Radio Searches of Fermi Blind Search Pulsars and Unassociated Sources

Paul S. Ray (NRL)
for the Fermi Pulsar Search Consortium

2011 May 10

Fermi Symposium, Rome

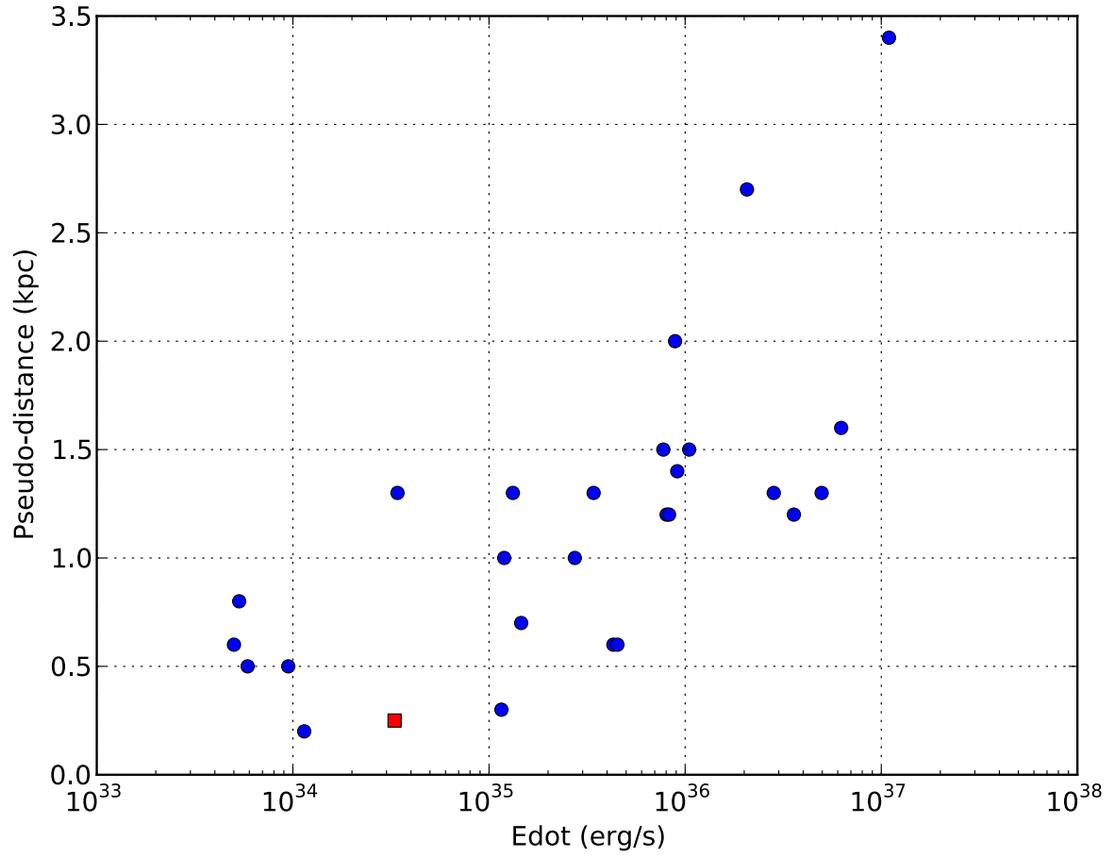
Fermi Pulsar Search Consortium (PSC)

- **Purpose**: To organize deep radio searches of the blind search pulsars and unidentified LAT sources
- Fermi LAT members:
  - Ray, Smith, Harding, Ferrara, Kerr, Thompson, Saz Parkinson, Ziegler, Abdo, Wood, Romani, Kramer (**Effelsberg**), Johnston (**Parkes**), Theureau, Stappers, Cognard (**Nançay**)

- External members with expertise at particular telescopes:
  - **GBT**: Camilo, Ransom, Roberts, McLaughlin, Hessels
  - **Arecibo**: Freire
  - **Parkes**: Keith, Weltevrede, Camilo
  - **GMRT**: B. Bhattacharyya, J. Roy, D. Bhattacharya, Y. Gupta

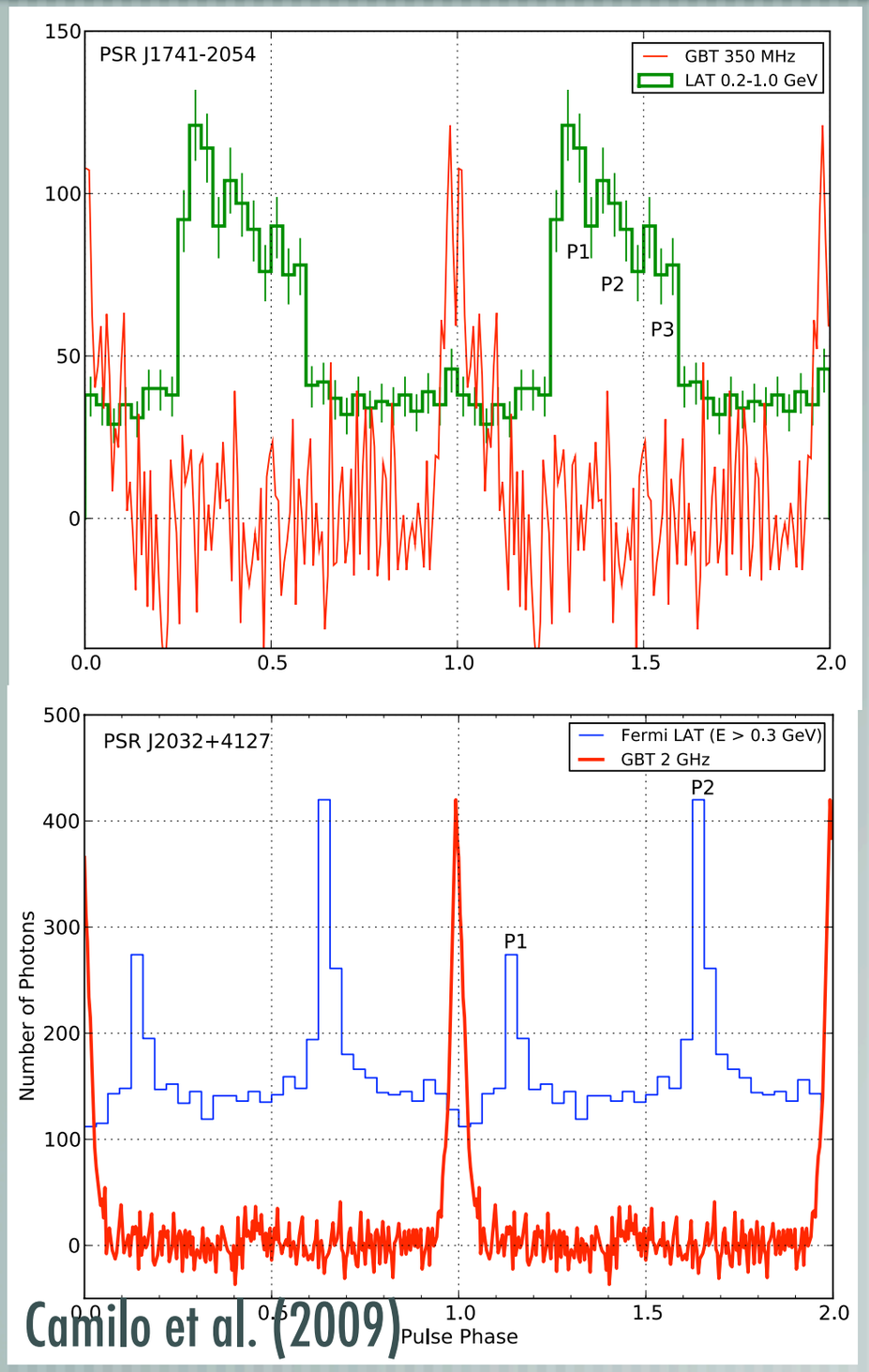
Blind Search Pulsars

- Blind searches of LAT data allow us to find pulsars where the radio beam might not be pointed at us
- 24 discovered in first year of survey data (Abdo et al. 2009, Saz Parkinson et al. 2010)
- 2 new ones in searches of two years of survey data (**see poster by Saz Parkinson**)
  - It is getting harder, but more discoveries will be coming
- Science questions: Are they really radio quiet? What is the beaming fraction in gamma-ray vs. radio?
- PSC has searched all for radio emission
  - Deep observations at GBT, Parkes, and Arecibo

