Search and Characterization of Radio-quiet Gamma-ray Pulsars with Fermi-LAT

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Outline

- Fermi-LAT and gamma-ray pulsars
- Blind searches for pulsars with Fermi-LAT
- Sensitivity of blind periodicity searches
- Timing pulsars across glitches with the LAT
- Extending the searches to MSPs and binaries

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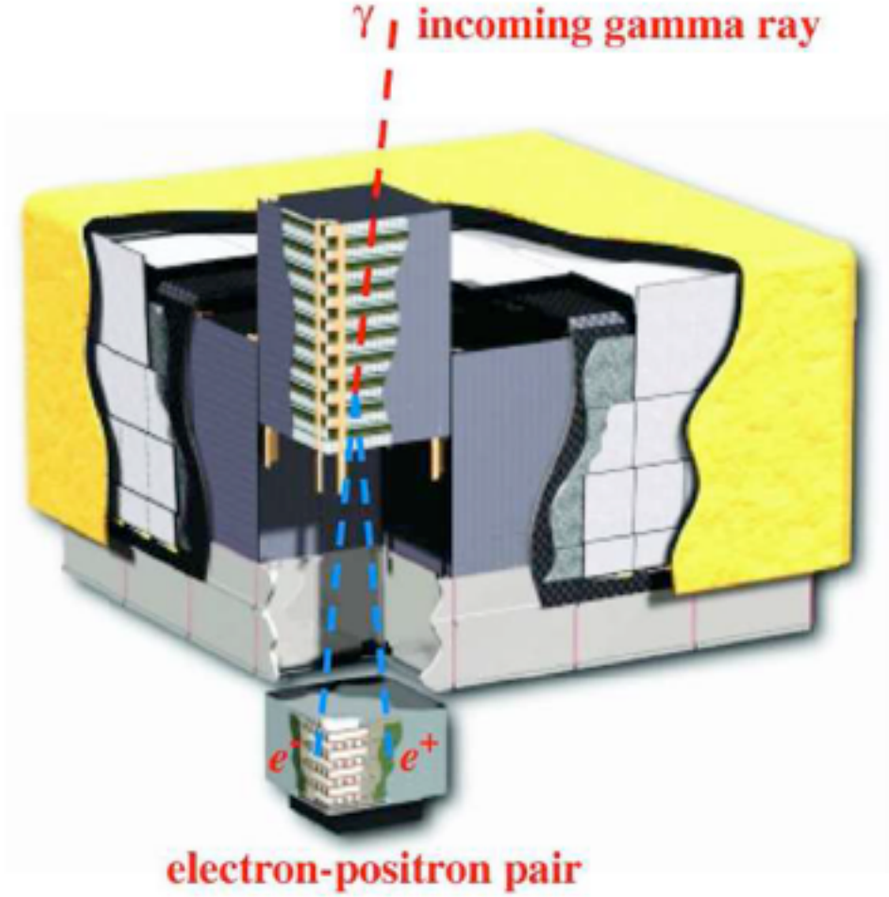
Fermi-LAT and pulsars

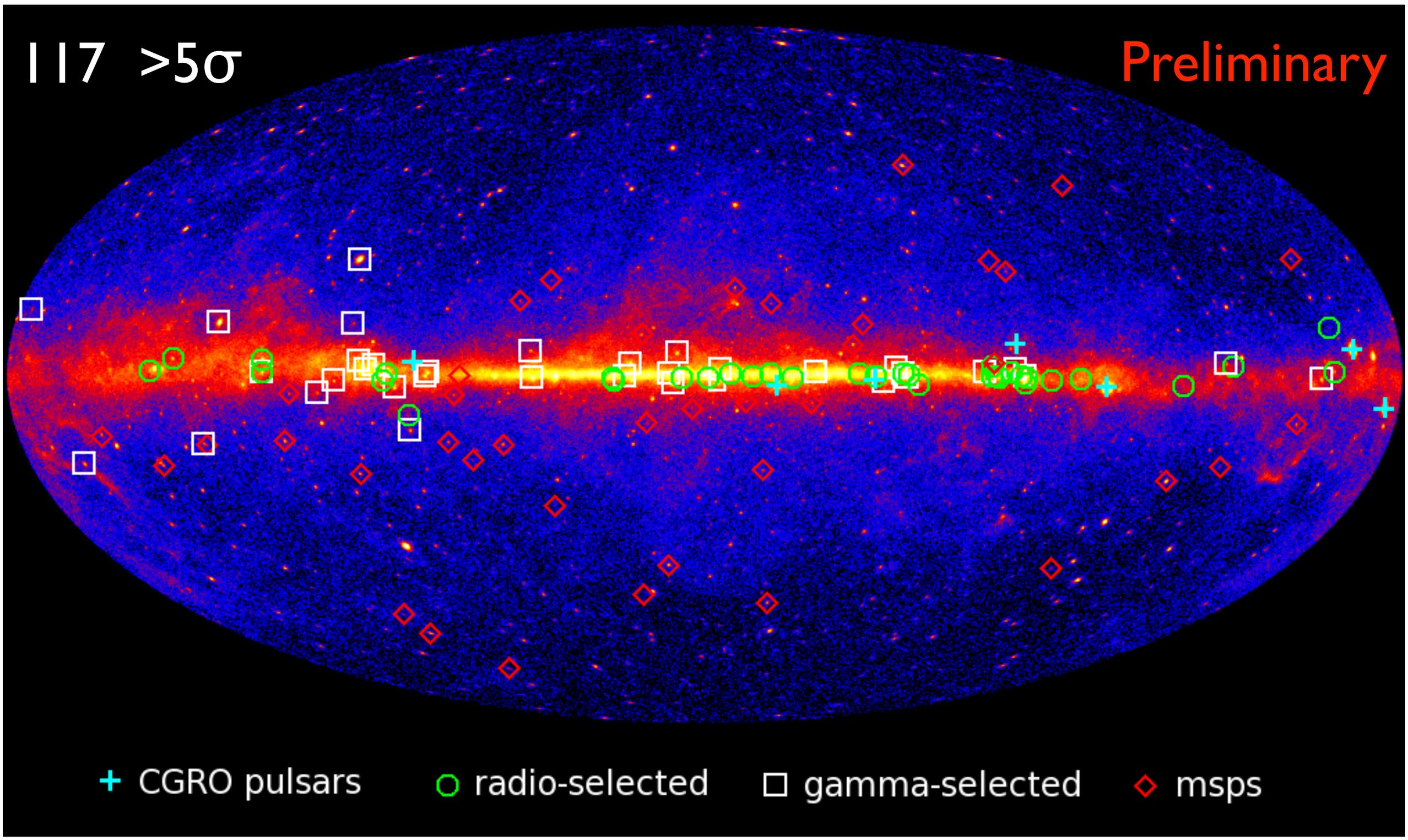
Abdo et al. 2009, APh, 32, 193
Atwood et al. 2009, ApJ, 697, 1071
Abdo et al. 2012, arXiv:1206.1896,

- International collaboration
- Launched on June 11 2008
- Energy: 20MeV to >300GeV
- Eff. Area @1GeV: 8000 cm^2
- PSF @1GeV: 0.6-0.8 deg
- Timing accuracy: <10μs
- Surveys the sky every ~3 hours

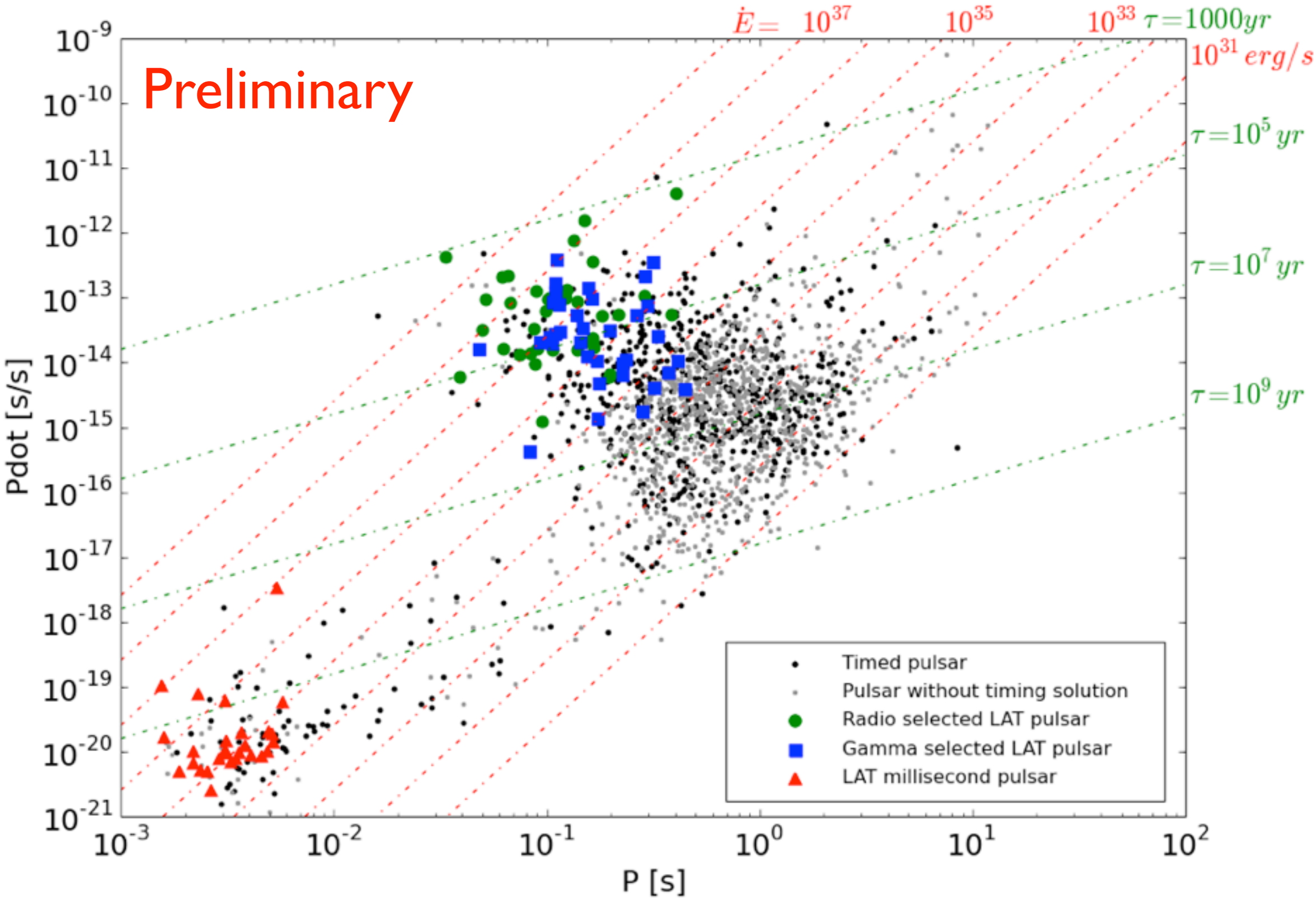


Fermi-LAT and pulsars

Upcoming: The second Fermi LAT catalog of gamma-ray pulsars (2PC)

