Five New Millisecond Pulsars From a Parkes Survey of LAT Sources

Matthew Kerr (KIPAC/Stanford U.) and Fernando Camilo (Columbia U.)
on behalf of the Fermi LAT Collaboration and the Pulsar Search Consortium

Millisecond pulsars (MSPs) have a large scale height, and undirected, deep radio searches for them require a prohibitive amount of telescope time. The Fermi Large Area Telescope (LAT) surveys the entire sky and has proven sensitive to nearby MSPs. Focusing radio pulsar searches on unidentified LAT sources whose spectra resemble those of known MSPs is an efficient search method. We report here the discovery of 5 MSPs in a survey of 14 promising southern LAT sources. We have obtained a timing solution for one of them, PSR J0101-6422, and subsequently detected gamma-ray pulsations.

Target Selection and Observations

The spectra of MSPs are well-described by exponentially-cutoff power laws, $\frac{dN}{dE} = N_0 \left(\frac{E_0}{E}\right)^{\Gamma} \exp\frac{-E}{E_c}$. (See Figure 2 for an example.) For each source in the 1FGL catalog, we performed maximum likelihood fits to determine the spectral parameters, position, and spectral energy density. By eye, we ranked sources without known blazar counterparts by how well their spectra resembled those of known pulsars. Roughly, the highly-ranked sources satisfied $1 < \Gamma < 2$ and a possessed a statistically significant $E_c < 10$ GeV. We excluded sources whose localization uncertainty exceeded the Parkes 1.4 GHz beam, about 14'. Finally, we excluded sources too close to the confused Galactic plane, where spectral estimation becomes difficult, and those north of Decl. -40, at which latitude sources become visible to the more sensitive Green Bank Telescope.
In total, we observed 14 targets for 1-2 hours with the 1.4 GHz receiver of the 64m Parkes radiotelescope and discovered 5 MSPs; a sixth was discovered independently.

New Millisecond Pulsars

The targets along with the observed coordinates and total integration times; MSP detections highlighted.

1FGL Name	R.A. J2000.0	Decl. J2000.0	Obs. Time hr	Period ms	DM $pc\,cm^{-3}$	DM Distance[a] kpc	Binary
J0101.0-6423	$01^h00^m58^s$	$-64°24'03''$	1.0	2.57	11.93	0.6	yes
J0933.9-6228	$09^h33^m58^s$	$-62°27'54''$	2.0	—	—	—	—
J0603.0-4012	$06^h03^m04^s$	$-40°11'02''$	2.0	—	—	—	—
J1036.2-6719	$10^h36^m16^s$	$-67°20'34''$	2.0	—	—	—	—
J1227.9-4852	$12^h27^m50^s$	$-48°51'54''$	2.0	—	—	—	—
J1232.2-5118	$12^h31^m49^s$	$-51°18'50''$	2.0	—	—	—	—
J1514.1-4945	$15^h14^m05^s$	$-49°45'32''$	2.0	3.59	31.5	1.0	yes
J1624.0-4041	$16^h24^m06^s$	$-40°40'48''$	2.0	—	—	—	—
J1658.8-5317	$16^h58^m43^s$	$-53°17'45''$	1.3	2.44	30.9	0.9	no
J1743.8-7620	$17^h43^m44^s$	$-76°20'42''$	1.5	—	—	—	—
J1747.4-4035	$17^h47^m29^s$	$-40°36'07''$	1.4	1.65	152.9	3.3	no
J1902.0-5110	$19^h02^m05^s$	$-51°09'43''$	1.2	1.74	36.3	1.2	yes
J2039.4-5621	$20^h39^m30^s$	$-56°20'42''$	1.2	—	—	—	—
J2241.9-5236[b]	$22^h41^m52^s$	$-52°37'37''$	2.0	2.19	11	0.5	yes

(a) NE 2001 model (Cordes and Lazio 2002); uncertainty of order 30%.
(b) Discovered independently, see Keith et al. 2011.

Discussion and PSR J0101-6422

The estimated DM distances of ≈1 kpc or less for 5 of the 6 MSPs (including the independently-discovered PSR J2241-52) detected is consistent with our expectation that Fermi is highly sensitivity-limited and thus detects mainly the ~isotropically-distributed nearby MSPs. The larger implied distance for PSR J1747-40 suggest it boasts an appreciably greater spindown luminosity, in agreement with its very low period of 1.65 ms. Further and deeper surveys will help determine more precisely how complete the sample of nearby radio- and gamma-loud MSPs is.

