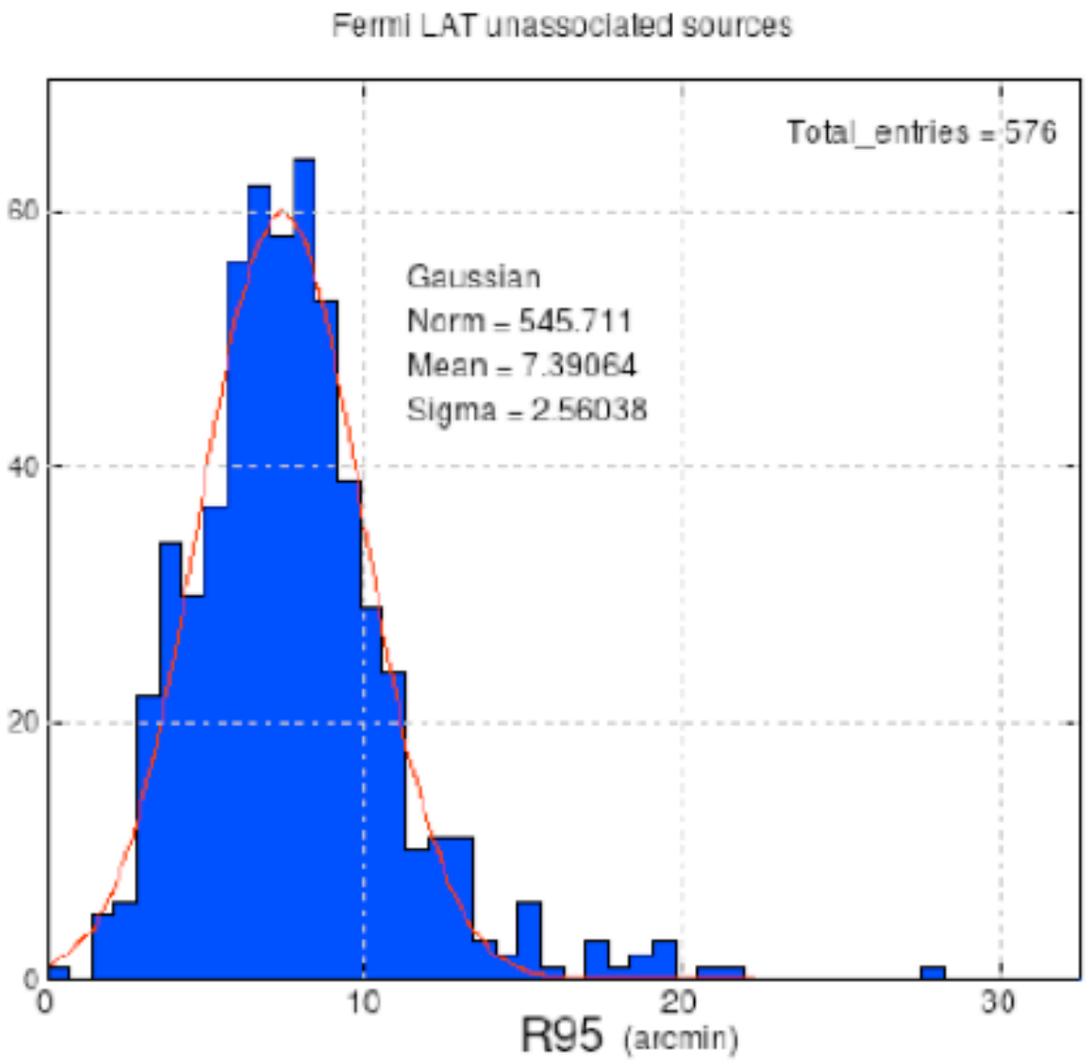
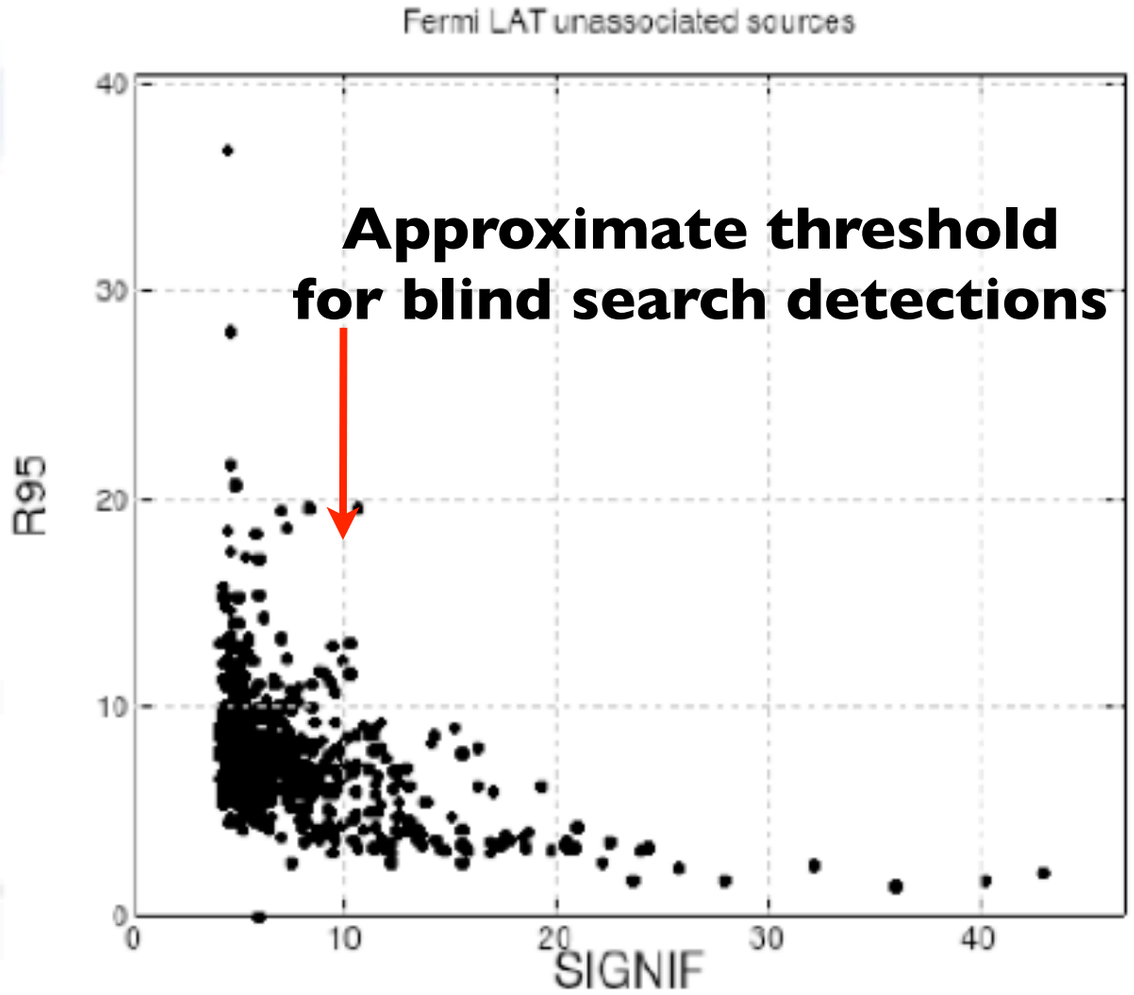


