High Energy Observations of Pulsars J1057-5226, J1709-4429 and J1952+3252 with the *Fermi* Large Area Telescope

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We report here the results obtained from the analysis of 9 months of *Fermi*-LAT data on three EGRET pulsars. The excellent sensitivity of *Fermi*-LAT allowed us to perform a detailed analysis of the light curves and spectra for these pulsars and test past claims regarding unique features of these pulsars based on EGRET observations.

Abstract

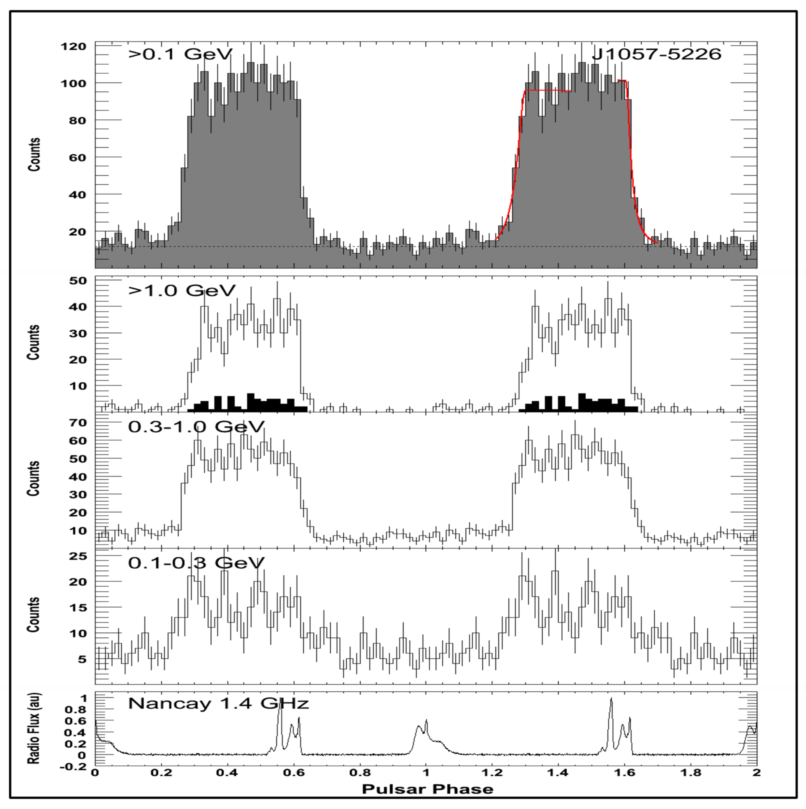
The *Fermi*-LAT data have confirmed the pulsed emission from all six high-confidence gamma-ray pulsars previously known from the EGRET observations. We report results obtained with the analysis of 9 months of LAT data for three of these pulsars: J1057-5526 (B1055-52), J1709-4429 (B1706-44), and J1952+3252 (B1951+32).

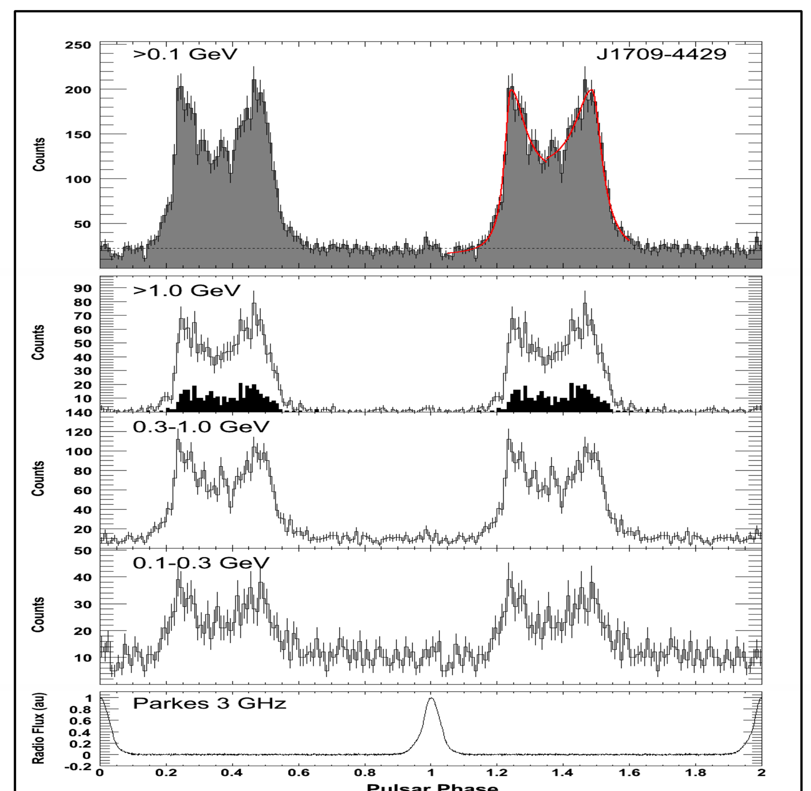
Each of these pulsars had some unique feature among the EGRET pulsars. With the excellent sensitivity of LAT, it was possible to perform a more sensitive light curve and spectral analysis to investigate these features with higher statistics. Moreover, the broader energy range of the LAT allowed us to measure the cutoff energy of pulsed emission from these pulsars for the first time and provided a more complete picture of the emission mechanism. The results confirm some, but not all, of the features of the EGRET results.