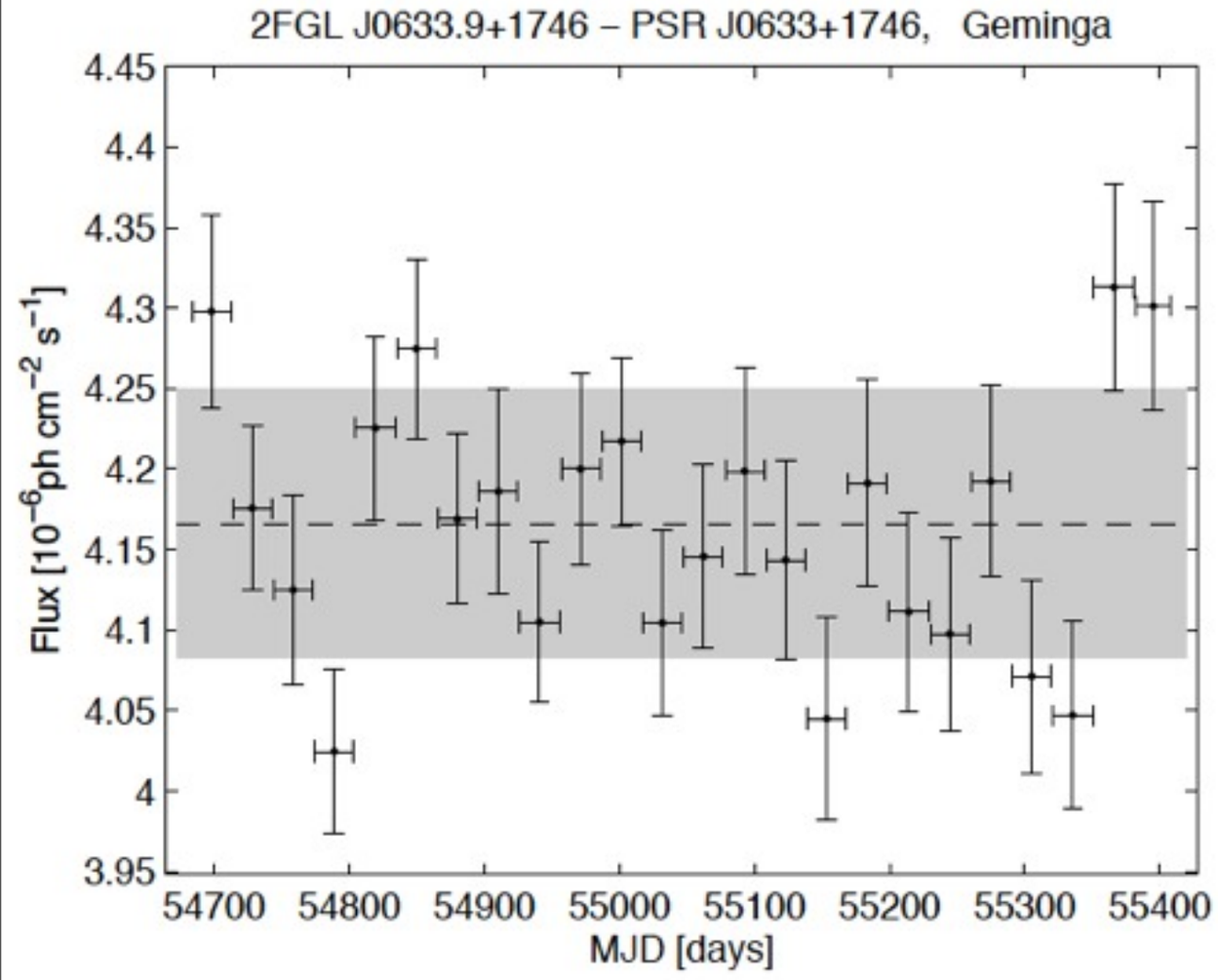


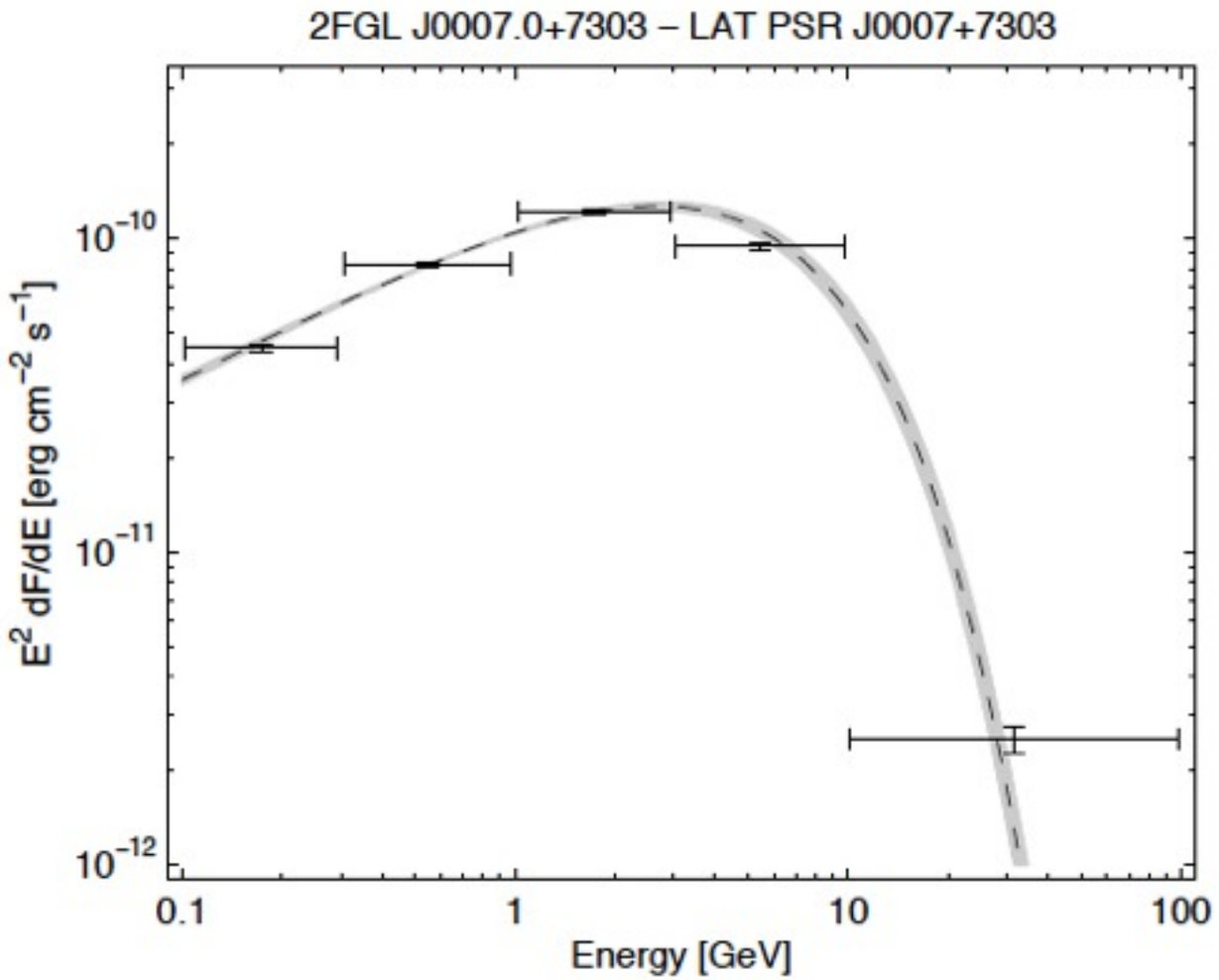
Fermi-LAT and pulsars



Fermi-LAT and pulsars

- Pulsars are the main class of Galactic gamma-ray sources
- 7 CGRO pulsars in detail + 110 others, including MSPs
- Non-variable, with spectral cutoff in the ~GeV range





Plots from Nolan et al. 2012 (2FGL)

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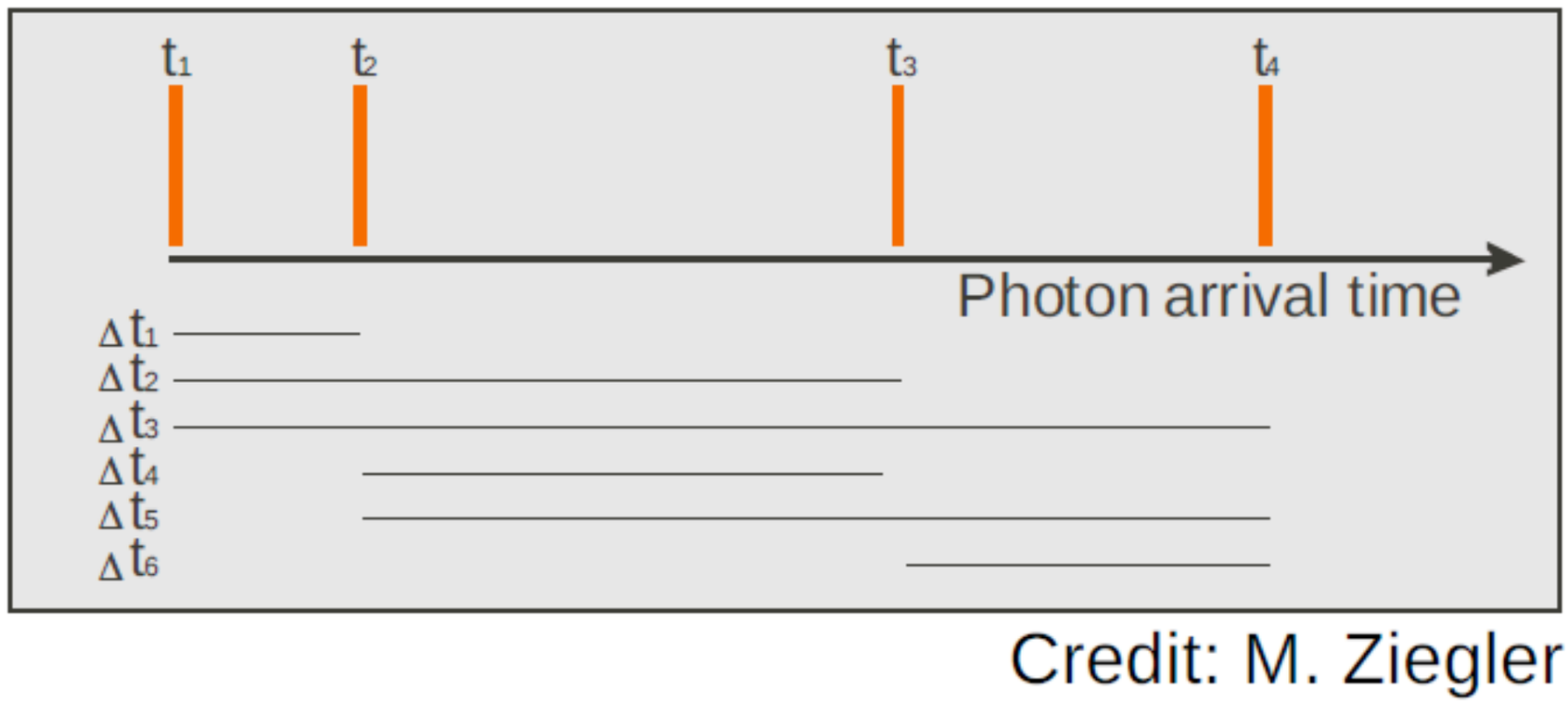
blind searches for pulsars