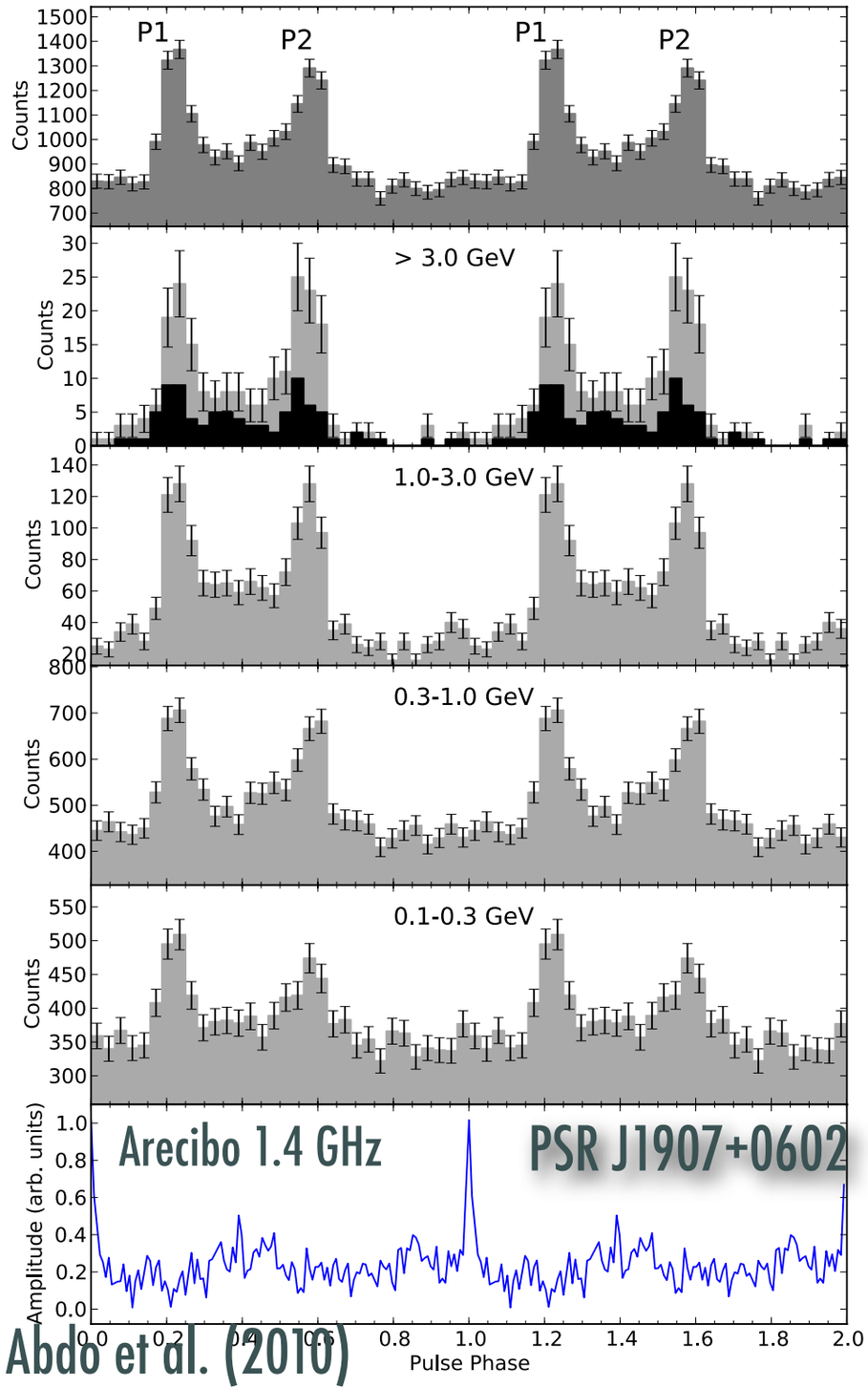


Three Discoveries of Radio Pulsations

Gamma-ray Space Telescope

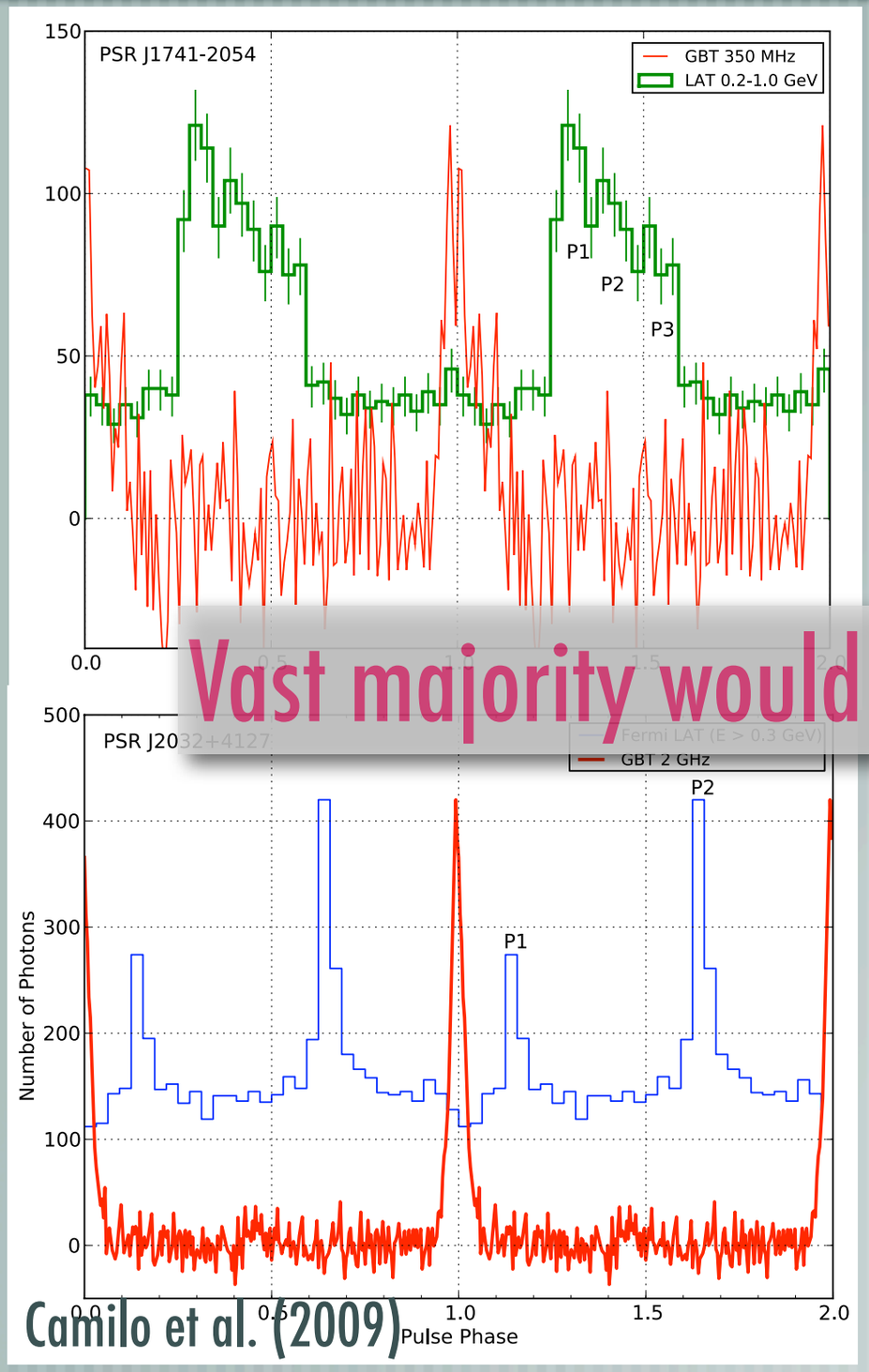


Camilo et al. (2009)

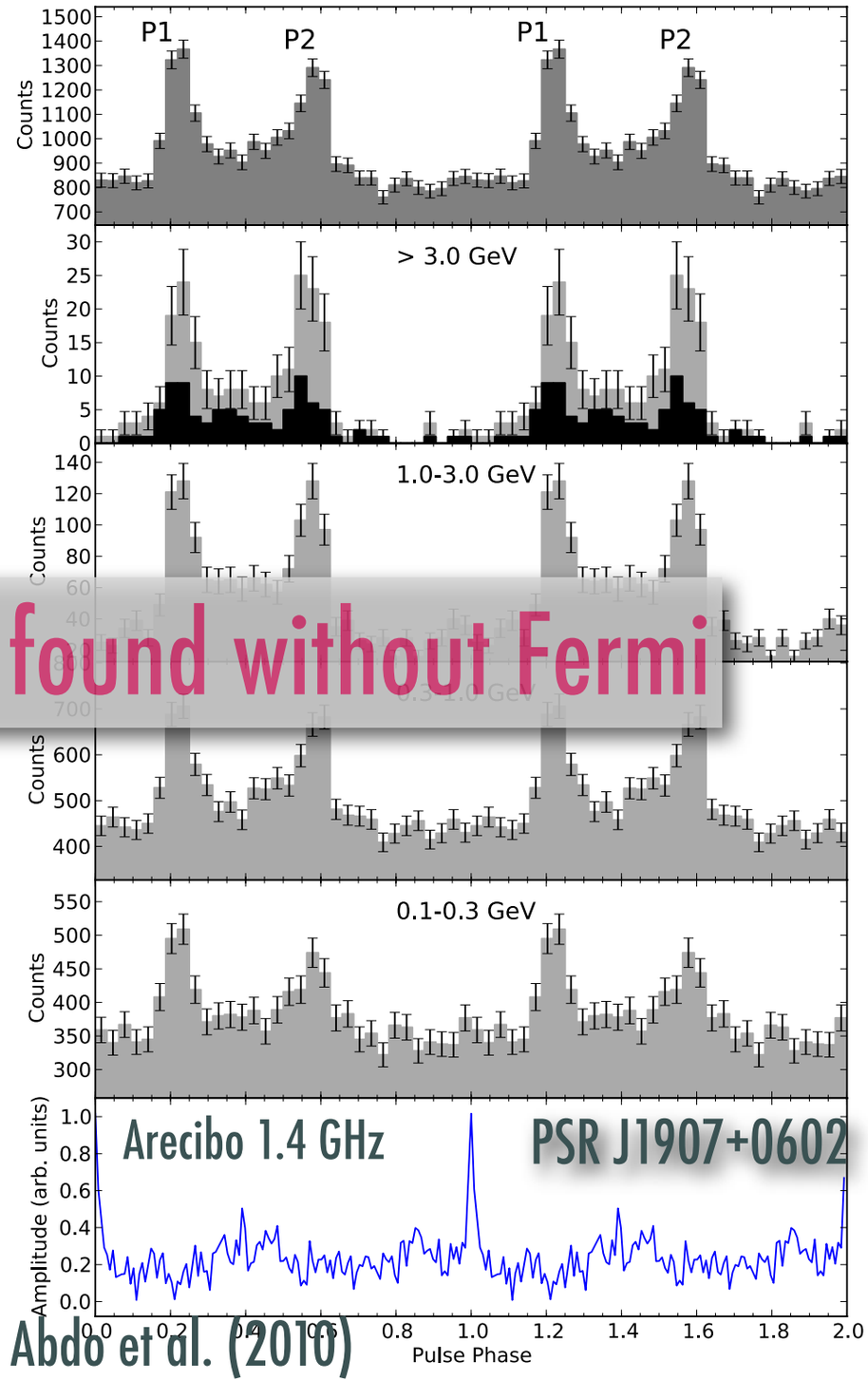


Abdo et al. (2010)