Figure: PSR J1809-2332: $\sim 10''$ offset – Max H-test=1355

LAT position uncertainties



r95% (in arcmin) of 2FGL unassociated sources



r95% (in arcmin) of 2FGL unassociated sources vs significance (in sigma)

Blind searches at Hannover

- 6720 CPU-core cluster
- Blind search techniques adapted from GW search
- Efficient scan in position
- 10 pulsars discovered
- Pletsch et al. 2012a, 2012b

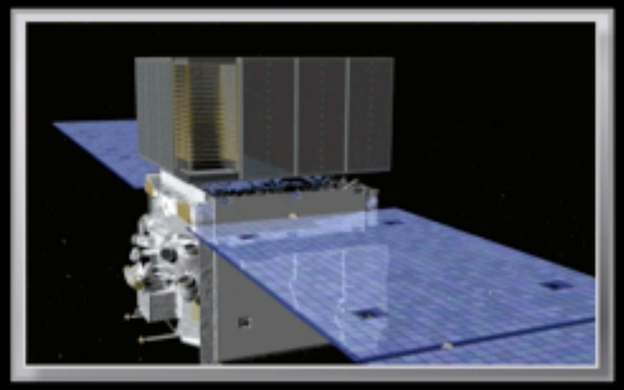
Fermi LAT meets Einstein@Home

MAX-PLANCK-GESELLSCHAFT

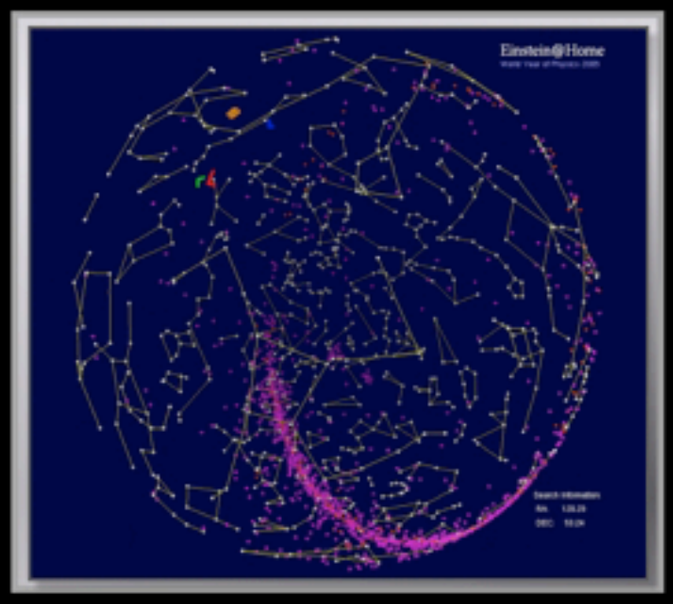
Max Planck Institute
for Gravitational Physics
ALBERT EINSTEIN INSTITUTE