- The search for pulsars is traditionally done in the radio band, sometimes in X-rays
- The main problem is the scarcity of gamma-ray photons, requiring very long observation times
- The LAT PSF and the diffuse background do not allow to assign safely events to a specific source
- The young gamma-ray pulsars have an erratic timing behavior, with timing noise and glitches
- Standard FFT techniques require a full coherence and are also impractical with such long time series

blind searches for pulsars

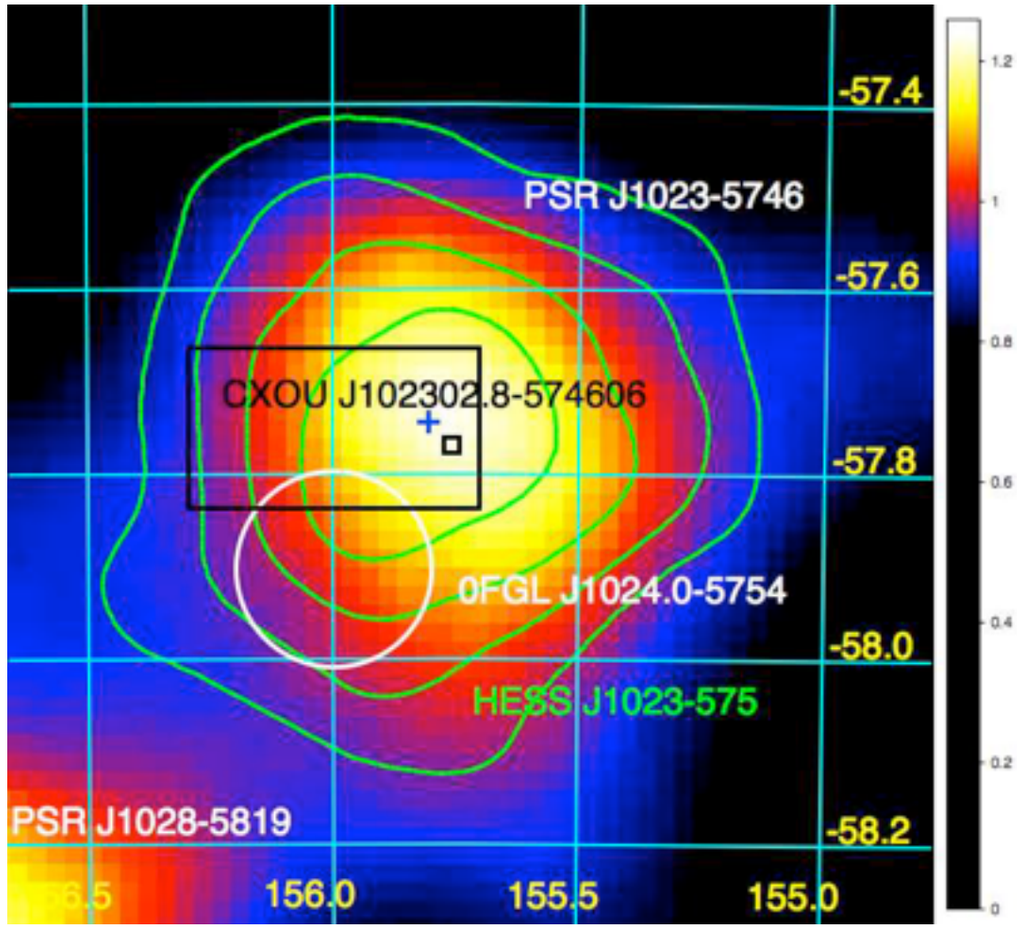
- The time-differencing technique (Atwood et al. 2006)
  - FFT over time differences instead of event times
  - less intensive on CPU and memory (smaller FFTs)
  - coherence requirement greatly reduced
  - only modest loss in power wrt the coherent search

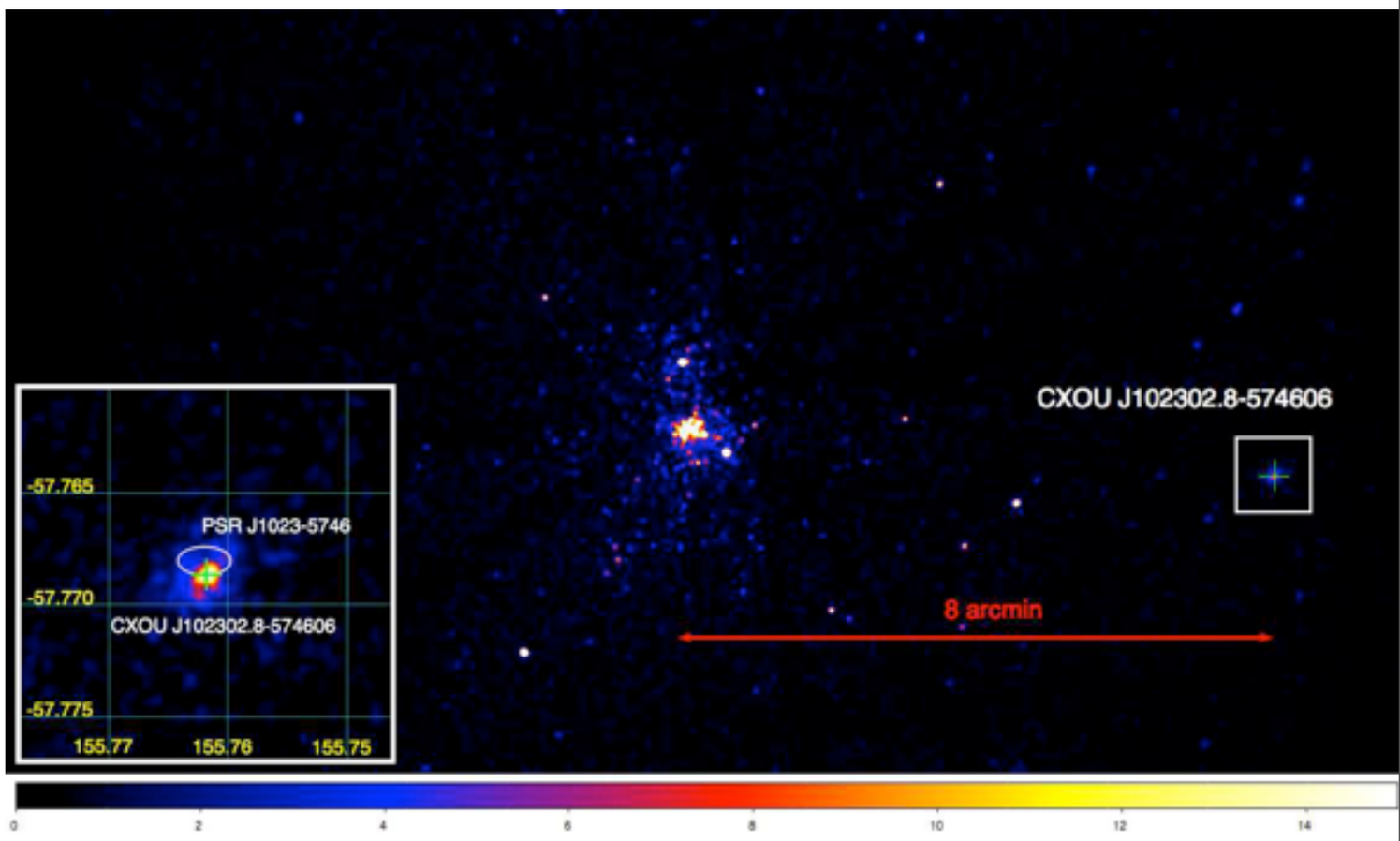


blind searches for pulsars

- Early discoveries in the first months: 16 (Abdo et al. 2009, Science, 325, 840) + 8 (Saz Parkinson et al. 2010)
- Coincide with previously UnID sources from EGRET
- Many associations with TeV sources, SNRs, PWNe
- With 2 years of data: PSR J0734-1559 and J1135-6055 (Saz Parkinson et al. in prep.)
- A new technique: 9 discoveries (Pletsch et al. 2012)
- Deep and multiple radio follow-up: only 5 detected, some faint and low-freq only, constraining the beaming models
- You can now join the effort with Einstein@home

blind searches for pulsars





The radio-quiet pulsar PSR J1023-5746 in the Carina region
HESS J1023-575: associated with WD2? (Aharonian et al 2007)
timing localization consistent with a Chandra source outside WD2
evidence for a PWN? (Ackermann et al 2011, ApJ, 726, 35)
Re-observed by HESS: complex picture (Abramowski et al 2011)