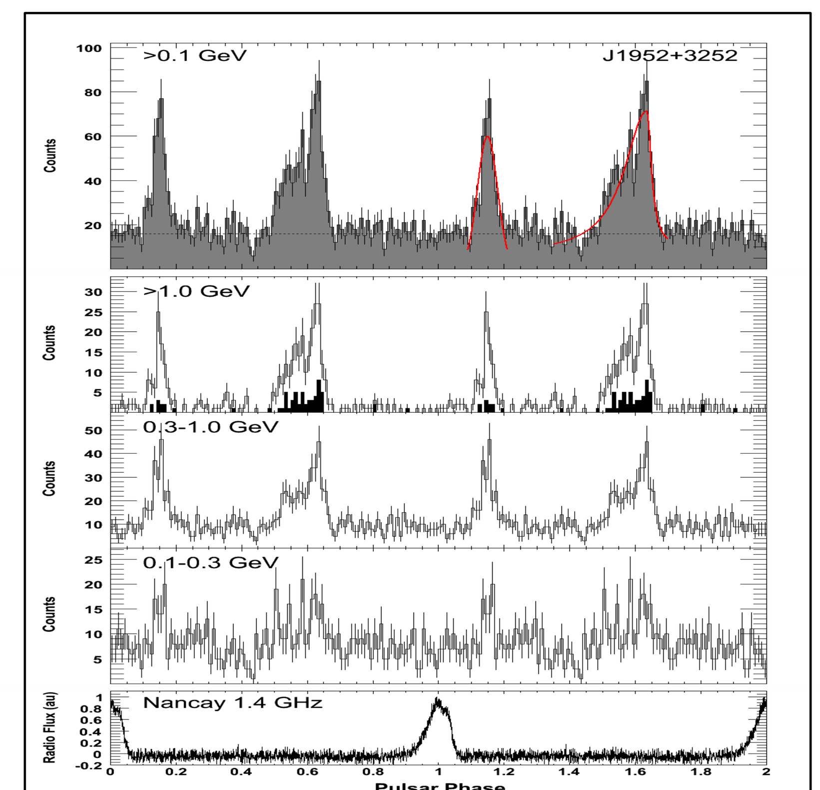
Timing Analysis

- Data collected from June 25, 2008 up to May 1st, 2009 are included.
- Events with energies > 100 MeV are used for temporal analysis.
- Events are selected from an energy dependent ROI:

  min{1.0°, max[0.35°, 0.8 x $(E_{GeV})^{-0.8}$]}
- The pulse profiles are constructed for the full energy band >0.1 GeV and 3 separete energy bands, 0.1-0.3 GeV, 0.3-1.0 GeV and >1.0 GeV. The energy band >3.0 GeV is also shown as filled histogram superimposed on the highest energy band.
- The results are reported in "The first Fermi-LAT Catalog of Gamma-ray pulsars"[1] submitted on astro-ph.







PSR J1057-5226

- P=197ms, P'=5.83 x 10^{-15}, Age= 535 kyr, E'_{SD} = 3.01 x 10^{34} ergs s^{-1}.
- Timed by Parkes[5] radio telescope, the radio template is shown on the bottom panel - Residual RMS= 159µs.
- There are 5 photons > 5.0 GeV in the on-pulse region, with a highest energy of 7.9 GeV.
- The pulse profile shows one broad peak with a complex structure between φ = 0.25-0.65 with a mean at (0.45 ±0.02). The radio lag is 0.35±0.05.
- The pulse shape can be fitted with two half-Lorentzian functions for the tails with a flat top.
- Peak-like features seen in the lowest energy band.
- EGRET light curve shows two close-peaks as opposed to the one broad peak seen with the LAT data.

