Faint *Fermi*-LAT Gamma-ray Pulsars Using Radio Ephemerides

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Abstract

Gamma-ray pulsations from 145 pulsars (May 2013) have been detected with the Large Area Telescope (LAT) on board the *Fermi* satellite since June 2008. Of these, 125 are listed at the LAT public web page [2] including 117 objects detailed in the Second *Fermi*-LAT Catalog of Gamma-ray Pulsars [3]. Analysis and publication of new LAT pulsars is ongoing, but clearly the bright gamma-ray pulsars have been studied. Discovering new pulsars requires special care to extract faint signals. Pulsation Search Using Ephemerides (PSUE) of known radio/X-ray pulsars has been an efficient method and has permitted more than 88 detections. The rest are discovered either by blind period searches of the gamma-ray data or through deep radio observations of unidentified LAT sources followed by PSUE. We report here the discovery of several new PSUE gamma-ray pulsars and characterize their light curves and spectral properties.

Introduction

Figure 1 shows the classical pulsar period vs. period derivative plot with 117 gamma-ray pulsars in color presented in the Second *Fermi* Catalog of Gamma-ray pulsars [3]. Six more pulsars reported here have been detected using radio ephemerides and are highlighted with arrows and their names.

Table 1 lists the six new gamma-ray pulsars with their general properties from ATNF [4] along with the **PRELIMINARY** *Fermi*-LAT timing and spectral analysis results. Except for J1732-5049, the pulsars have benefited from regular radio timing [1] which provides ephemerides used to "phase-fold" gamma-ray photons. Besides the updated ephemerides used, these detections also benefit from the use of ***reprocessed*** LAT data [5] of improved quality.

J1732-5049 is a special case. During the preparation of the *Fermi*-LAT all-sky gamma-ray source list using 4 years of reprocessed data, one source modeled with a pulsar spectral shape (Power law + exponential cutoff) has been found to be coincident with this radio pulsar. It is a PPTA pulsar observed by the Parkes radio telescope in Australia [6]. An ephemeris valid till Jan 2011 promoted this one to the LAT gamma-ray pulsar family.

The results reported here used reprocessed data covering Aug 4 2008 – Dec 12 2012 along with the corresponding internal preliminary P7REP_SOURCE_V13 Instrument Response Functions (IRFs) and 4 year diffuse models. Photons with energy of 100 MeV – 100 GeV are selected in the standard timing and spectral analysis. The "*" in Table 1 indicates an unreliable fit due to the pulsar's weakness. Distances (Dist 1 in Table 1) used to calculate the gamma-ray luminosity are all estimated from dispersion measure (DM) and may in some cases differ from the true distance significantly.

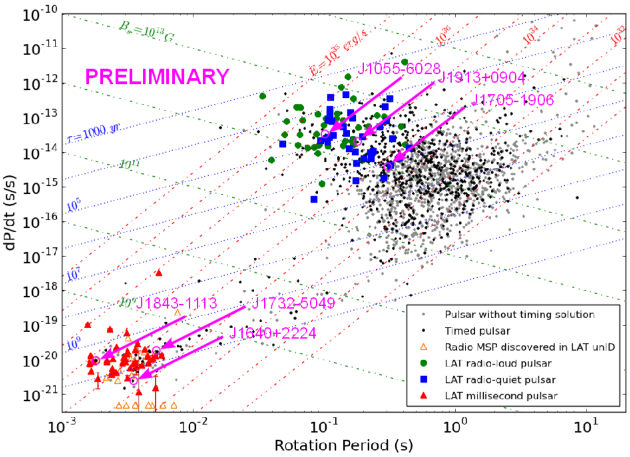
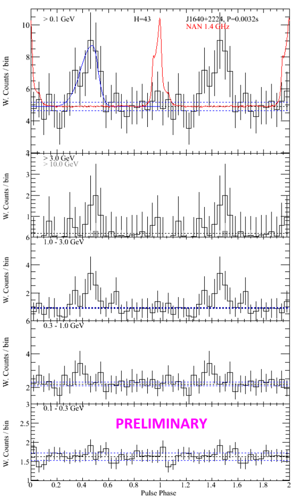


Figure 1: Pulsar P – Pdot distribution from [3] with *Fermi* gamma-ray pulsars in color and six new ones highlighted with arrows.