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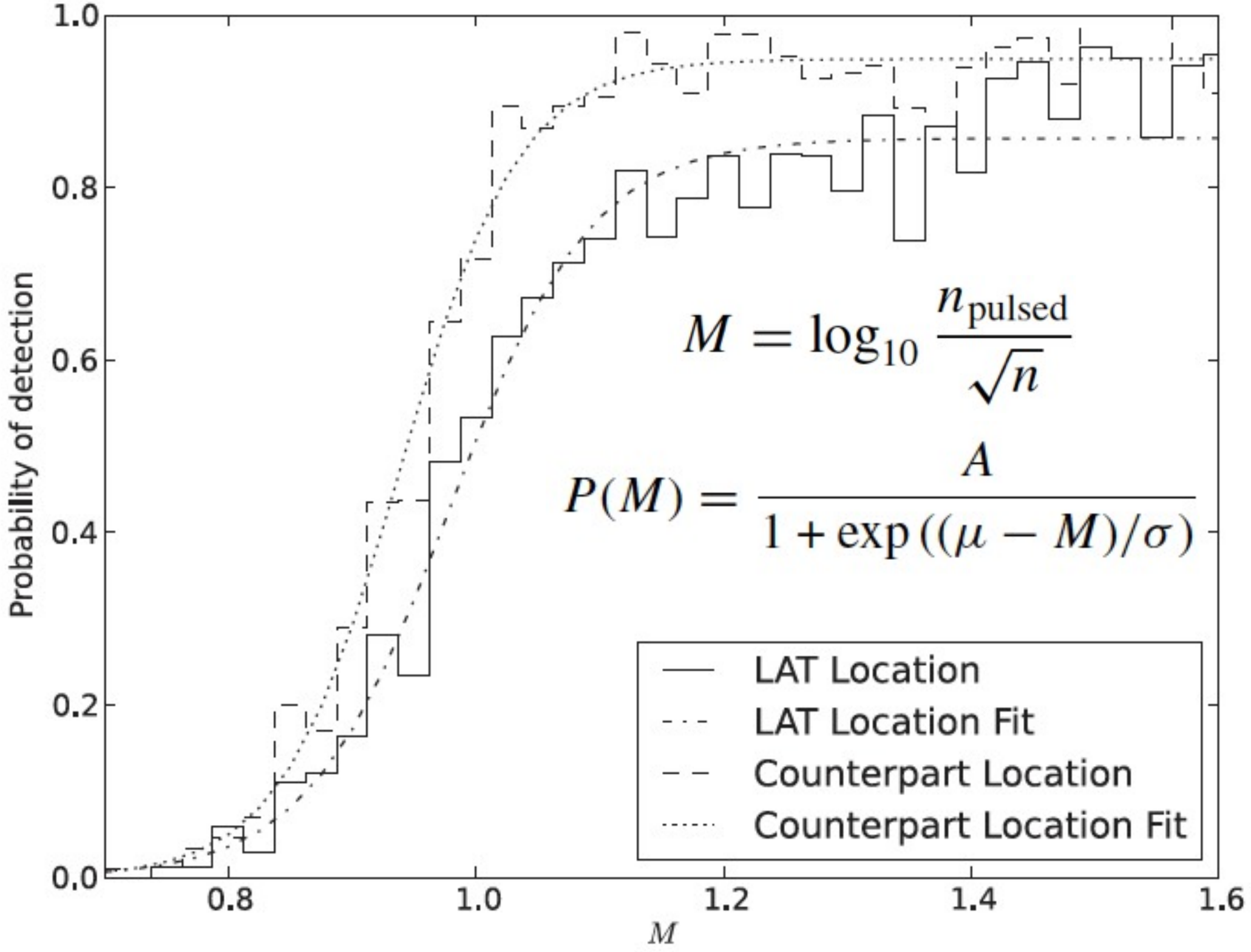
blind search sensitivity

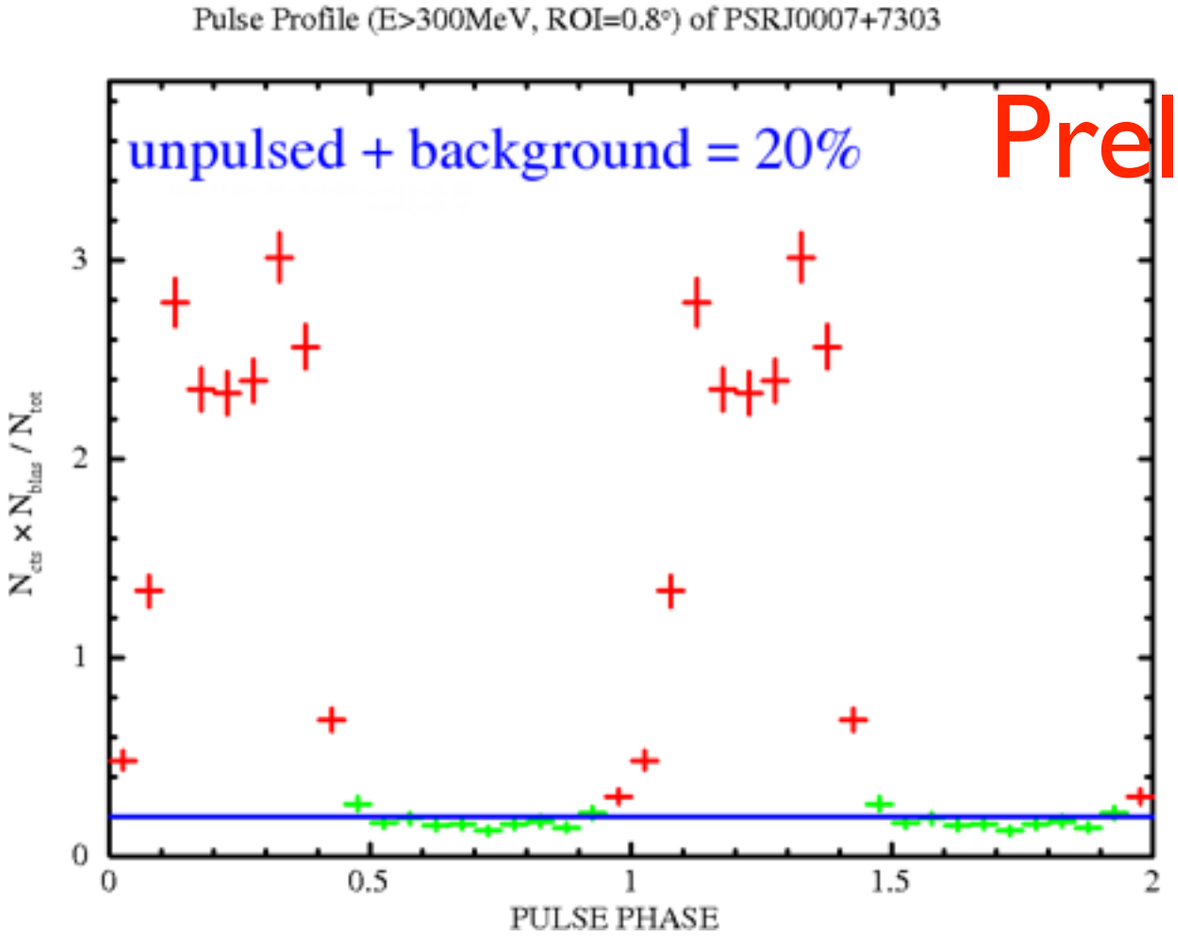
- Monte Carlo simulation of gamma-ray pulsars on top of 1year of LAT actual data (Dormody et al. 2011)
- only for young pulsars: MSPs are another story
- search for the LAT source (exactly like 1FGL)
- blind search for pulsations in the LAT source
- sampled variables: sky position, spin parameters, spectrum, flux, pulse profile
- hardest part: parametrizing the pulse profile
- validation on the 2PC young LAT pulsars
- there is a plan to refine and extend to multi-year

blind search sensitivity

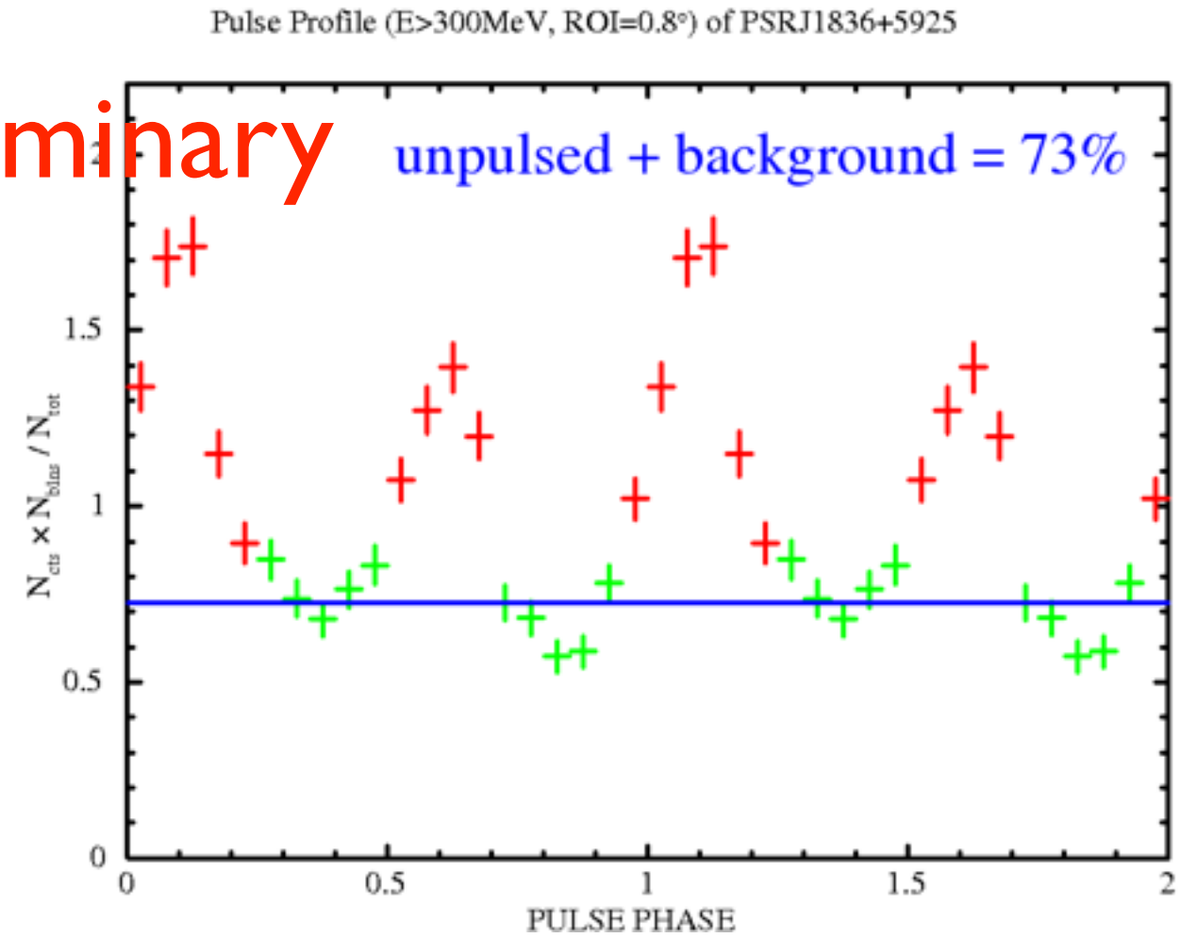


blind search sensitivity

Validation study: what is the blind-search detectability of LAT pulsars?