Three Discoveries of Radio Pulsations



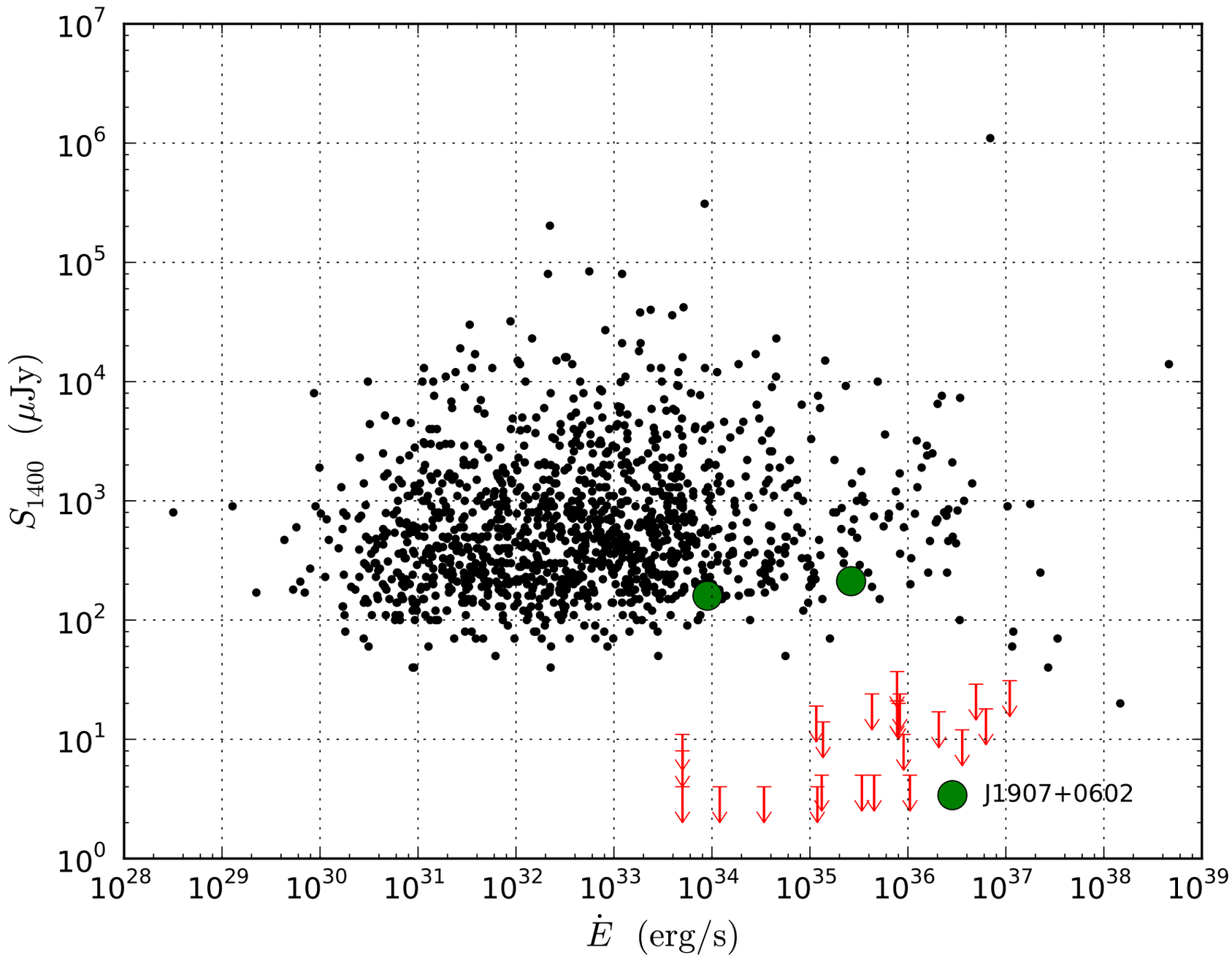
Camilo et al. (2009)



Abdo et al. (2010)

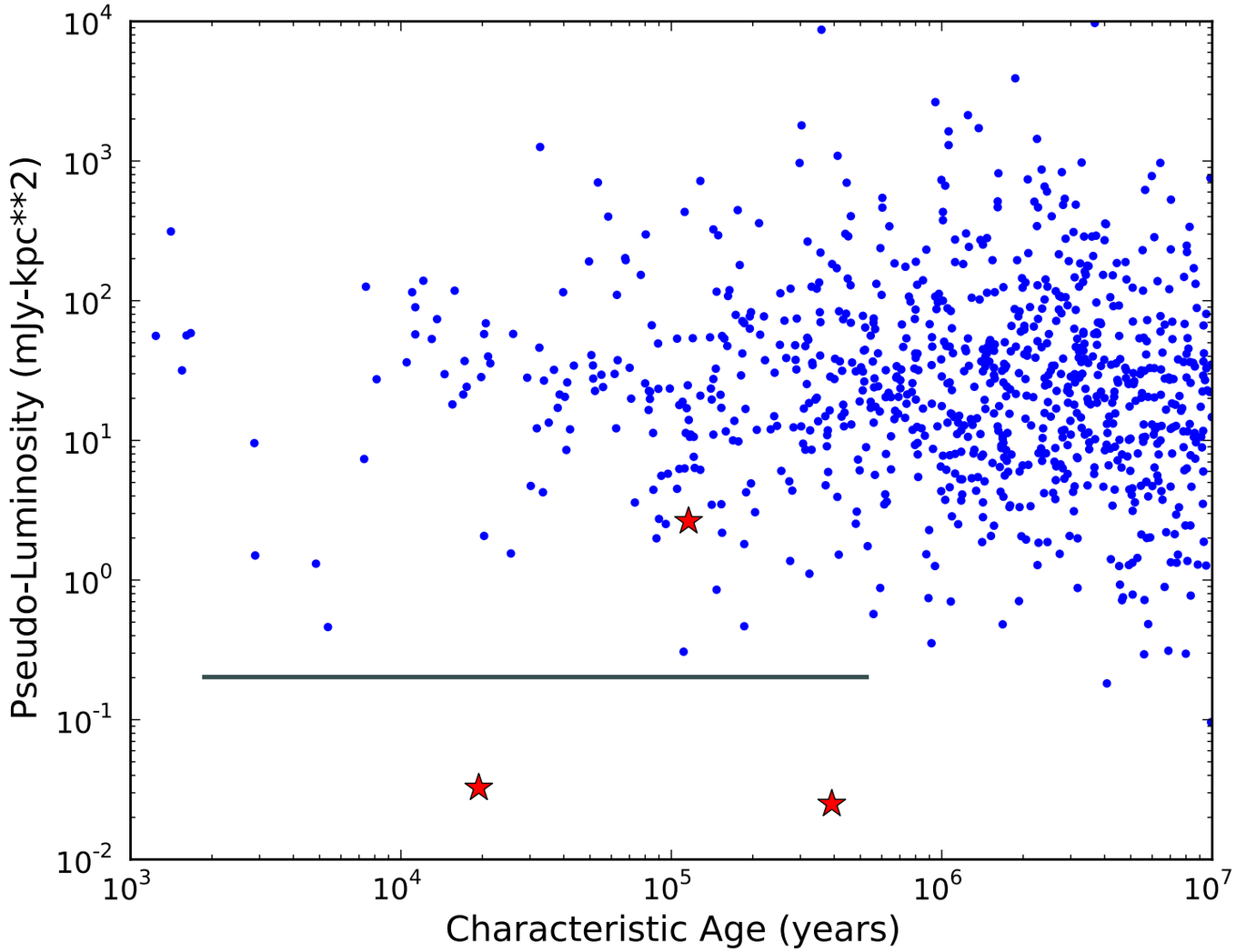
Vast majority would never have been found without Fermi