NSF

UWM



In July 2011, Einstein@Home began searching for pulsars in Fermi LAT data.



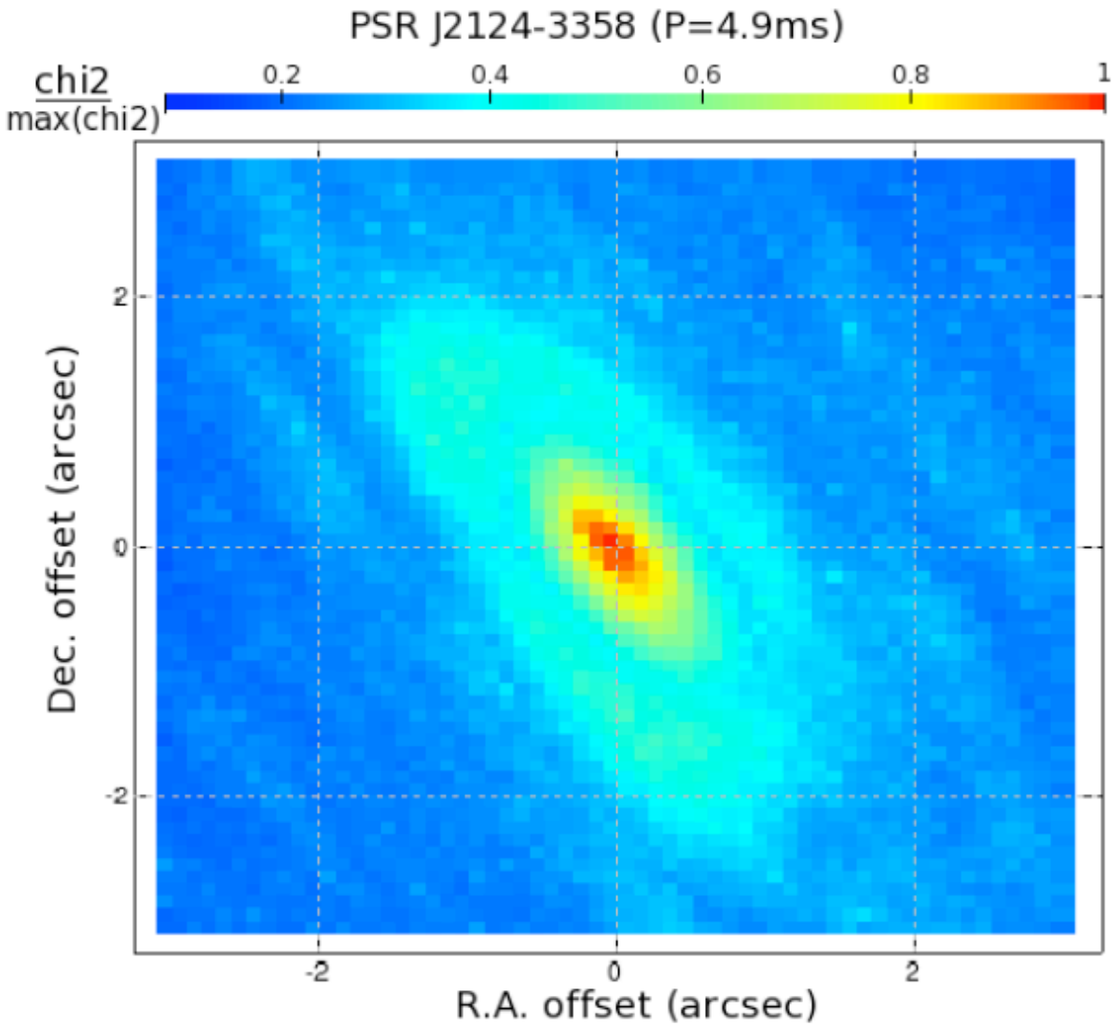
Some 300,000 people have contributed to Einstein@Home.

Each week, more than 60,000 computers contact project servers at the University of Wisconsin, Milwaukee, and at the Albert Einstein Institute in Hannover, Germany, to get work units and report their results.