Preliminary

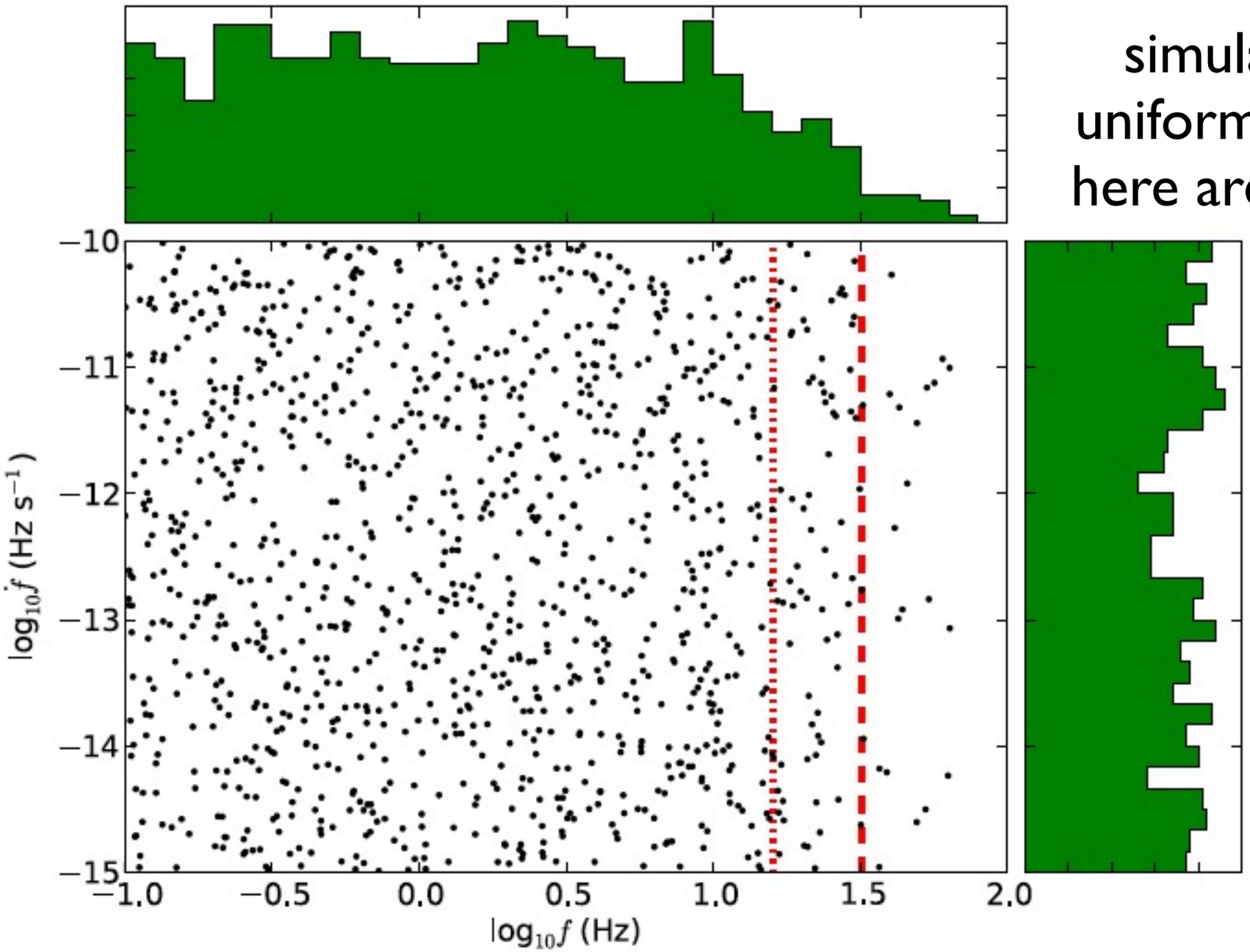


Key ingredient: pulsed fraction - purely statistical - no physical meaning

- most pulsars found in 1-year blind search are fully detectable (P~1)
- some radio pulsars are also fully detectable (EGRET pulsars + J1028-5819 + J1048-5832 + J2021+3651 + J2229+6114)
- many lie somewhere in between: there is no clear cut

blind search sensitivity

High-frequency pulsars harder to detect (harmonics? position?)