Radio Fluxes and Upper Limits



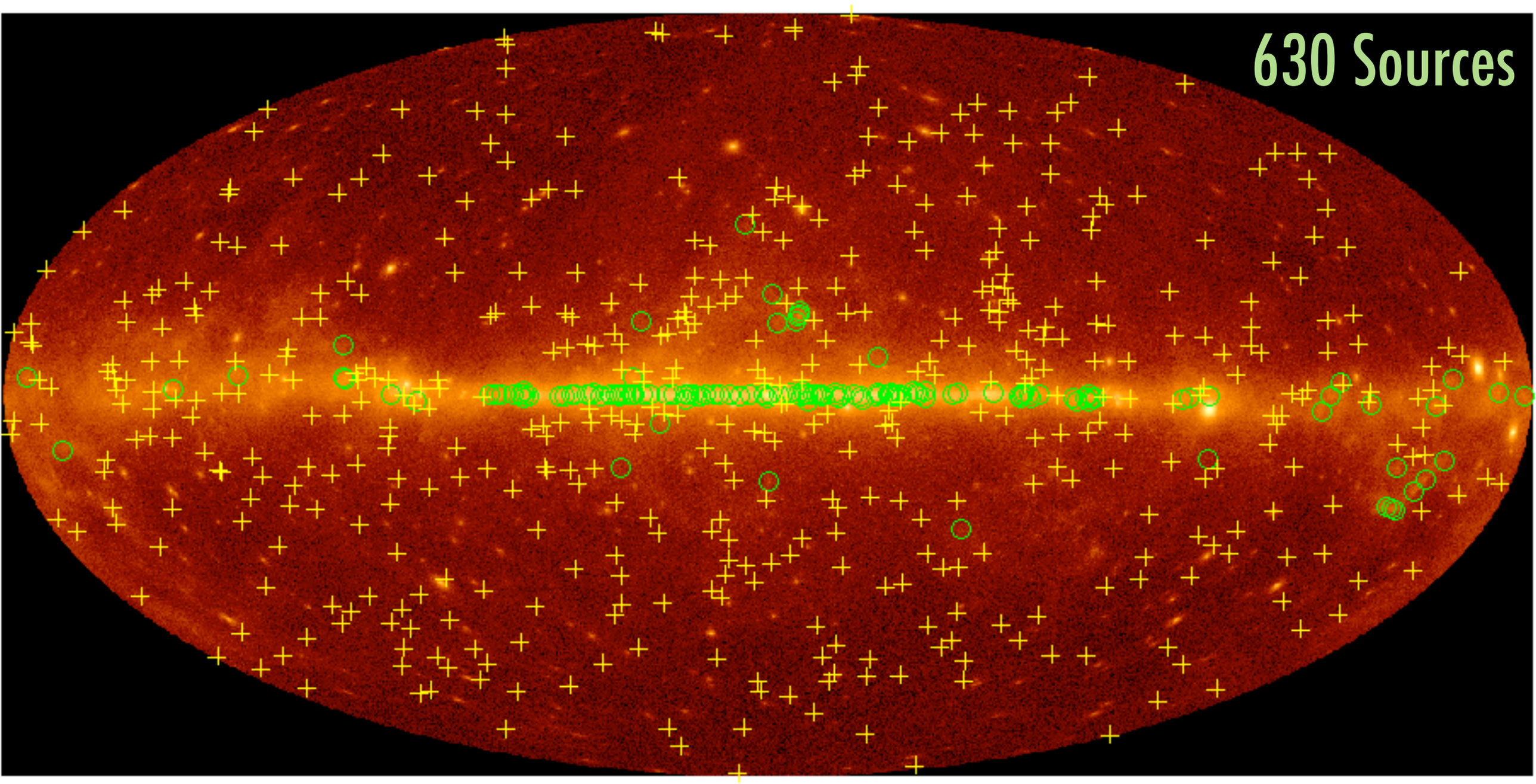
Radio Luminosities: How Faint is Faint?

Radio detections → distance from DM → luminosities



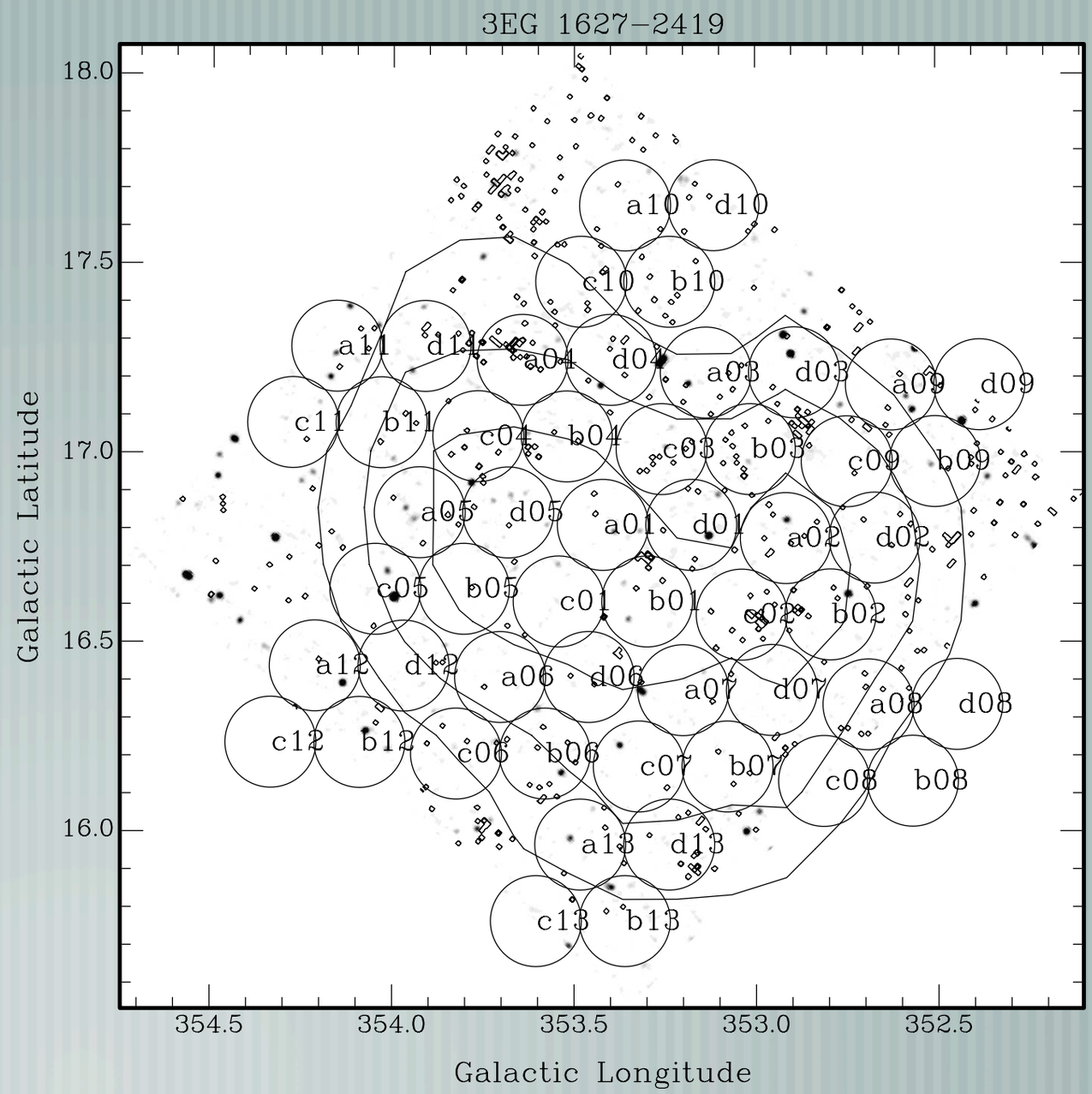
Interesting note: Geminga has a claimed detection at very low frequency (Malofeev & Malov, 1997). There is a renaissance in low frequency radio astronomy in progress, led by LOFAR, so confirmation and/or other discoveries are possible!

Unassociated Sources



Gamma-ray Sources as Pulsar Search Targets

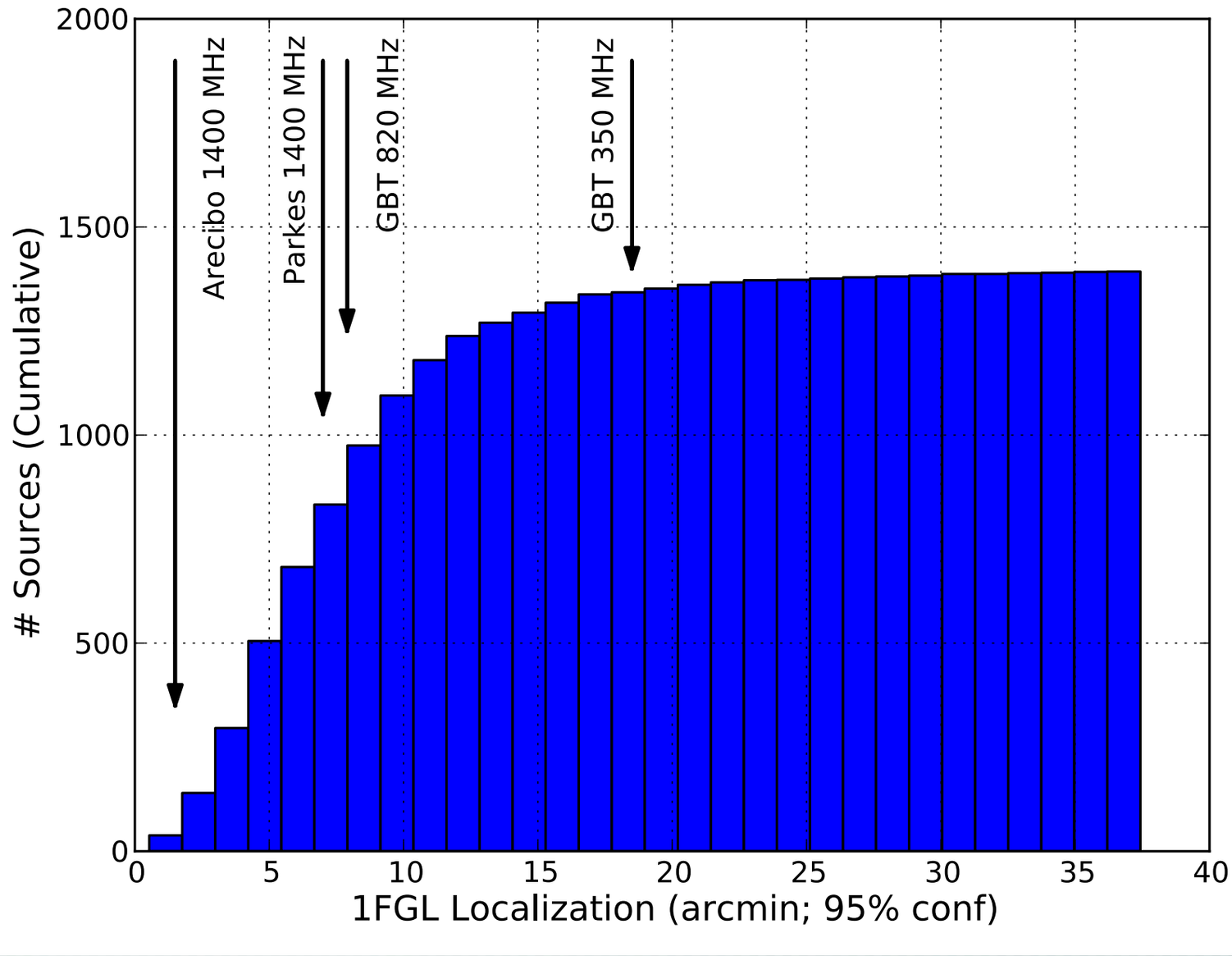
- Many searches were done of EGRET unidentified sources
- Lots of effort with modest success
- Hampered by poor localizations