We have constructed a coherent timing solution for PSR J0101-6422 with 32 pulse times-of-arrival (TOAs) spanning 16 months. This interval is long enough for a robust estimation of the pulsar's spindown luminosity, $\dot{E} = 1.1 \times 10^{34}$ erg/s, and binary parameters. The binary period, 1.79 days, and the relatively small mass function, 1.65×10^{-3} solar masses, imply a companion mass of between 0.16 and 0.54 solar mass. The low eccentricity, $< 1.2 \times 10^{-5}$, and binary period suggest the companion is a light helium white dwarf.

The timing solution allows a coherent fold of all LAT photons collected since the instrument began routine data taking in Aug. 2008. We detected highly-significant modulation in the folded gamma-ray data; the resulting light curve, with absolute phase alignment to within $\delta\phi < 0.01$, is shown in Figure 1.

A detailed characterization of the emission geometry of PSR J0101-6422 awaits a careful analysis of radio polarimetry. However, from the peak structure, we can draw a rough picture in which the first radio peak at $\phi = 0.5$ is emitted from one hemisphere of the magnetosphere while the two gamma-ray peaks and bright radio peak are produced in the opposite hemisphere, consistent with radio emission from a lower altitude than gamma-ray emission.

The phase-averaged spectral energy density is shown in Figure 2. The associated gamma-ray flux is $F_\gamma \approx 1.3 \times 10^{-11}$ erg/cm^2/s. At the DM distance, this implies an isotropic gamma-ray luminosity $L_\gamma \approx 5 \times 10^{32}$ erg/s, 4% of the spindown luminosity. This is a lower limit to the efficiency, as the Shklovskii effect, currently unmeasured, enhances the magnitude of the observed frequency/period derivative (Camilo, Thorsett, and Kulkarni 1994).

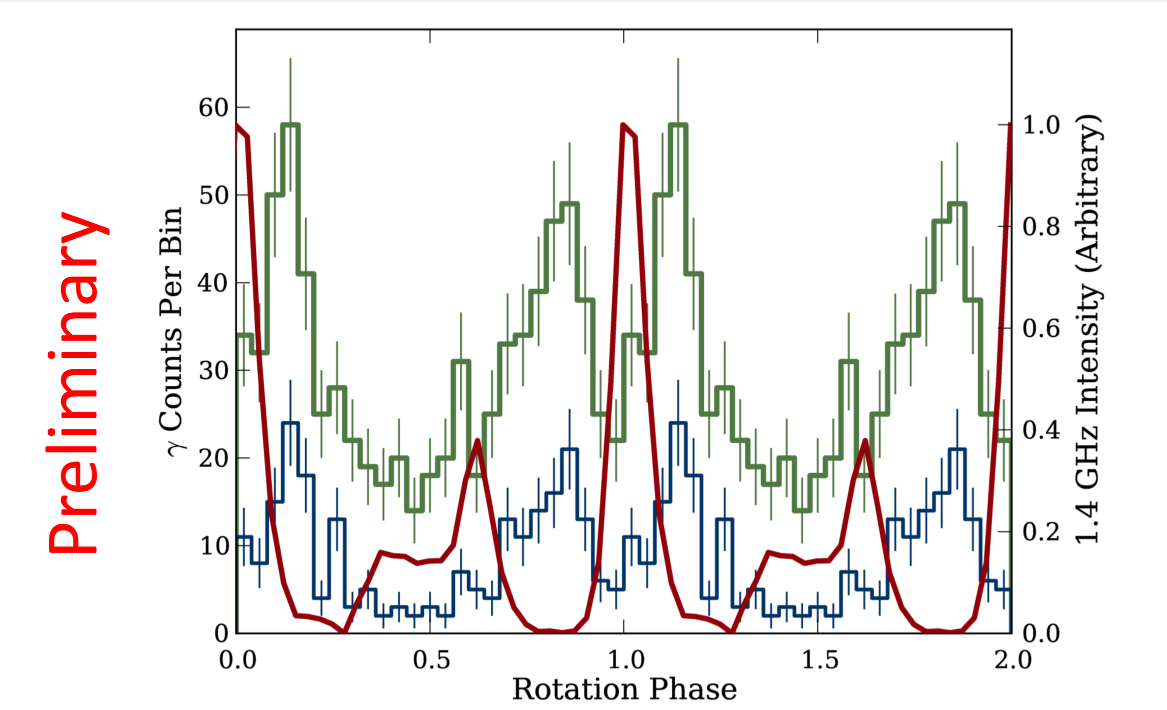

Figure 1: *Radio (red); all gamma rays (0.3 GeV < E < 3 GeV; green); high-energy gamma rays (1 GeV < E < 3 GeV; blue).*