simulated pulsars were uniformly sampled in f-fdot here are the detected ones

simulated range:
.1 Hz < f < 64 Hz

search up to 64 Hz
f > 32 Hz: 1 harmonic
f < 16 Hz: 4 harmonics

there is no LAT pulsar with f < 2 Hz

The lack of low-frequency LAT pulsars is not an observational bias

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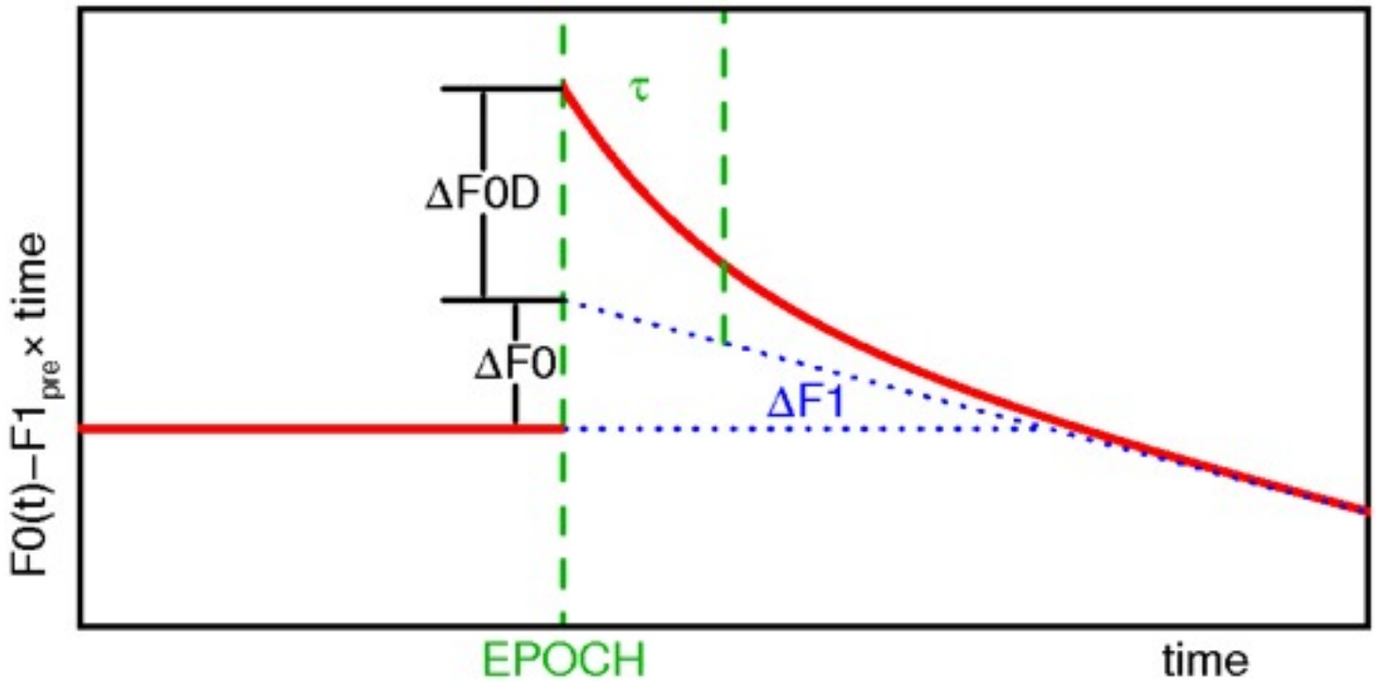
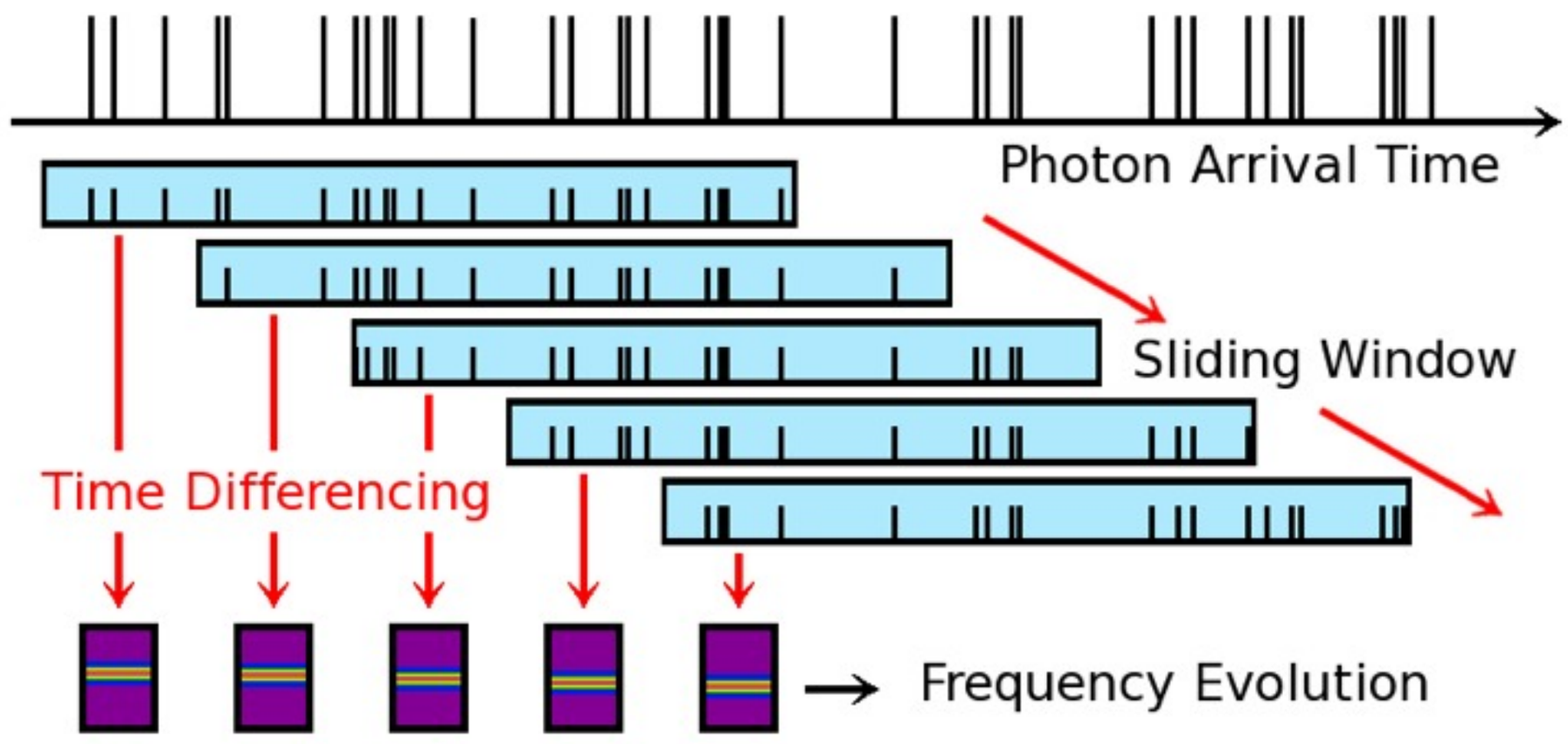
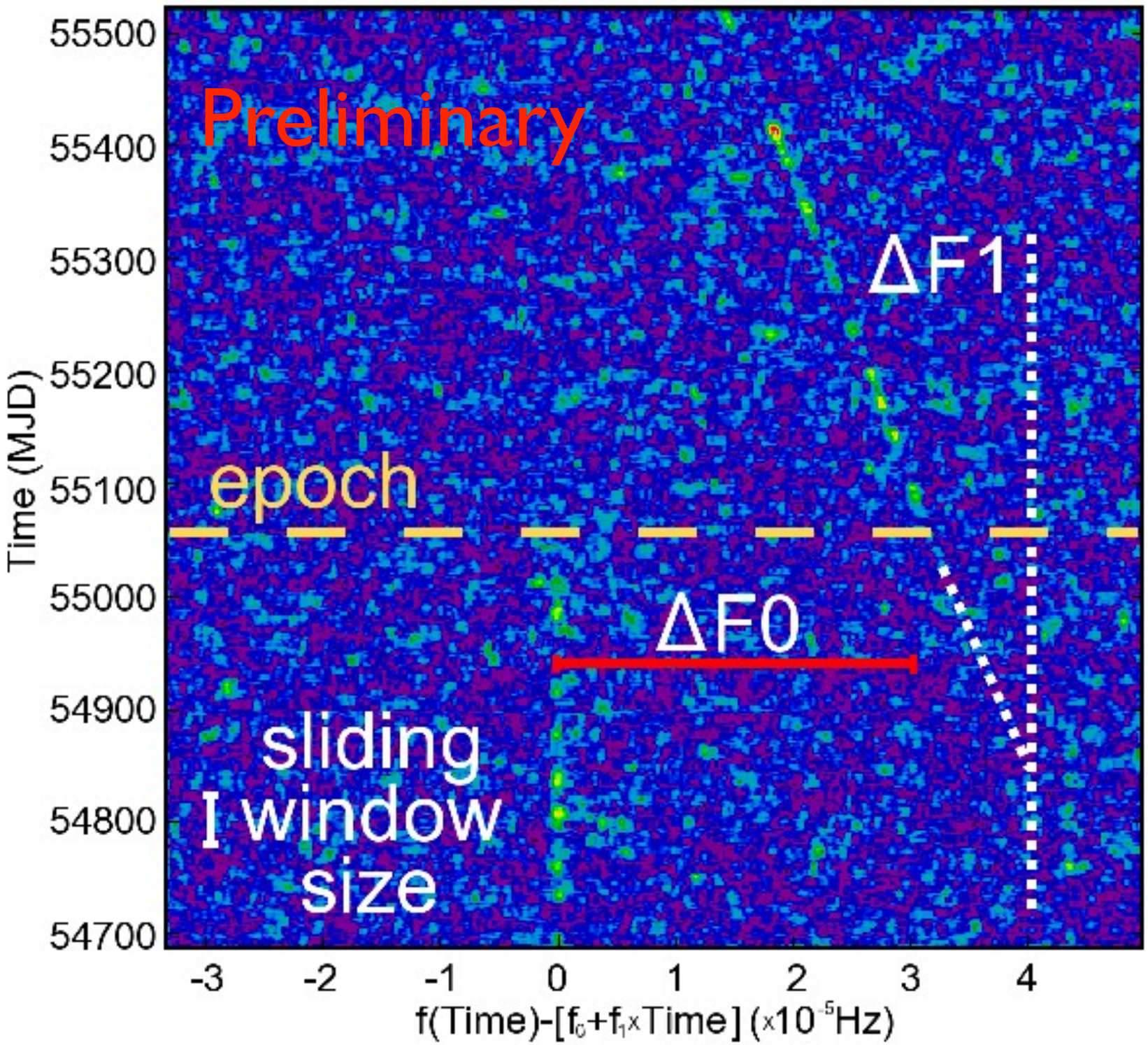
timing pulsar glitches