Crawford et al. (2006, ApJ, 652, 1499)

LAT Sources as Pulsar Search Targets

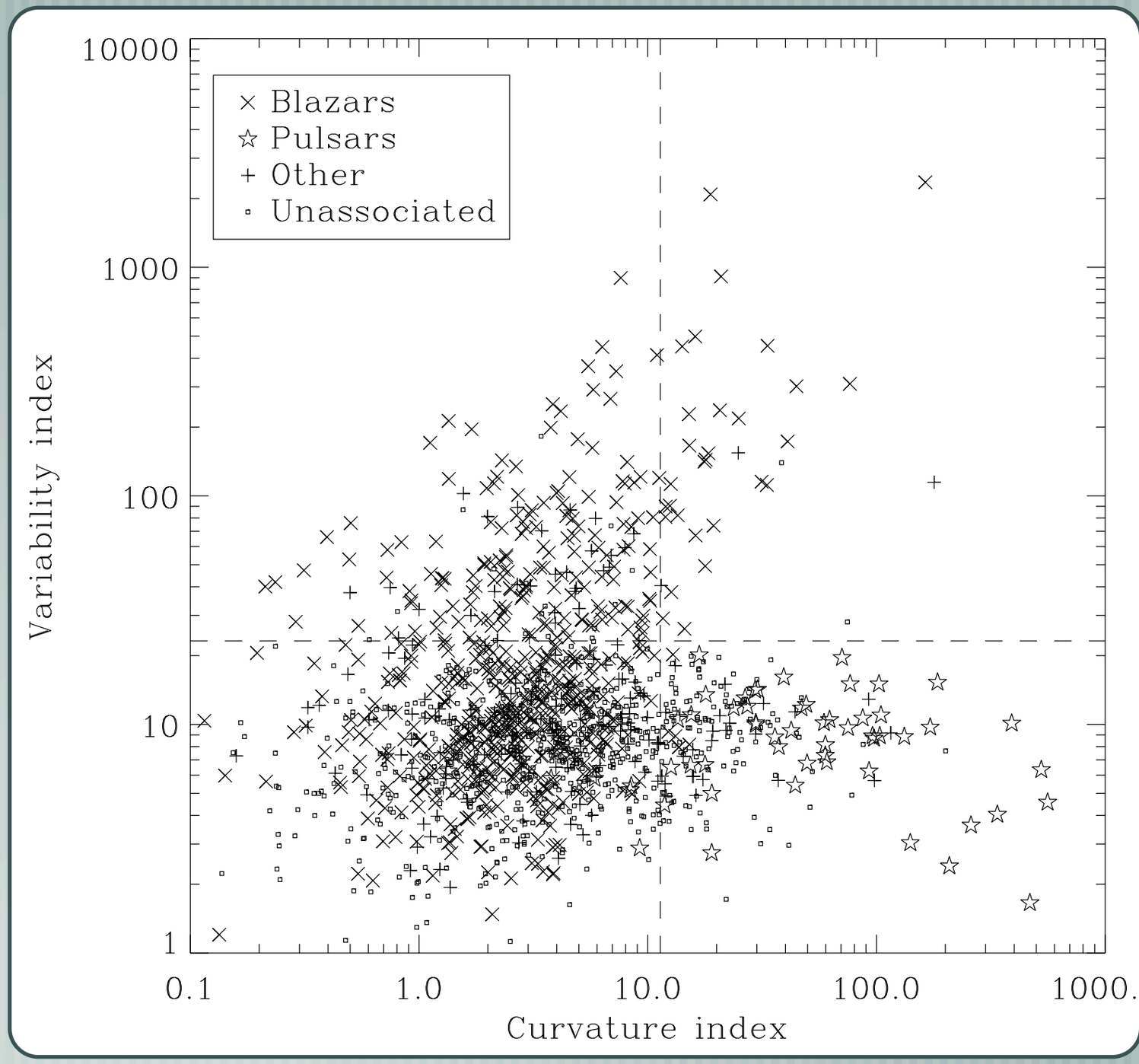
- LAT localizations make the job MUCH easier!
- Vast majority of 1FGL sources can have full 95% confidence region covered in a **single** pointing (with the right frequency choice)



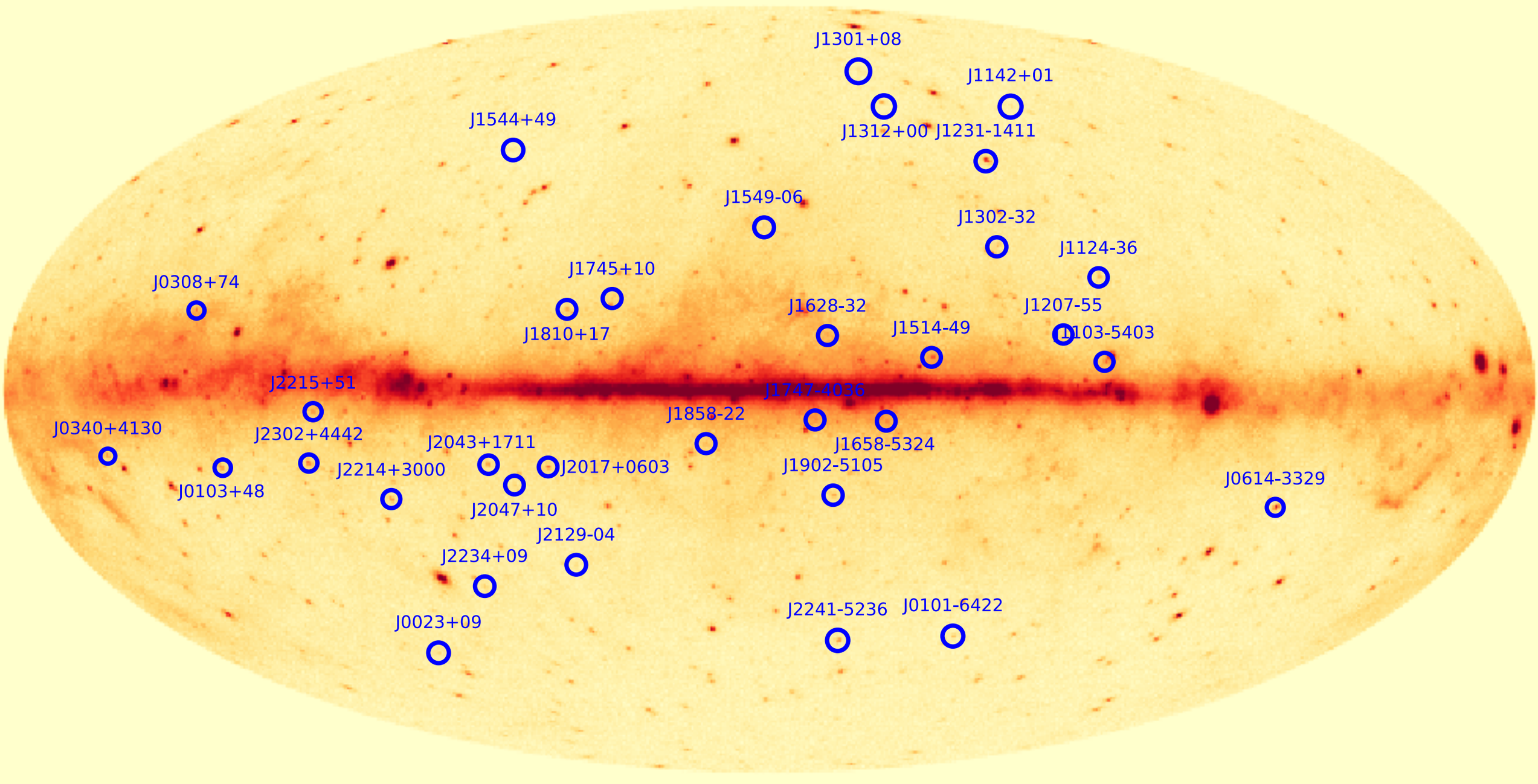
Using LAT to Find Radio Pulsars

- Best targets are sources with low variability and "pulsar-like" spectra
- Used multiple techniques for ranking sources
  - See UNASSOC source poster by Monzani
  - Visual inspection has been best technique