PSR J1709-4429

- P=102ms, P'=9.3 x 10^{-14}, Age= 17.5 kyr, E'_{SD} = 3.41 x 10^{36} ergs s^{-1}.
- A glitch detected from this pulsar on August 14th, 2008 from analysis of the LAT data .
- Timed by Parkes[5] radio telescope, the radio template is shown on the bottom panel- Residual RMS= 505 µs.
- There are 45 photons >10.0 GeV in the on-pulse region, with a highest energy of 47.7 GeV.
- The pulse profile shows two close broad peaks, separated by 0.25 ± 0.01 , between φ = 0.17-0.63. The radio lag is 0.24± 0.01.
- The peaks can be fitted by two asymmetric Lorentzian shapes.
- A third peak-like feature is seen at different locations on different energy bands.
- EGRET could not distinguish between a 2-peak or 3-peak shape for the light curve of this pulsar as opposed to clear 2-peak shape seen with LAT.

PSR J1952+3252

- P=39.5ms, P'=5.84 x 10^{-15}, Age= 107 kyr, E'_{SD} = 3.74 x 10^{36} ergs s^{-1}.
- Timed by Nancay[8] radio telescope, the radio template is shown on the bottom panel - Residual RMS= 117µs.
- There are 8 photons >10.0 GeV in the on-pulse region, with a highest energy of 25.7 GeV.
- The pulse profile shows two narrow peaks separated by 0.49±0.01, with an on-pulse region between φ = 0.1-0.7, the radio lag is 0.15±0.01.
- The first peak can be fitted with a symmetric Lorentzian, whereas the second peak can be fitted with an asymmetric Lorentzian shape.
- A third peak-like feature is seen at the inner shoulder of P2.
- EGRET and LAT pulse shapes are similar.

Spectral Analysis

- Data collected in sky-survey mode are used: August 4th, 2008 – May24th, 2009
- Energy Range = 100 MeV – 100 GeV
- Events from a 10 deg ROI are used.

- *Fermi* Science Tools, *gtlike*
- IRFs: Pass6 v3
- Considered nearby sources in ROI of 17deg, modeling their spectral with Power Law
- Galactic & extra-galactic diffuse backgrounds: gll_iem_v02.fit and isotropic_iem_v02.txt

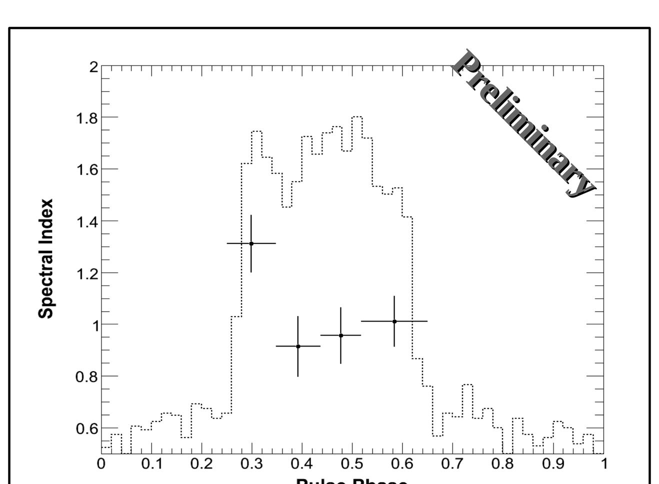
- Pulsars in ROI are modeled with "Power Law with Simple Exponential Cut-off" given by:

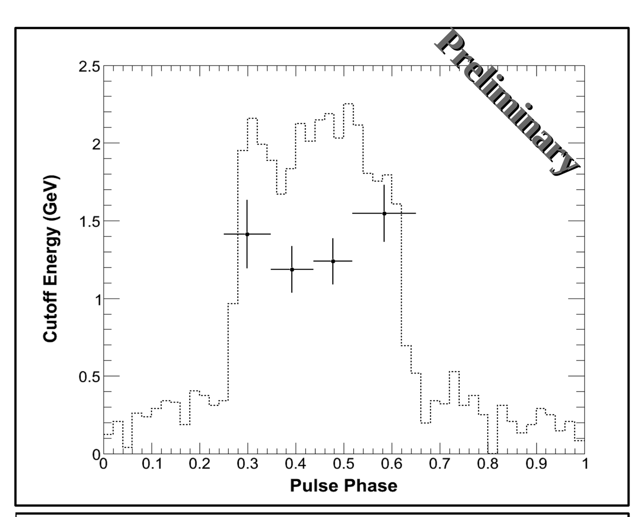
  $$dN/dE = K(E_{GeV})^{-\Gamma} \exp[-(E/E_{cutoff})]$$
- ECPL1 shape of the spectrum assumption for the pulsar of interest is tested against Simple Power Law shape