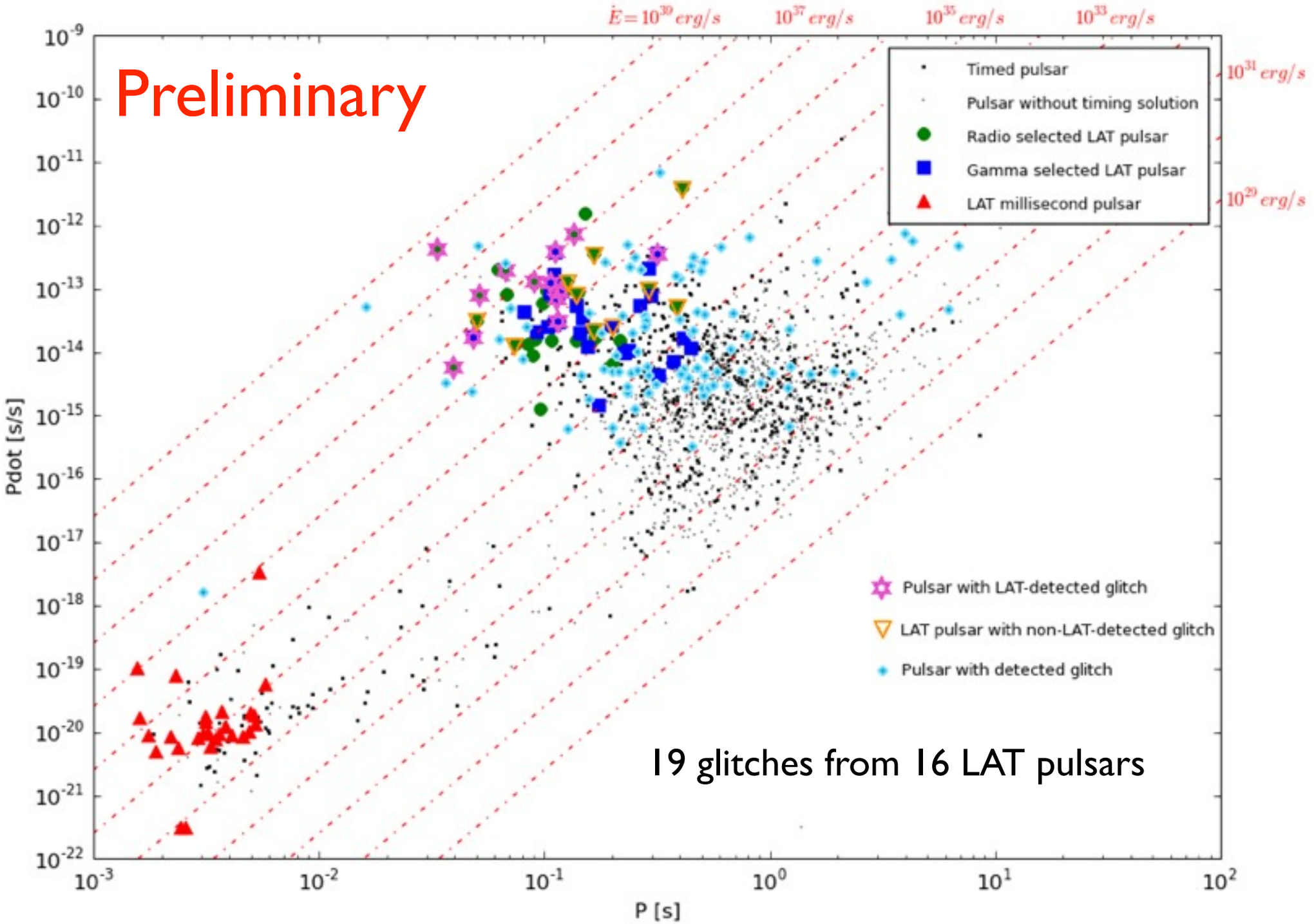


timing pulsar glitches

Huge glitch (df/f~3.6e-6) from the radio-quiet PSR J1023-5746



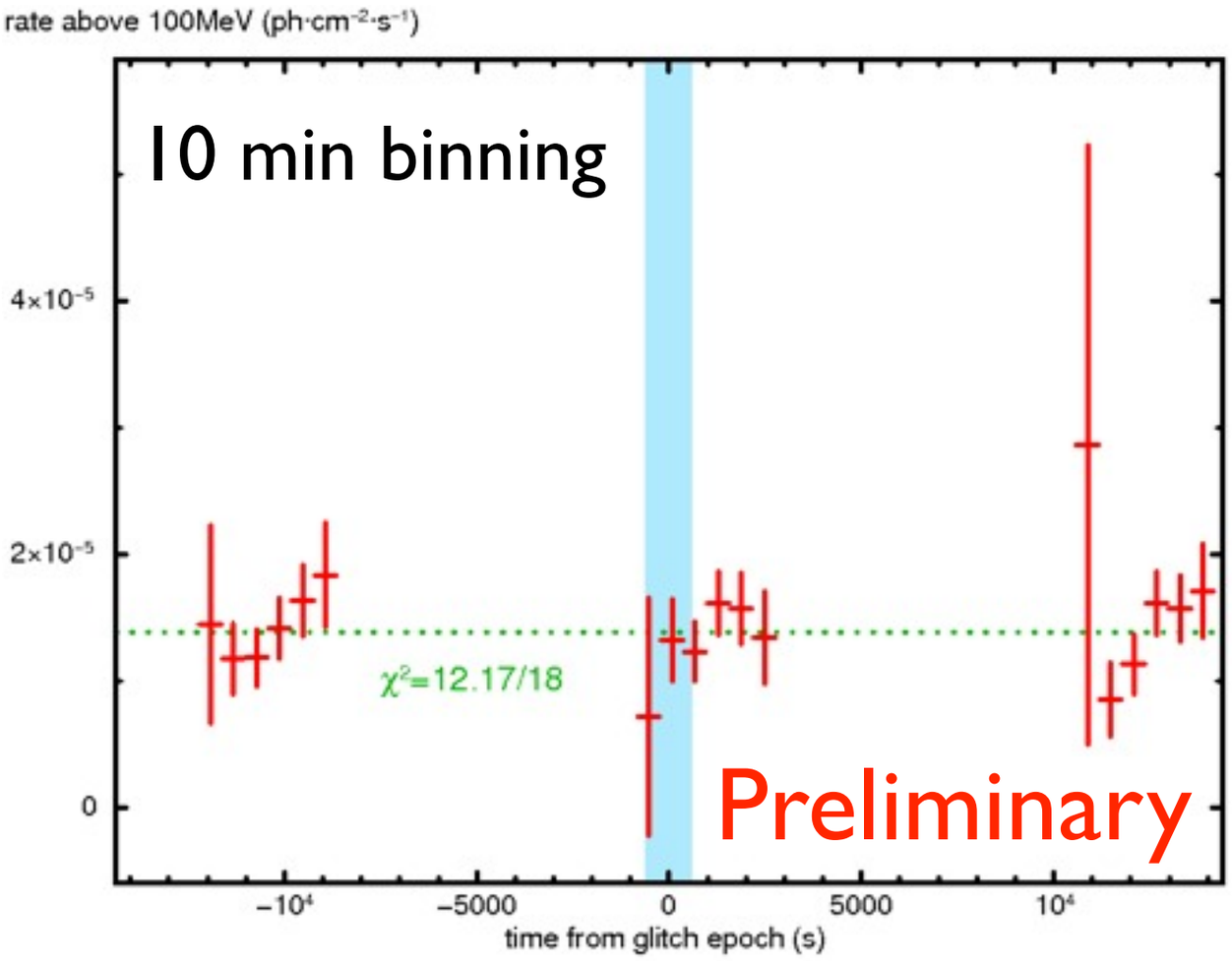
timing pulsar glitches

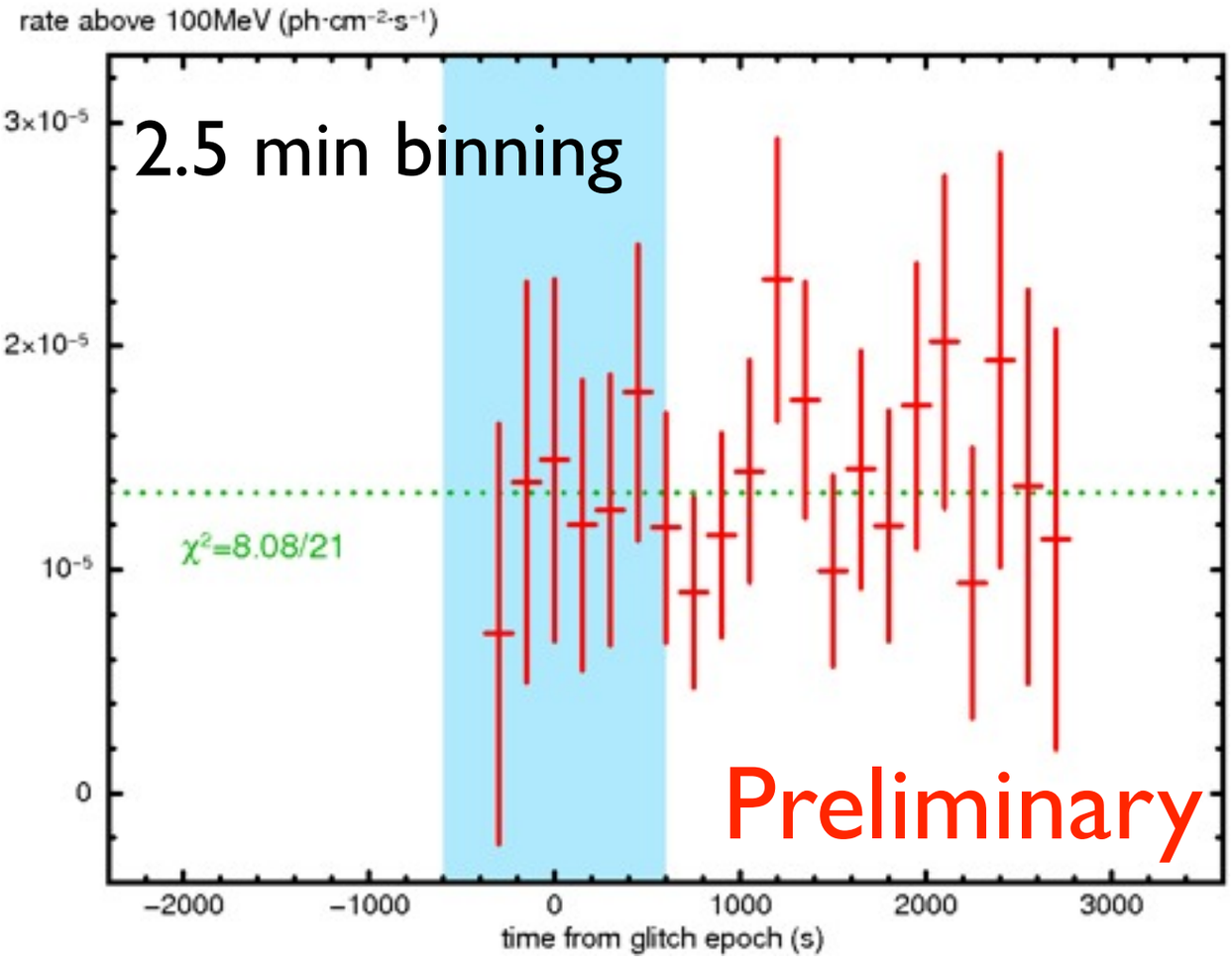


The young LAT pulsars overlap with the glitching sample
The survey strategy allows for continuous monitoring

timing pulsar glitches

Vela PSR very bright at ~GeV + large glitch = search for flares
suggested e.g. by Ruderman (1991) or Pellizzoni et al. (2009)





The LAT was likely pointing at the Vela PSR at the glitch epoch
However, no evidence for flares, nor changes in the pulse profile

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blind search extended

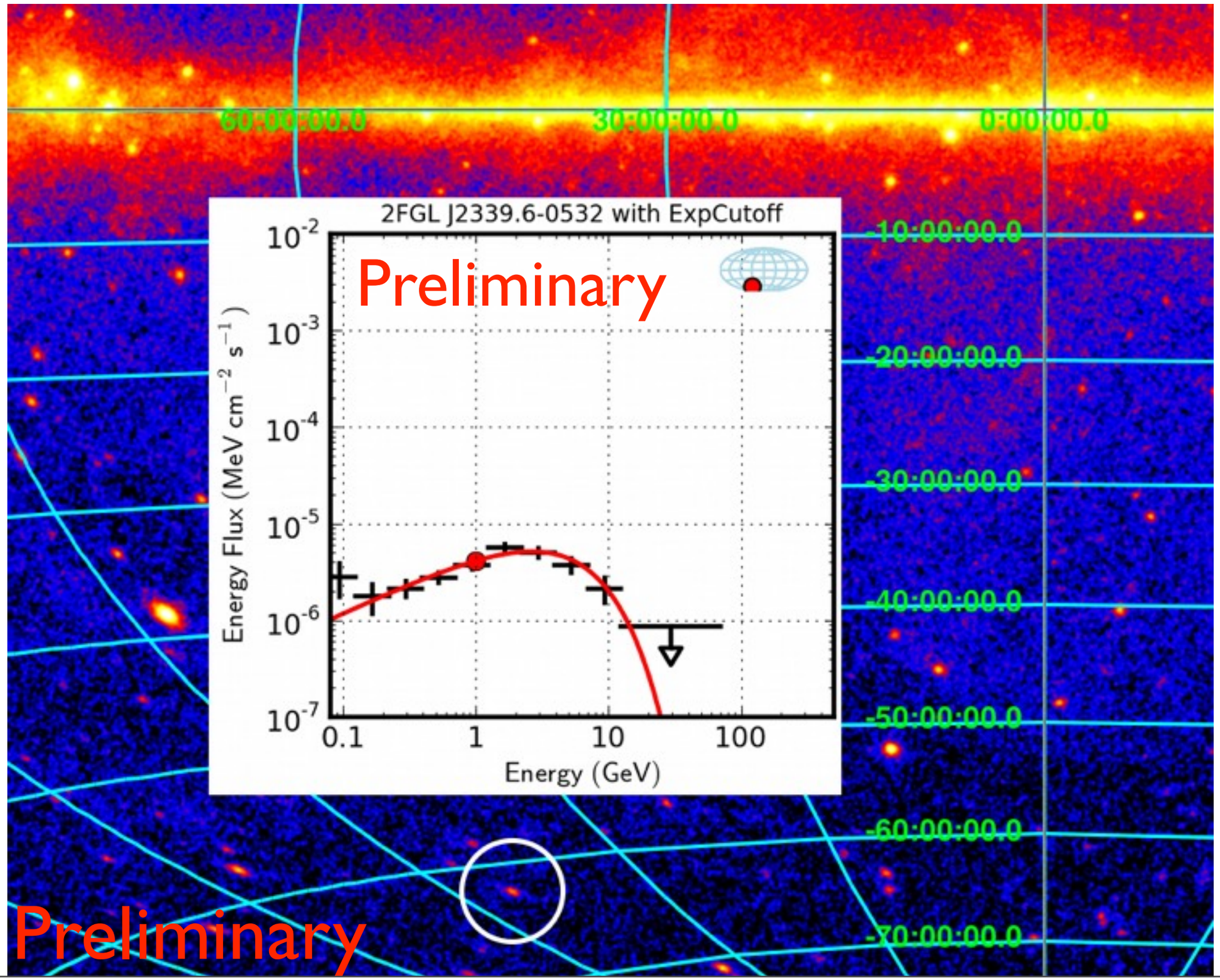
- New directions: pulsars in binaries and MSPs
- FFT core of blind search = need a periodic signal
- 3 effects mask the periodicity:
  - intrinsic spin-down of the pulsar
  - orbital motion of the pulsar
  - orbital motion of the LAT and of the Earth
- An error in the correction causes a loss in power that scales as: $\Delta pow / pow \sim -(\Delta par \times Freq)^2$
- Grid in the parameters: sensitivity vs resources

blind search extended

- no radio-quiet MSP discovered so far (are there any?)
- searches for isolated MSPs like for young pulsars
- very challenging (FFT size, position accuracy)
- feasible and validated on known LAT MSPs
- follow-up on X-ray seeds (XMM, Chandra, Swift,...)
- the general binary system requires searching too many parameters (A1, T0, PB, E, OM, position)
- black widows (circular tight orbits) could be found
- we have excellent candidates (e.g. 2FGL J2339-0532)