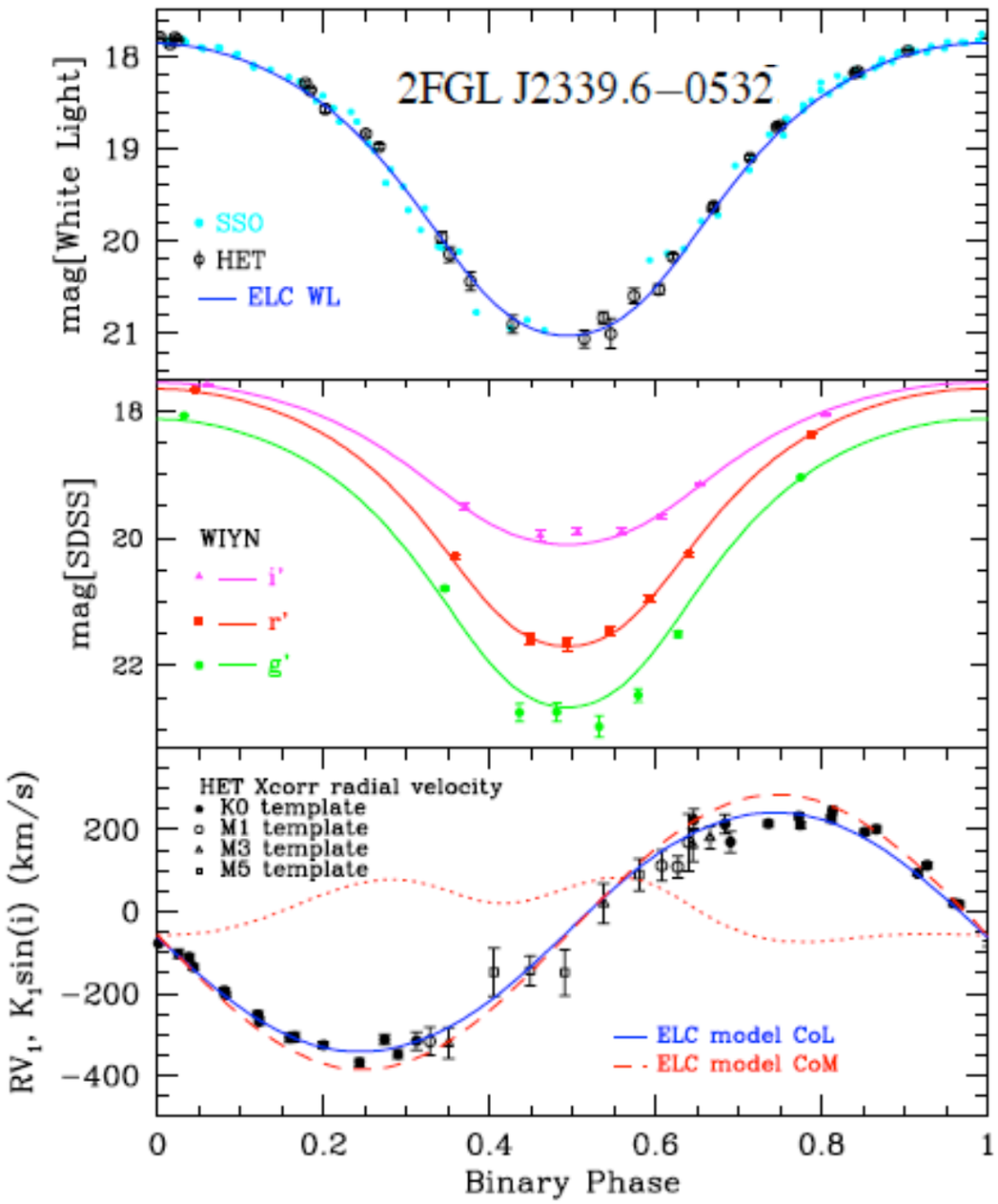
http://einstein.phys.uwm.edu

LAT Searches for MSPs

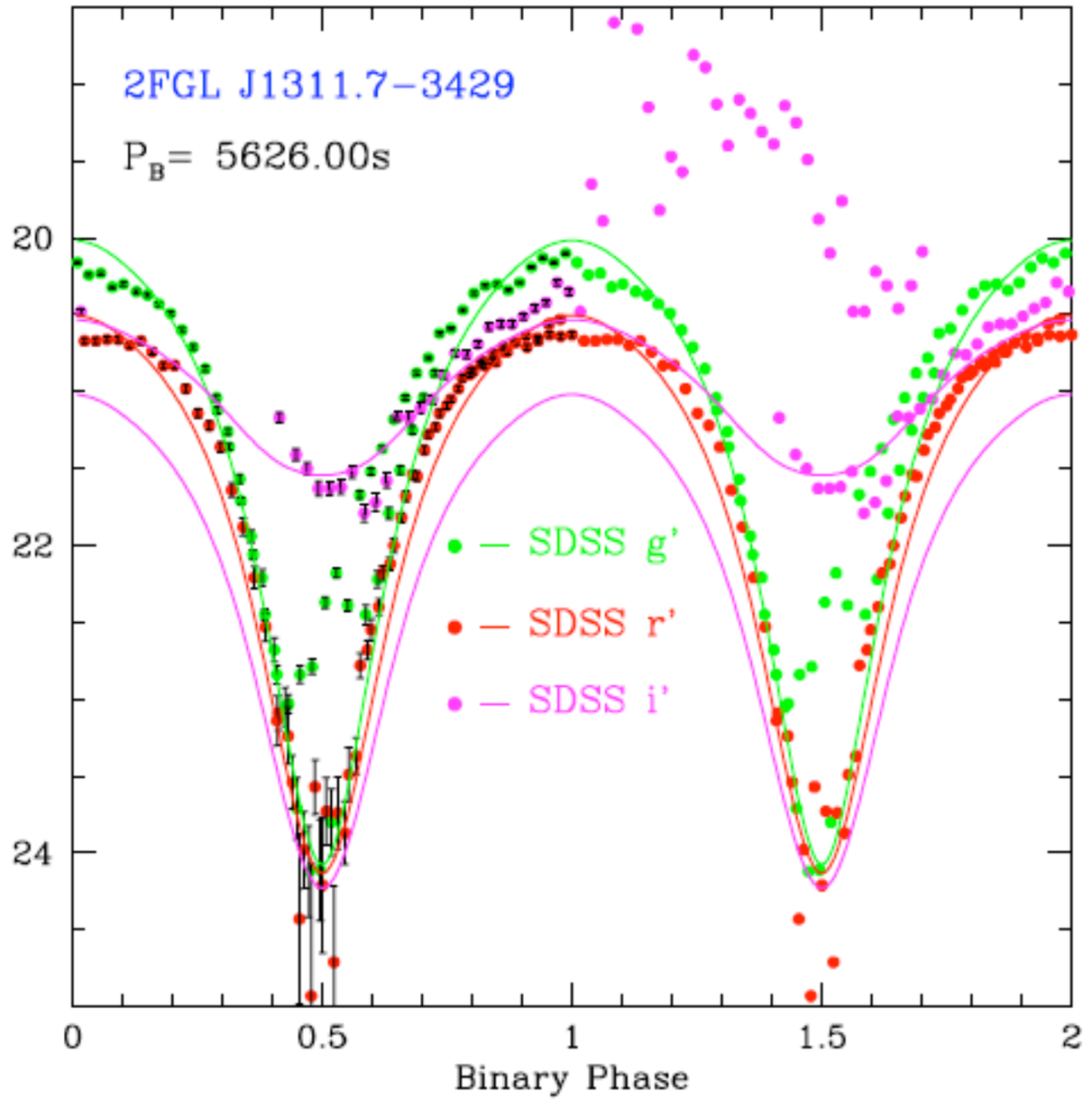
- CPU/memory intensive
- More sensitive to position
- Most (~80%) are in binaries
- Full blind search of binary pulsars is currently unfeasible
- MWL obs. are desirable for isolated MSP searches and essential for binary ones
- Fortunately ... MSPs are extremely stable!



Searches for Black Widows



Romani & Shaw, ApJL 743, 26 (2011)