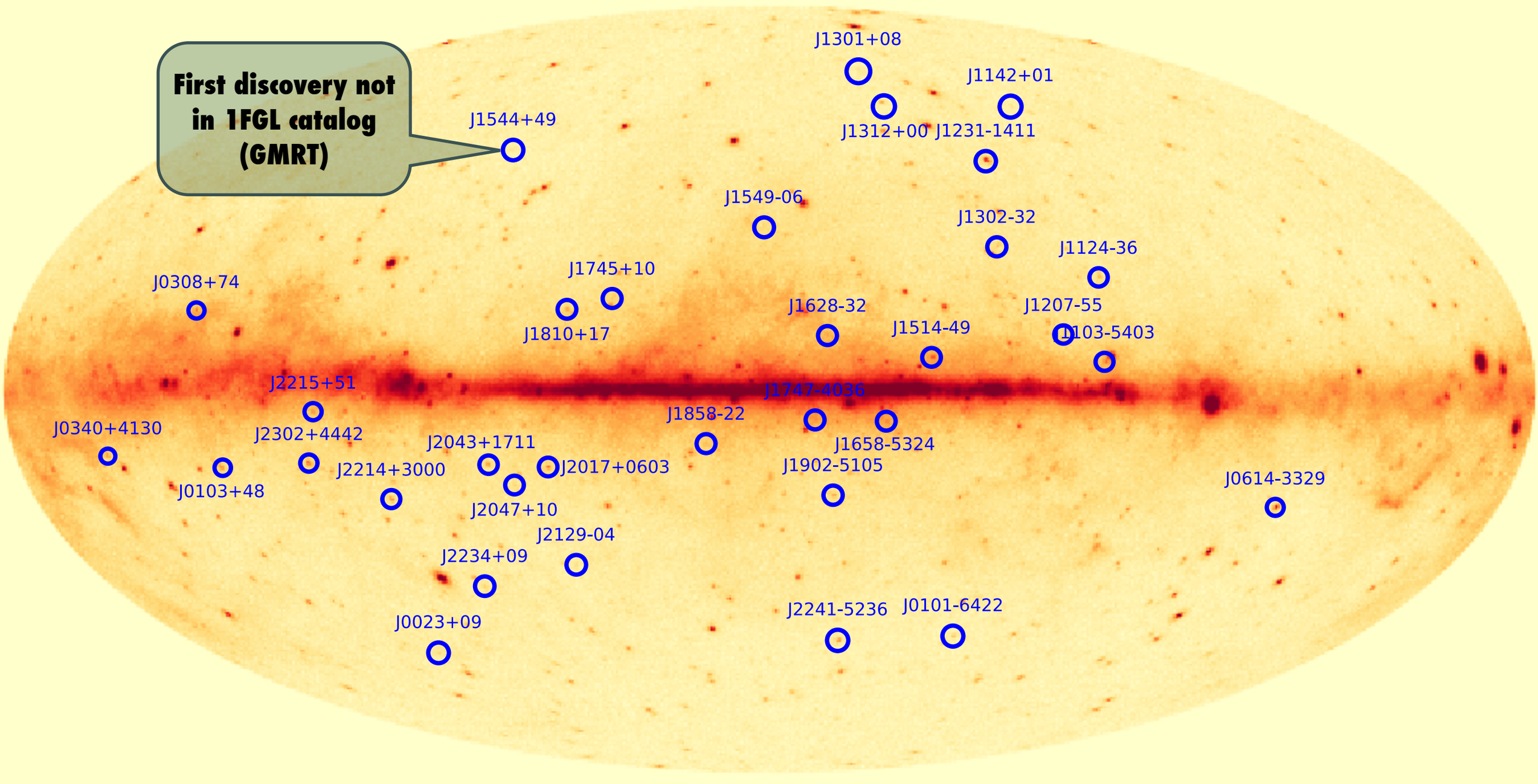
(Abdo et al. 2010, ApJS, 188, 405)



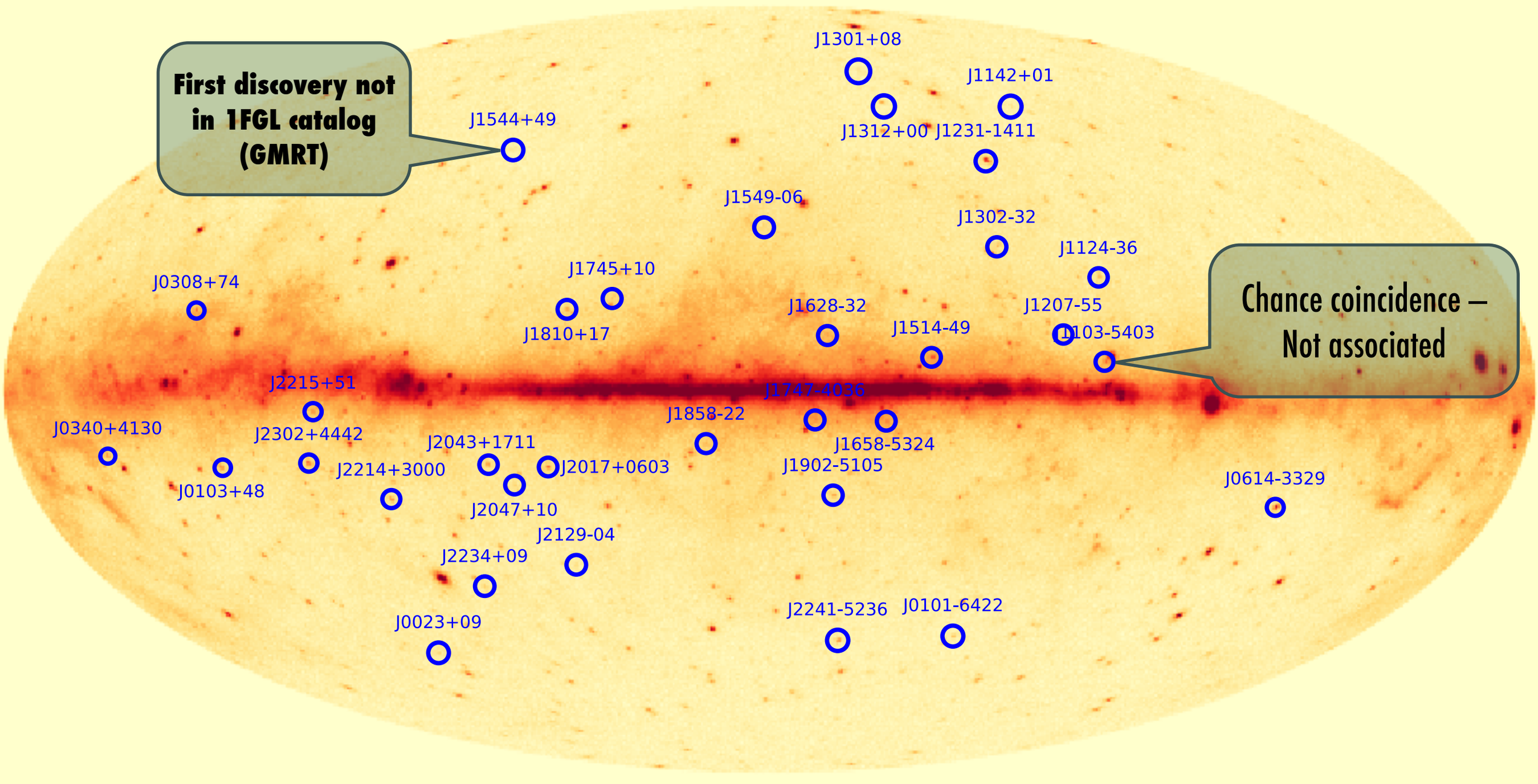
Success! 33 MSPs found!



Success! 33 MSPs found!



Success! 33 MSPs found!



PSC Searches of LAT UNASSOC Sources

Instrument	PI	# Sources	# MSP	# Normal PSR
GBT 820 MHz	Ransom	25	3	
Nançay 1.4 GHz	Cognard	13	3	
Parkes 1.4 GHz	Keith	11	2	1
GBT 350 MHz	Roberts	48	10	
Parkes 1.4 GHz	Camilo	30	5	
Arecibo 327 MHz	Freire	22	[2]	
Effelsberg 1.4 GHz	Kramer	~200	1	
GBT 2.0 GHz	Camilo	3		1
Parkes 1.4 GHz (II)	Keith	52	1	
GBT 820 MHz (II)	Ransom	81	6	
GMRT 610 MHz	Bhattacharyya/Roy	40	2	
			33	2