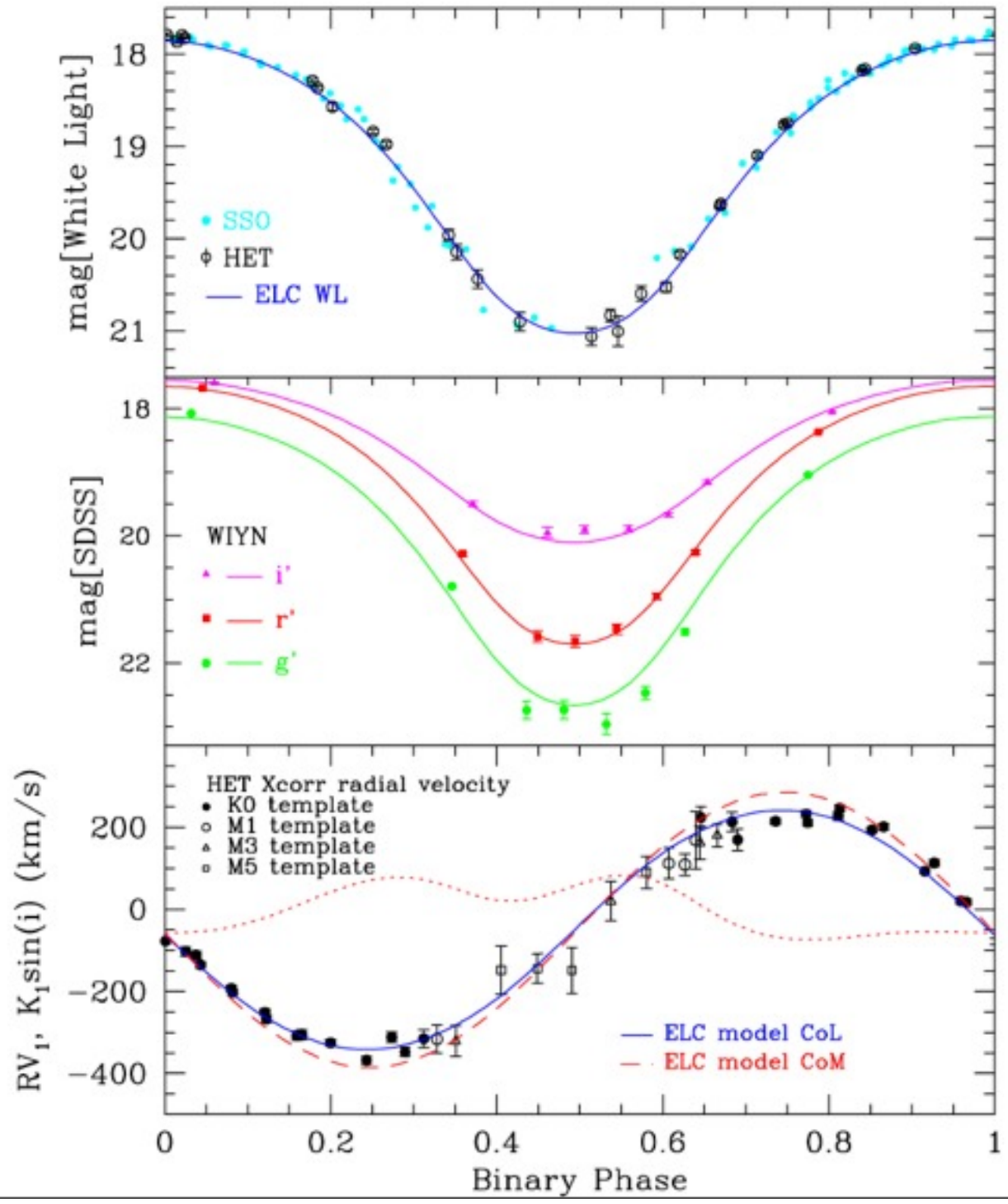
blind search extended

Bright - Off the plane - Pulsar-like spectrum - Non-variable



blind search extended

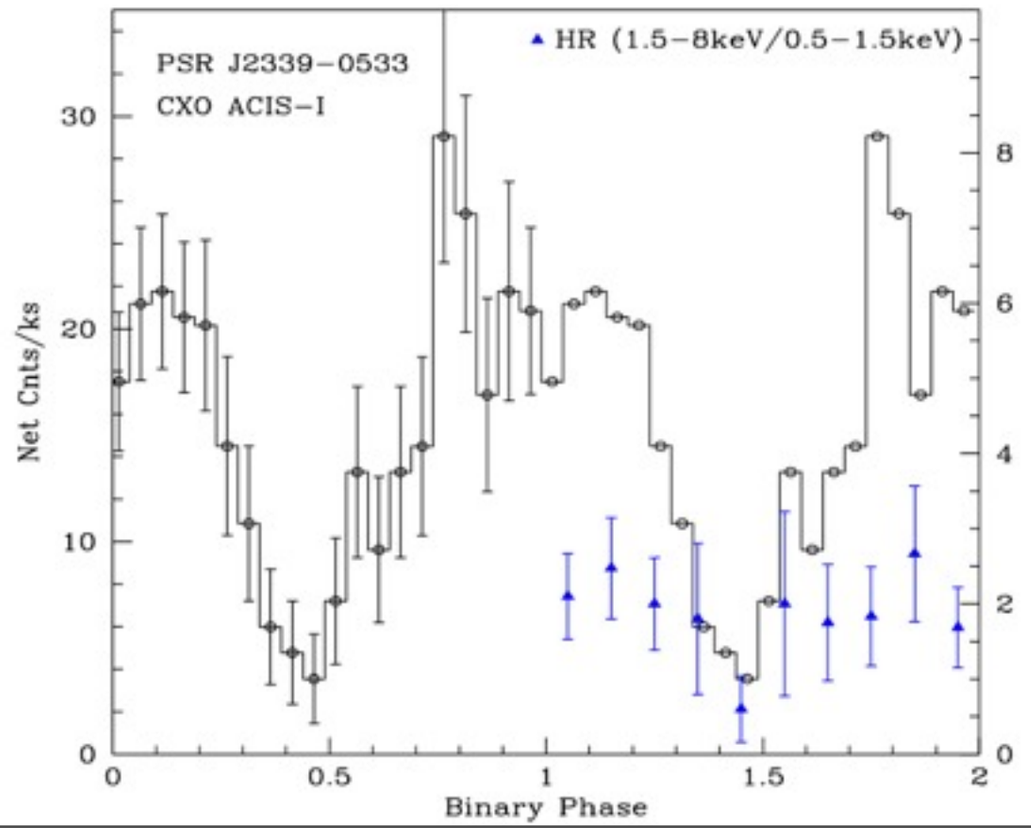
Position + Orbital parameters from optical and X-ray observations



from Shaw & Romani 2011

Table 1
J2339−5033 System Parameters

Parameter	ELC Fit Value
R.A. (J2000)	23:39:38.75
Decl. (J2000)	−05:33:05.3
P_b (days)	$0.19309790 \pm 1 \times 10^{-7}$
T_0 (MJD-TDB)	55500.4833 ± 0.0002
M_1 ($M_\odot$)	0.075 ± 0.007
M_2 ($M_\odot$)	1.40 ± 0.04
i (deg)	57.4 ± 0.5
f_1	0.90 ± 0.01
T_1 (K)	2800 ± 50
$\log[L_X]$ (erg s^{-1})	33.5 ± 0.1



blind search extended

- we consider the 5 brightest LAT black widows
- we verify we can detect them and tune the search
- we run an extensive validation of code, grid, and setup
- the search for J2339 is on-going (supported by Colfax)

- we expect to detect or to set stringent upper limits

name	l deg	b deg	Ntot	Nsig	H-test	SE	σ	F0 Hz	F1/F0 Hz/s/Hz	A1 lt s	PB d
J1124-3653	284.1	22.7	8738	525	359	4.82	12.1	415.0	-2.5×10^{-18}	0.080	0.227
J1810+1744	44.6	16.8	44287	2111	412	26.55	18.3	601.4	-2.7×10^{-18}	0.095	0.148
J1959+2048	59.2	-4.7	12506	659	220	6.15	12.4	622.1	-10.5×10^{-18}	0.089	0.382[a]
J2214+3000	86.9	-21.7	21704	1750	301	19.98	34.7	320.6	-4.8×10^{-18}	0.059	0.417
J2241-5236	337.4	-54.9	16362	1536	239	4.34	36.0	457.3	-3.1×10^{-18}	0.026	0.146
J2339-0532	81.3	-62.5	15383	1234	?	?	32.2	?	?	0.116?	0.193

[a] J1959+2048 has also a large PBDOT $= 2.98 \times 10^{-11}$ d d^{-1}

Summary

- 2PC in preparation with 117 LAT pulsars
- ~1/3 found in blind searches, mostly radio-quiet
- A sensitivity study can constrain the pulsar population
- The LAT monitors gamma-ray pulsars for glitches
- Single pulsars can be characterized even if radio-quiet
- The blind search techniques and strategies are evolving
- We focus now on radio-quiet MSPs in black widows
- You can discover new LAT pulsars with Einstein@home