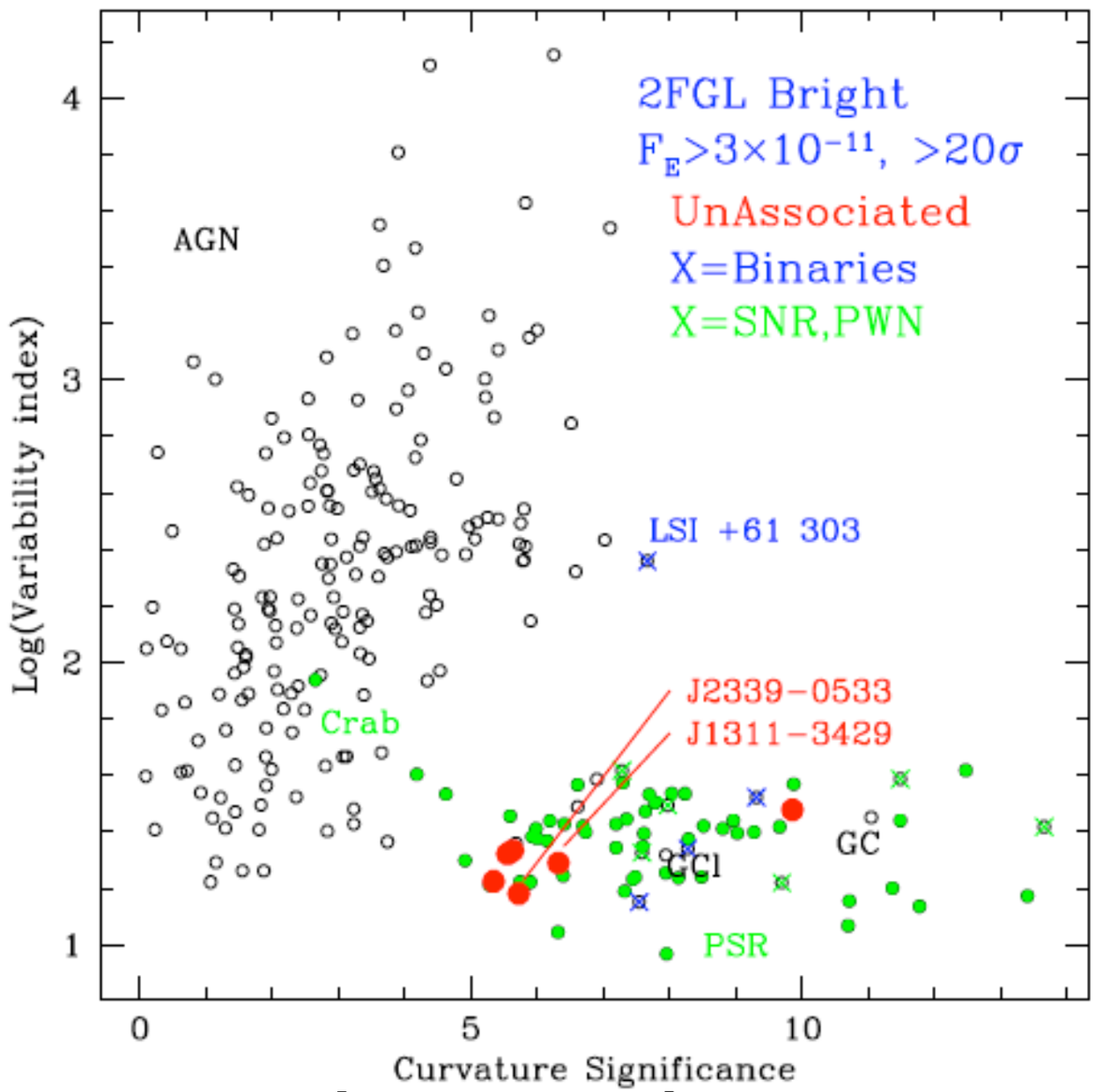
Romani, ApJL 754, 25 (2012)

See talk by A. Belfiore

The expected fraction of radio-quiet MSPs

- Look at brightest/most significant LAT sources
- 249 > 20 sigma and F>3x10^{11} erg cm^2 s^{-1}
- 41 young pulsars (17 RL)
- 12 MSPs (12 RL)
- 6 unassociated sources

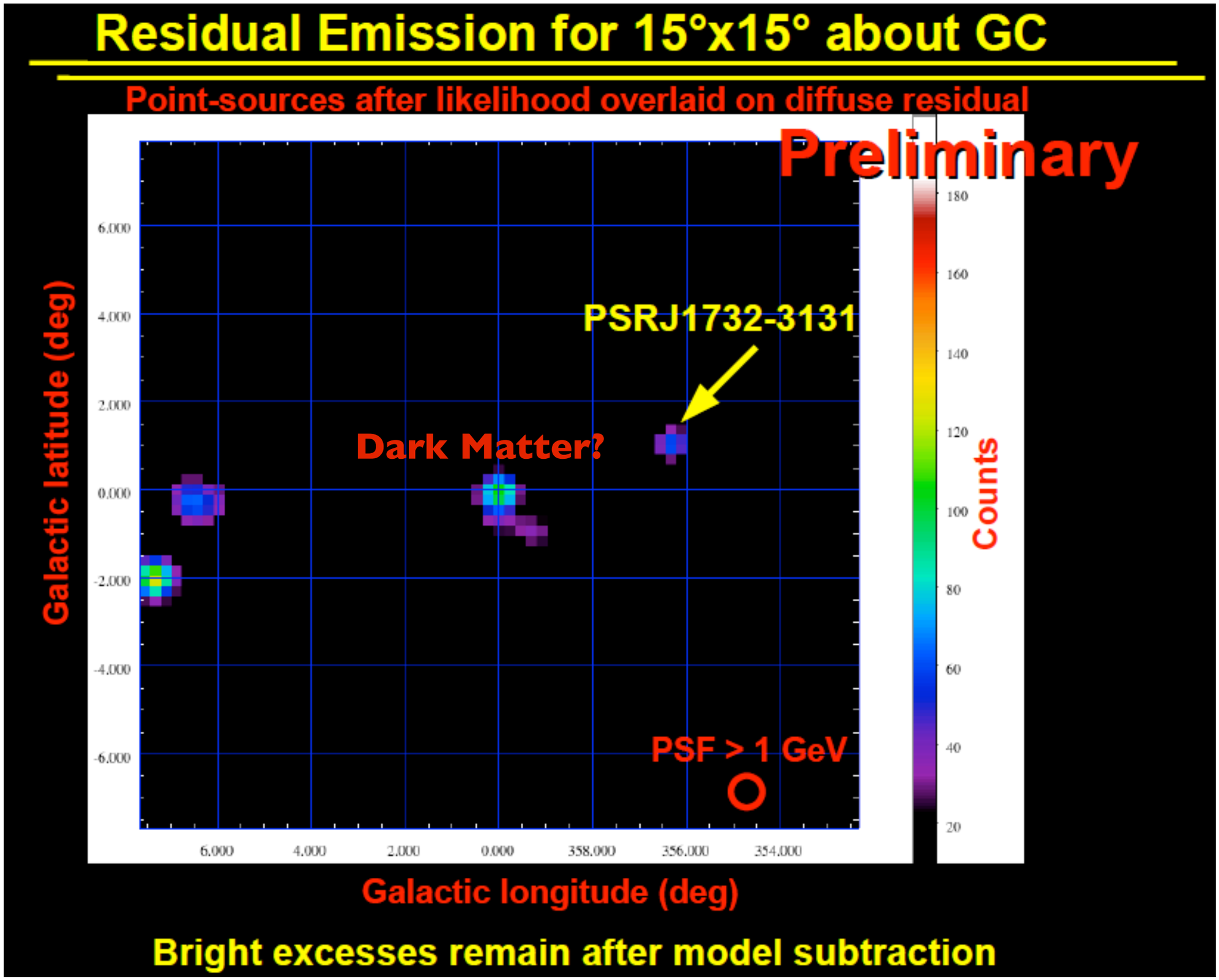
Romani, ApJL 754, 25 (2012)