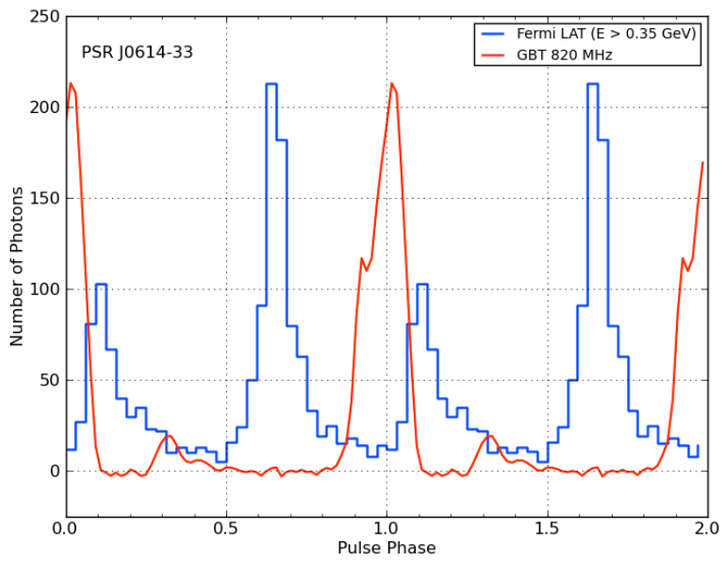
Exciting Discoveries

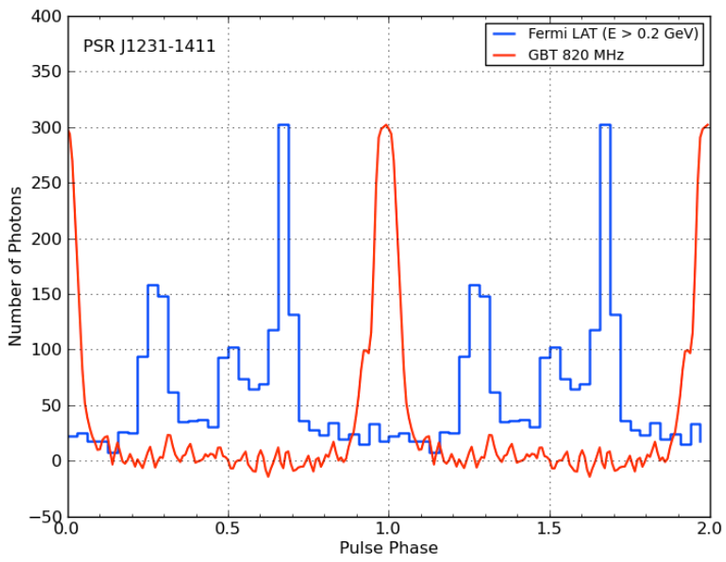
- **Many** unassociated high-Galactic latitude sources that are non-variable are millisecond pulsars!
- At least **nine** new "Black Widow" systems (only 3–4 previously known outside of globular clusters) found in these searches
  - Much larger fraction than in typical surveys. Why?
  - Plus, **two** new "Redbacks" that are eclipsing but with a more massive companion (~0.2 Msun). Probably a cousin of the missing link pulsar J1023+0038

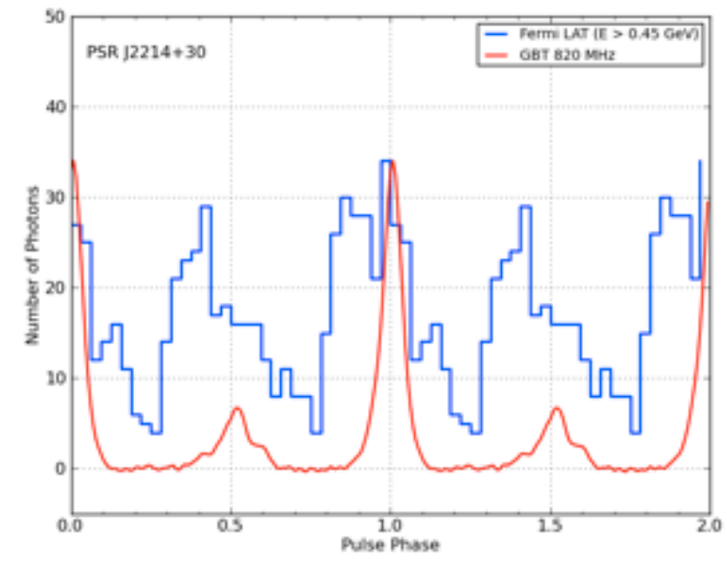
See poster by Hessels

- Several are very bright and may be great additions to pulsar timing arrays
- Since they are all coincident with LAT pulsar-like point sources, we expect to find GeV pulsations from them (except one chance coincidence)

Twelve Now Have LAT Detections!







P_{psr} =	3.15 ms	3.68 ms	3.12 ms
P_{orb} =	53.6 days	1.86 days	0.42 days
$M_{c,min}$ =	0.28 $M_\odot$	0.19 $M_\odot$	0.014 $M_\odot$
Dist	1.9 kpc	0.4 kpc	1.5 kpc
Age	2.8 Gyr	3.1 Gyr	3.6 Gyr
B	2.4×10^8 G	2.6×10^8 G	2.1×10^8 G
Edot	2.3×10^{34} erg/s	1.5×10^{34} erg/s	1.8×10^{34} erg/s
F(>100 MeV)	8×10^{-8} ph/cm^2/s	1×10^{-7} ph/cm^2/s	5×10^{-8} ph/cm^2/s
Notes:	**Two brightest gamma-ray MSPs**		**Black Widow**

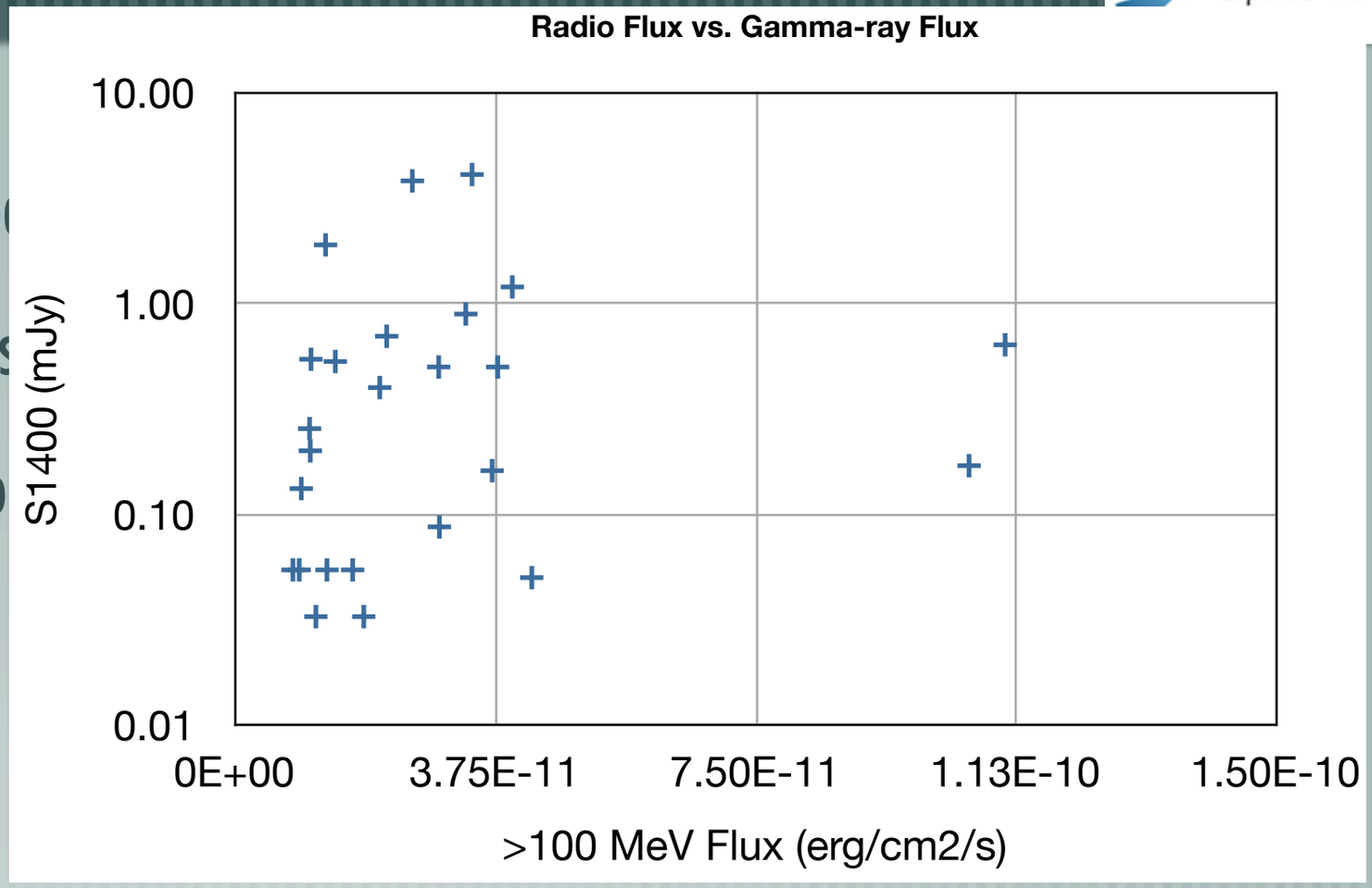
(Ransom et al. 2011, ApJL, 727, L16)

Future Expectations

- Searches of LAT unidentified sources ongoing
  - 2FGL catalog analysis has given us a bunch of new targets
  - Re-observations are important due to eclipses, scintillation, unknown pulsar spectra, RFI, etc...
  - Radio flux not correlated with gamma-ray so plenty more to find
- Timing results take time
  - Need about a year to get orbit, position, period derivative
  - Evaluating pulsar timing array potential and getting proper motions (for Shlovskii effect) takes longer