PSRJ	P (s)	Edot (erg s^{-1})	$\sqrt{\dot{E}/d^2}$ ($erg^{1/2}\ s^{-1/2}\ kpc^{-2}$)	Dist1 (kpc)	Gb (deg)	N_{peak}	Radio Lag δ	γ-ray peak sep. Δ	Photon flux (ph $cm^{-2}\ s^{-1}$)	Energy flux (erg $cm^{-2}\ s^{-1}$)	E_{cut} (GeV)	Γ	Luminosity (erg s^{-1})	Efficiency (%)
J1055-6028	0.0997	1.18E+36	4.51E+15	15.5	-0.745	1	0.426±0.019	...	3.4±1.9E-8	2.3±0.7E-11	5.2±1.8	1.9±0.3	6.6±2.1E35	56±17
J1640+2224	0.0032	3.53E+33	4.40E+16	1.16	38.271	1	0.474±0.026	...	2.9±1.1E-9	2.5±0.5E-12	*	*	4.0±0.8E32	11±2
J1705-1906	0.2990	6.11E+33	1.01E+17	0.88	13.026	1	0.569±0.008	...	*	2.2±1.8E-12*	4.4±2.7	2.0±0.5	2.0±1.7E32*	3.3±2.7*
J1732-5049	0.0053	3.74E+33	3.08E+16	1.41	-9.454	2*	0.555±0.031	0.184±0.032	...	< 8E-12 (†)	...	...	< 1.9E33	< 51
J1843-1113	0.0018	6.02E+34	8.48E+16	1.7	-3.397	1	0.085±0.005	...	6.0±0.5E-8	1.9±0.1E-11	*	*	6.7±0.4E33	11.1±0.7
J1913+0904	0.1632	1.60E+35	4.43E+16	3	-0.684	2	0.206±0.005	0.413±0.008	3.6±0.7E-8	2.6±0.3E-11	0.9±0.2	1.1±0.3	2.8±0.4E34	17±2

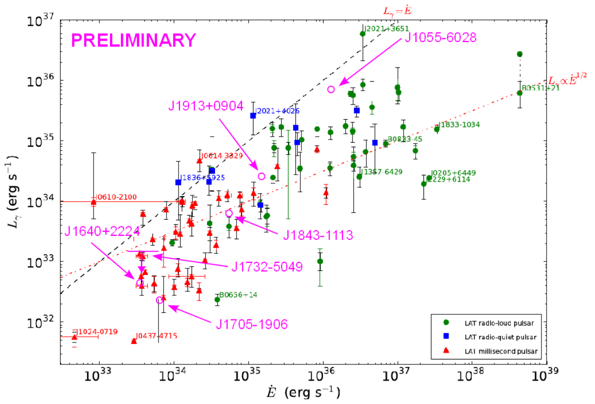
Table 1: Properties of six new radio-selected gamma-ray pulsars. (†): from Figure 17 in [3].

Detection and Light Curves



Pulsations are searched by phase-folding gamma-ray photons from within 2° of the radio pulsar position. The measured spectrum convoluted with the energy dependent Point Spread Function gives weights representing the probability that the photon originates from the pulsar. A 5σ confidence level is required to declare the detection. At left are the weighted light curves for PSR J1640+2224. Black is for gamma rays, red is the radio profile and blue is the gamma-ray light curve fit with a Gaussian or a Lorentzian distribution. Such fits give the gamma-ray peak number N_{peak}, gamma-radio lag δ and gamma peak separation Δ in the case of two peaks in Table 1. Blue dotted horizontal lines indicate the estimated background level and uncertainties.

Spectral analysis and gamma-ray Luminosity



The spectral analysis uses photons within 15° of each pulsar position. A preliminary 4 year source list is used as input model and the spectral parameters of sources within 5° are left free to refit. To benefit from a higher signal-to-noise ratio for these weak pulsars, analysis has been performed with only the on-peak data, normalizing to all pulsar phases.

The figure, above, from [3] shows the gamma-ray luminosity versus spin-down power. The gamma-ray luminosity is calculated from $L_\gamma = 4\pi d^2 f_\Omega G_{100}$, with d the pulsar distance and G_{100} the energy flux from spectral analysis in Table 1. f_Ω is the pulsar emission model dependent beaming factor (here is 1). The six new pulsars are highlighted with arrows. In general, they show similar characteristics as the population in the pulsar catalog. J1705-1906 has the fourth lowest spin-down power among young gamma-ray pulsars. The first three with lowest spin-down power have no distance estimate and are thereby not shown in the figure. For visibility, error bars are not shown for the six pulsars.

Discussion

The six new gamma-ray pulsars reported here are very faint compared to the population presented in the Second *Fermi* Catalog of Gamma-ray pulsars. Several factors may account for their weakness: farther than the catalog pulsars (ex. J1055-6028); a lower spin-down power (J1640+2224, J1705-1906, J1732-5049); a high background (J1055-6028, J1913+0904), or a combination of these. Detection of such weak pulsars has special interest of allowing us to probe and extend the parameter space, like refining the "deathline". The upcoming Pass 8 data set and IRFs will permit more such detections and therefore a larger population which will make the probe deeper.

References

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