Conclusion: At least 2/3 of young pulsars and at most 1/3 of MSPs are RQ (Romani 2012)

See talk by M. Kerr

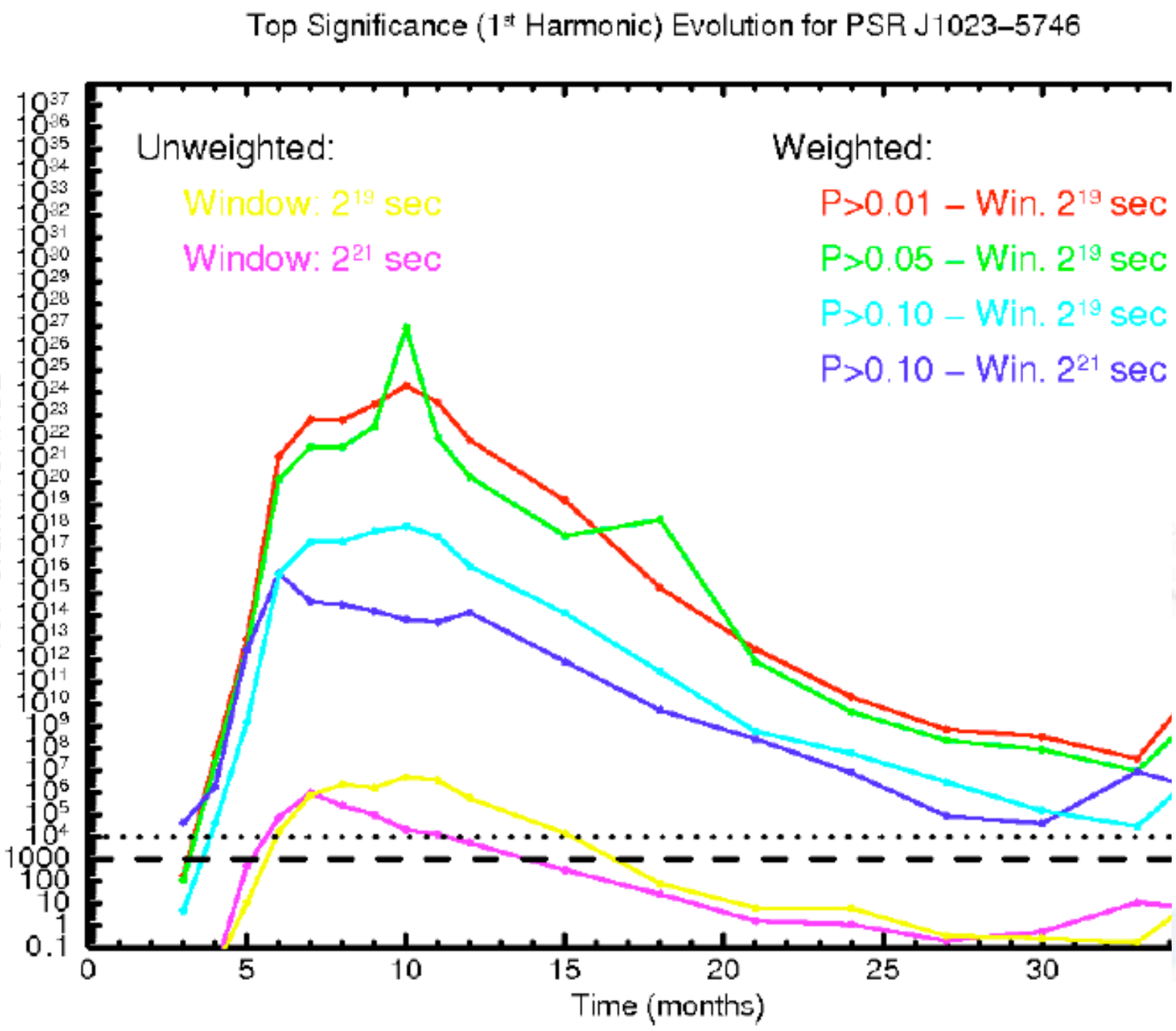
Pulsars around the GC?



