Radio Searches of Fermi Blind Search Pulsars and Unassociated Sources

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Fermi Pulsar Search Consortium (PSC)

**Purpose:** To organize deep radio searches of the blind search pulsars and unidentified LAT sources

Fermi LAT members:


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


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

Fig. 3.— Phase-aligned Fermi and GBT pulse profiles of PSR J1741–2054. In the upper panel, the radio profile is displayed with an arbitrary intensity scale along with LAT counts in the 0.2–1.0 GeV band. The bottom panel shows the higher-energy LAT counts and a comparison between the two panels shows clear evolution of the peak structure (P1 weakening, P3 strengthening) with energy. At the highest energies (>3 GeV), P3 dominates. The displayed gamma-ray and radio profiles have, respectively, 32 and 128 bins per period. Two full rotations are shown.

Fig. 5.— Phase-aligned GBT and Fermi pulse profiles of PSR J2032+4127. The gamma-ray peaks are modeled as Gaussians of, respectively, FWHM/P = 0.026 ± 0.003 and 0.051 ± 0.005. The radio profile is displayed with an arbitrary intensity scale. The radio and gamma-ray profiles are displayed with, respectively, 256 and 32 bins per period. Two full rotations are shown.

Camilo et al. (2009)
Abdo et al. (2010)
Three Discoveries of Radio Pulsations

Vast majority would never have been found without Fermi
Radio Fluxes and Upper Limits
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

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

For each trial DM, we summed the frequency channels with appropriate delays to create a time series. The time series was then Fourier transformed using a fast Fourier transform (FFT), and a red noise component of the power spectrum (i.e., low-frequency noise in the data) was removed. This was done by dividing the spectral powers by the local median of the power spectrum, increasing the number of bins used in the average logarithmically with frequency. We masked known interference signals in the power spectrum, corresponding to less than 0.05% of the spectrum, and used harmonic summing with up to 8 harmonics to enhance sensitivity to highly nonsinusoidal signals. In the acceleration search, we were sensitive to signals in which the fundamental drifted linearly by up to 100 Fourier bins during the course of the observation, providing sensitivity to pulsars in tight binaries; the maximum detectable acceleration was $a_{\text{max}} = 6.8 \times 10^{-5} \text{ms}^2/C_0^2$, where $P$ is the pulsar spin period in milliseconds. This is about 40% of the maximum acceleration searched in the Parkes Multibeam Survey processing, which used a segmented linear acceleration search (Faulkner et al. 2004; Lyne 2005). We estimate that our acceleration search would have been sensitive to all but one of the known pulsars in double neutron star binary systems (the one exception being PSR J0737$-3039$). We performed folding searches around candidate periods and period derivatives and examined the results by eye. The characteristic signal of interest was a dispersed, wideband, extremely regular series of pulsations.

Averaged over the survey, the sensitivity to pulsars in an RFI-free environment was $0.2 \text{mJy}$ for most periods and DMs (see Fig. 3). The sensitivity calculation is outlined in Crawford (2000) and Manchester et al. (2001) and was determined for ab lindefault search. RFI tends to introduce sporadic, highly variable red noise in the power spectra, especially at low dispersion measures (DM $\leq 10 \text{pc cm}^{-3}$). Therefore, sensitivity to slow pulsars ($P \leq 200 \text{ms}$) with low DMs is reduced in a way that is difficult to quantify. In addition, the DM peaks of long-period pulsars are broader than those of MSPs and hence are more difficult to distinguish from zero DM when the DM is very low. During this first processing run, we discovered Fig. 2.—Target EGRET source 3EG J1627$-2419$, showing the $\gamma$-ray error box (contour lines), the multibeam survey coverage in our search for radio pulsations (circles), X-ray emission from the ROSAT All-Sky Survey (pixelated squares), and 1.4 GHz emission from the NRAO VLA Sky Survey (gray scale) (Condore et al. 1998). The radio and X-ray images were obtained from NASA’s SkyView facility (http://skyview.gsfc.nasa.gov). The contours represent 68%, 95%, and 99% uncertainties in the $\gamma$-ray source position, and the circles indicate the Parkes half-power beam size. Four tiled multibeam pointings are shown (labeled a, b, c, and d) with 13 beams each.

See the electronic edition of the Journal for a color version of this figure.

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

Success! 33 MSPs found!
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First discovery not in 1FGL catalog (GMRT)
Success! 33 MSPs found!

First discovery not in 1FGL catalog (GMRT)

Chance coincidence — Not associated
<table>
<thead>
<tr>
<th>Instrument</th>
<th>PI</th>
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<th># MSP</th>
<th># Normal PSR</th>
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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!

Two brightest gamma-ray MSPs

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
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[Graph: Radio Flux vs. Gamma-ray Flux]

- S1400 (mJy)
- >100 MeV Flux (erg/cm²/s)
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BACKUPS
| Source class       | Sources at $|b| > 10^\circ$ | Sources at $|b| < 10^\circ$ | Ridge$^a$ sources |
|-------------------|----------------|----------------|-----------------------------|
| Associated        | 670            | 151            | 31                          |
| AGN               | 642            | 51             | 1                           |
| Pulsars           | 16             | 47             | 11                          |
| SNRs/PWNes        | 1              | 45             | 19                          |
| Other             | 11             | 8              | 0                           |
| Unassociated      | 373            | 257            | 88                          |
| Point sources     | 354            | 139            | 0                           |
| C-sources         | 19             | 118            | 88                          |
Acknowledgements

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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/