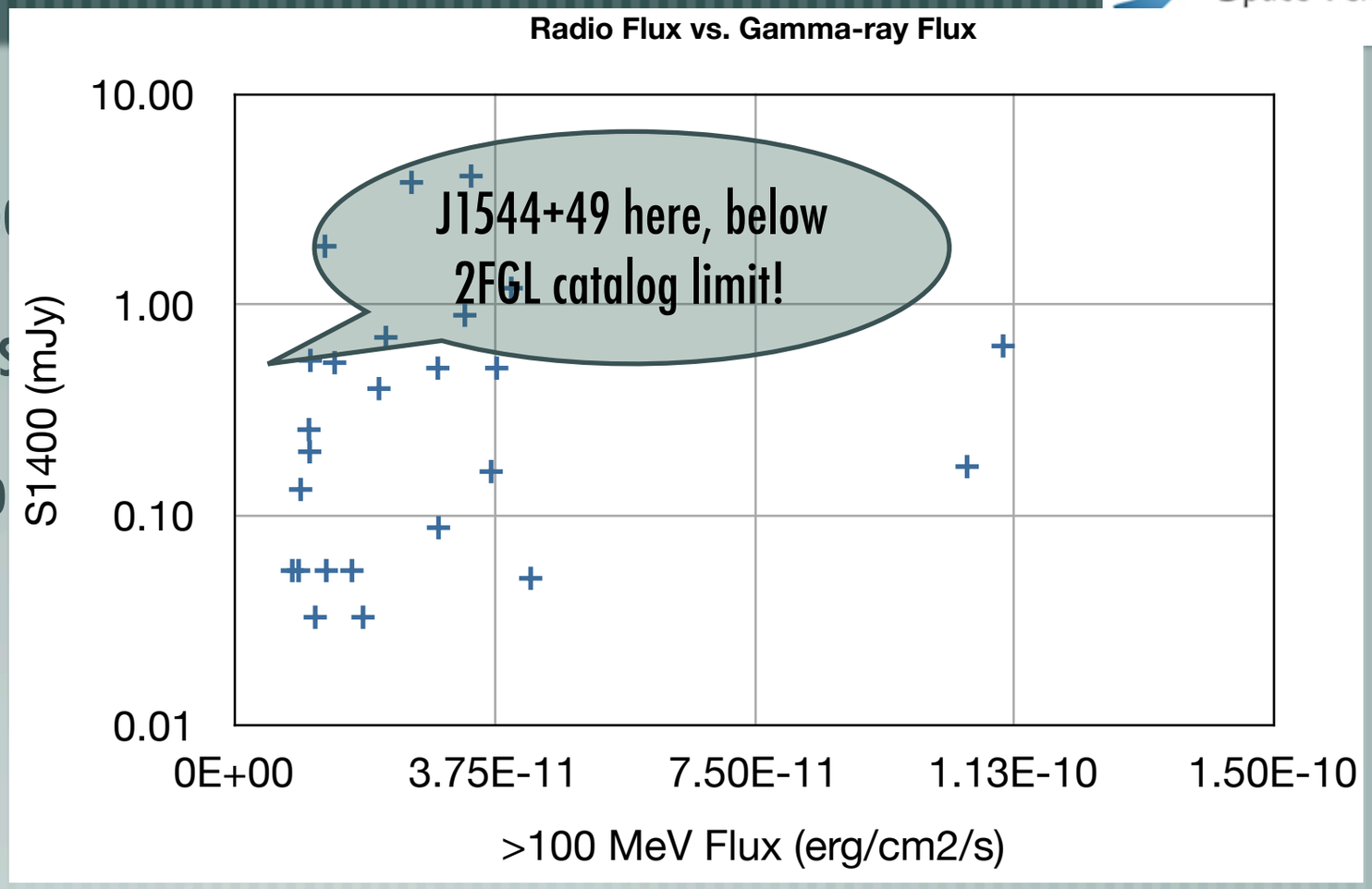
Future Expectations

- Searches of LAT unidentifie
  - 2FGL catalog analysis has
  - Re-observations are impo pulsar spectra, RFI, etc...
  - Radio flux not correlated
- Timing results take time
  - Need about a year to get orbit, position, period derivative
  - Evaluating pulsar timing array potential and getting proper motions (for Shlovskii effect) takes longer



Future Expectations

- Searches of LAT unidentifie
  - 2FGL catalog analysis has
  - Re-observations are impo pulsar spectra, RFI, etc...
  - Radio flux not correlated
- Timing results take time
  - Need about a year to get orbit, position, period derivative
  - Evaluating pulsar timing array potential and getting proper motions (for Shlovskii effect) takes longer

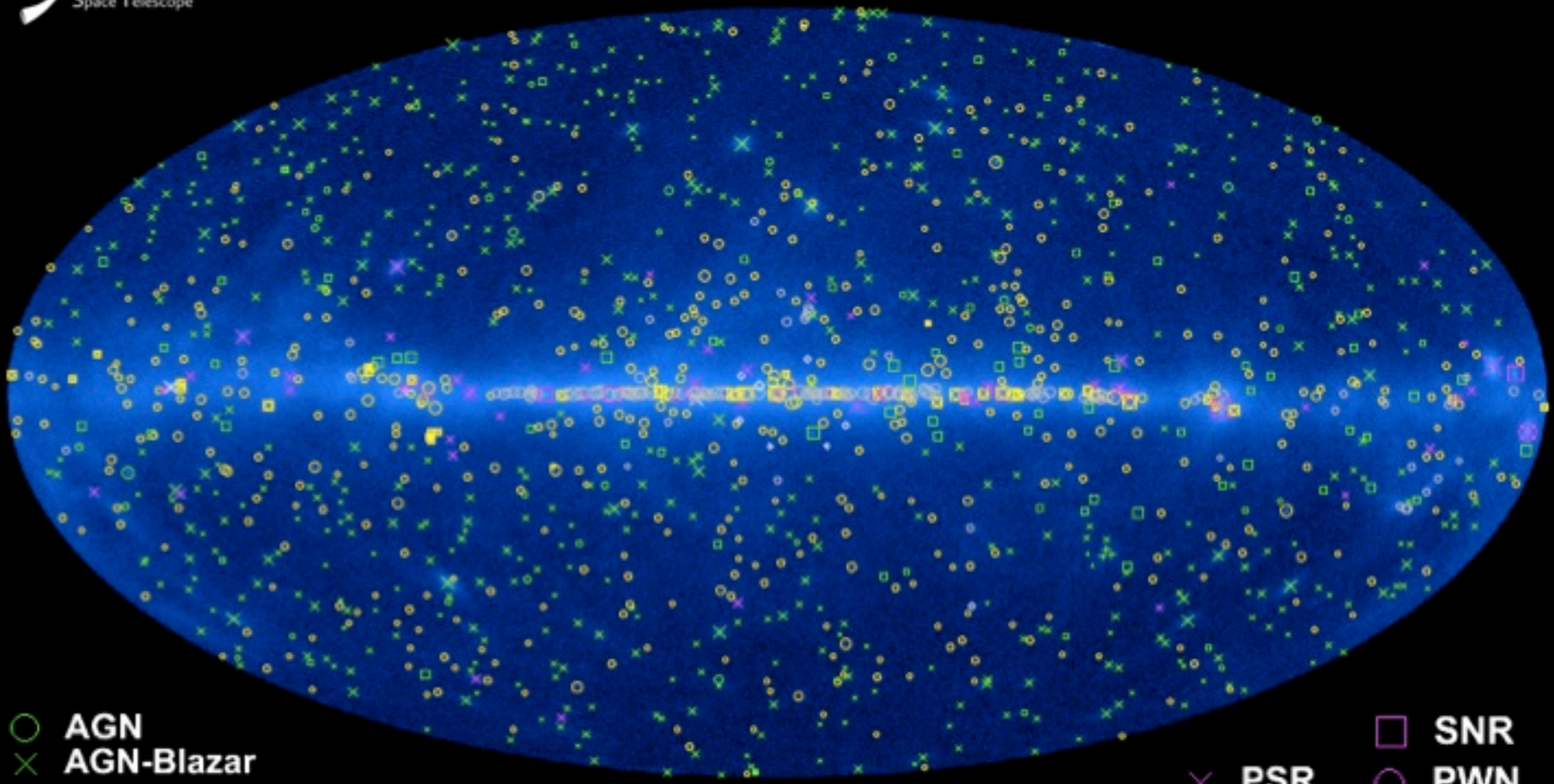


BACKUPS

The Fermi LAT 1FGL Source Catalog

1451 Sources

Fermi Gamma-ray Space Telescope



- AGN
- AGN-Blazar
- AGN-Non Blazar
- No Association
- Possible Association with SNR and PWN
- Possible confusion with Galactic diffuse emission
- Starburst Galaxy
- Galaxy
- SNR
- PSR
- PWN
- PSR w/PWN
- Globular Cluster
- HXB or MQO

Credit: *Fermi* Large Area Telescope Collaboration

Associations with Likely Counterparts

Source class	Sources at |b| >10°	Sources at |b| <10°	Ridge[a] sources
Associated	**670**	**151**	**31**
AGN	642	51	1
Pulsars	16	47	11
SNRs/PWNe	1	45	19
Other	11	8	0
Unassociated	**373**	**257**	**88**
Point sources	354	139	0
C-sources	19	118	88

Acknowledgements

The *Fermi* LAT Collaboration acknowledges generous ongoing support from a number of agencies and institutes that have supported both the development and the operation of the LAT as well as scientific data analysis. These include the National Aeronautics and Space Administration and the Department of Energy in the United States, the Commissariat à l'Energie Atomique and the Centre National de la Recherche Scientifique / Institut National de Physique Nucléaire et de Physique des Particules in France, the Agenzia Spaziale Italiana and the Istituto Nazionale di Fisica Nucleare in Italy, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), High Energy Accelerator Research Organization (KEK) and Japan Aerospace Exploration Agency (JAXA) in Japan, and the K. A. Wallenberg Foundation, the Swedish Research Council and the Swedish National Space Board in Sweden.

Additional support for science analysis during the operations phase is gratefully acknowledged from the Istituto Nazionale di Astrofisica in Italy and the Centre National d'Etudes Spatiales in France.

This work is performed under contract with NRL, contract N00173-08-2-C004

Three Ways to Detect Pulsars with the LAT

- Folding gamma-ray photons according to a known pulsar timing model, from radio or X-rays
- Blind searches for pulsations directly in the gamma-ray data
- Radio pulsar searches of LAT unidentified sources

Only this today!

You Can Join The Fun!

- LAT data are all public
  - All data available at the FSSC http://fermi.gsfc.nasa.gov/ssc/
  - New data added very soon after they are taken (~1 day)
- Science Tools available
  - gtbary for barycentering or geocentering
  - TEMPO2 plugin for assigning phases
  - Other contributions in FSSC User Contributions area:
    - http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/