Pulsars around the GC?

- Can we detect pulsars that far?
  - PSR J1823-3021A in NGC 6624 at 8.4±0.6 kpc
  - Crab at 8x distance = flux of faintest BSP
- Detailed diffuse model should improve event selection/weighting
- Multi-wavelength observations can improve sensitivity
- A modified observing profile could increase exposure by ~3.5, while maintaining all-sky coverage at ~1/3 current sensitivity

Effect of timing noise



PSRJ	J0205+6449	
RAJ	02:05:37.92000000	
DECJ	64:49:42.8000002	
F0	15.214509548790113 29	0.000000102429225922 53
F1	-4.401553707456254407 1c-11	2.543479913940508899 4e-14
F2	-1.750776475410137802 4e-19	4.678886760400122586 8e-21
F3	1.729563159225967878 6e-25	5.915917850765553534 69e-28
F4	-1.137577798723286334 9e-33	4.994405055006861456 e-35
F5	4.698538043546960571 6e-41	2.564756871931460340 8e-42
F6	-9.277360124757194570 9e-49	6.124975665466765431 2e-50
PEPOCH	54767	
POSEPOCH	54767	
DM	140.7	
START	54924.751377169355632	1.681061571556046753 1e-4932
FINISH	55707.851532934495431	
TZRMJD	55316.802304999944337	
TZRFRQ	1520	
TZRSITE	8	
TRES	284.779	
EPHVER	2	
CLK	TT(TAI)	
UNITS	TDB	
TIMEEPH	FB90	
DILATEFREQ	N	
PLANET_SHAPIRO	N	
T2CMETHOD	TEMPO	
CORRECT_TROPOSPHERE	N	
EPHEM	DE405	
NITS	1	
NTOA	119	
CHI2R	0.0000 76	
WAVEEPOCH	54767	
WAVE_OM	0.006334333337308 0	
WAVE1	-5.2396251620704 -14.565088422572	
WAVE2	-9.4330807463815 -11.411182775573	
WAVE3	-11.828725360325 -7.0075856170304	
WAVE4	-12.163014493599 -2.3367270979648	
WAVE5	-10.681904043004 1.6702360271222	
WAVE6	-8.0275545922164 4.3814294822778	
WAVE7	-4.3722231587667 5.590487632951	
WAVE8	-2.2065590764156 5.4823023527949	
WAVE9	-0.18023853691805 4.4989178692223	
WAVE10	0.97981152886983 3.1499400652054	
WAVE11	1.3870204779139 1.8550559044653	
WAVE12	1.2907613079888 0.8630274115075	
WAVE13	0.95814292352712 0.24793314038063	
WAVE14	0.59321402761495 -0.045715240857858	
WAVE15	0.30657582634807 -0.13268351799801	
WAVE16	0.13119705959939 -0.11577002890833	
WAVE17	0.042977471814231 -0.070970877274791	
WAVE18	0.0092390955869316 -0.03551997272963	
WAVE19	0.00065025036337588 -0.012719364172365	
WAVE20	-0.00036983929599862 -0.0038624020052028	
WAVE21	4.1478989315765e-05 -0.00081516905385676	

Conclusions

- The LAT has detected > 100 pulsars in 3 years (~1/3 in blind searches); the first gamma-ray telescope to discover pulsars in blind searches
- All (36) LAT-discovered pulsars so far are young (or middle-aged) isolated pulsars (mostly radio-quiet)
- Blind searches for MSPs are computationally intensive, but feasible, especially aided by MWL observations
- Searches for LAT pulsars around the Galactic Center could be enhanced with a modified observing profile
- LAT data are public ... anyone can search for pulsars!

谢谢