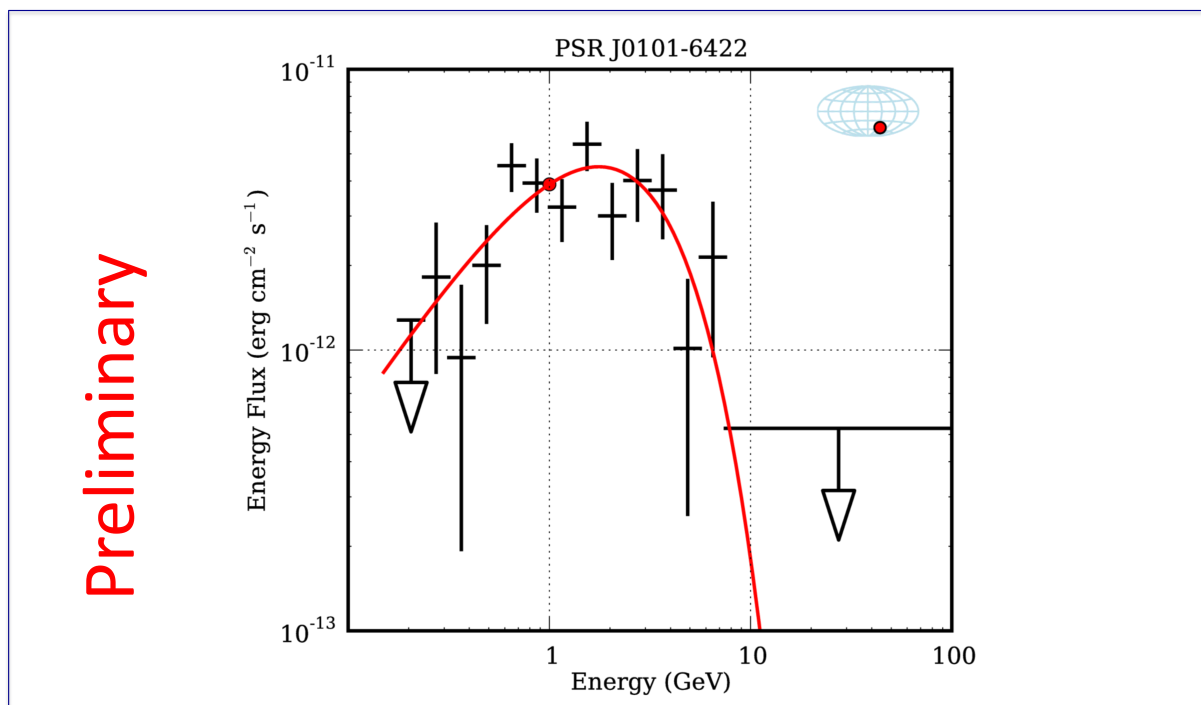

Figure 2: *Spectral energy distribution of the MSP J0101-6422. Only a handful of photons are detected above 3 GeV. Pass 6 data through 30 Mar, "diffuse" class, energy > 178 MeV, P6_V11 IRF.*

Conclusions

The discovery of 5 (6) field MSPs, an increase of about 5% to the existing population, with only 25 hours of radiotelescope time is exceedingly efficient. The new pulsars will help elucidate the mechanisms by which radio and gamma-ray emission are produced, and these observations will also provide insights and constraints on the evolution of binary systems in the Galactic field. Finally, securing firm identifications for these LAT sources is leading to a better understanding of the gamma-ray sky.

References

Camilo, F., Thorsett, S.E., Kulkarni, S.R., ApJL 421 1994
Cordes, J. M., & Lazio, T. J. W. 2002, **arXiv:astro-ph/0207156**
Keith, M. J., et al. 2011, **arXiv:1102.0648**