PSR J1057-5226

Phase Averaged Spectra
F(>100 MeV) = (3.045 ± 0.17) x 10^{-7} $cm^{-2}s^{-1}$
Index = (1.06 ± 0.10)
CutOff = (1.3 ± 0.1) GeV
Power Law is excluded by ~19σ

Phase Resolved Spectra
- No emission is detected outside of φ = (0.25-0.65)
- Spectral index is higher in the first peak
- CutOff energy is approx. constant over pulsed region

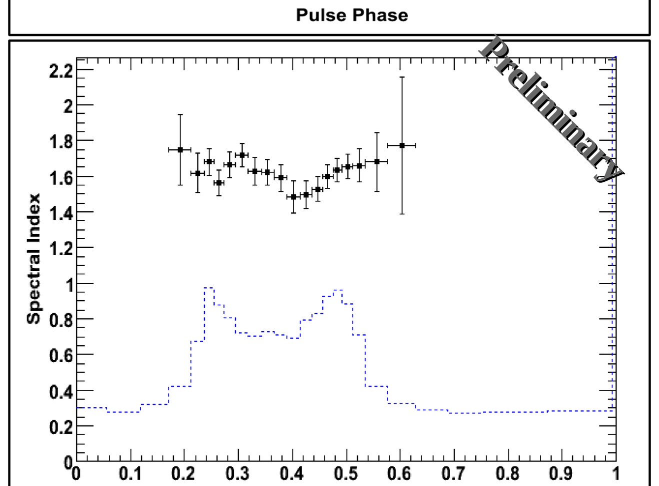


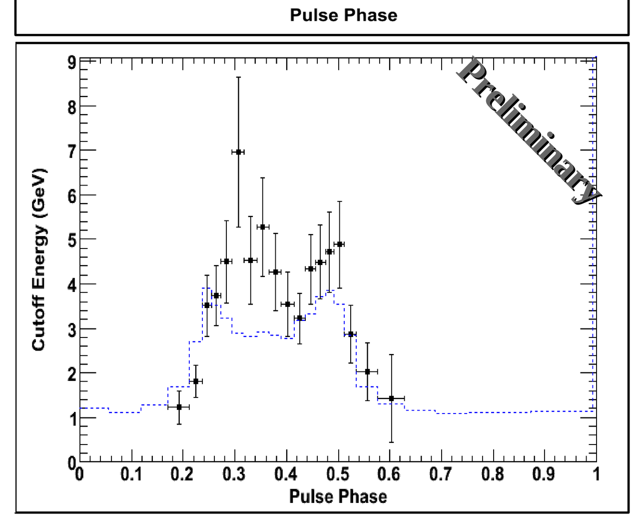


PSR J1709-4429

Phase Averaged Spectra
F(>100 MeV) = (1.498 ± 0.041) x 10^{-6} $cm^{-2}s^{-1}$
Index = (1.70 ± 0.04)
CutOff = (4.9 ± 0.4) GeV
Power Law is excluded by ~19σ, Broken Power Law by ~5.6σ

Phase Resolved Spectra
- No emission is detected outside of φ = (0.17-0.63)
- CutOff energy varies drastically over the pulsed region up to a max cutoff energy of (6.96 ± 1.7) GeV

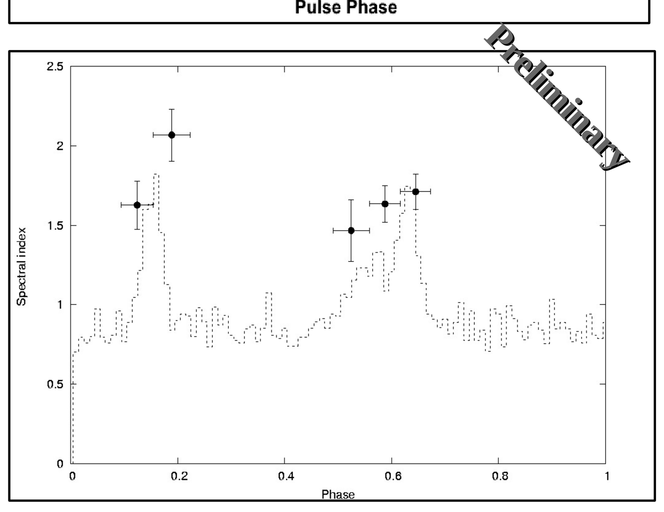


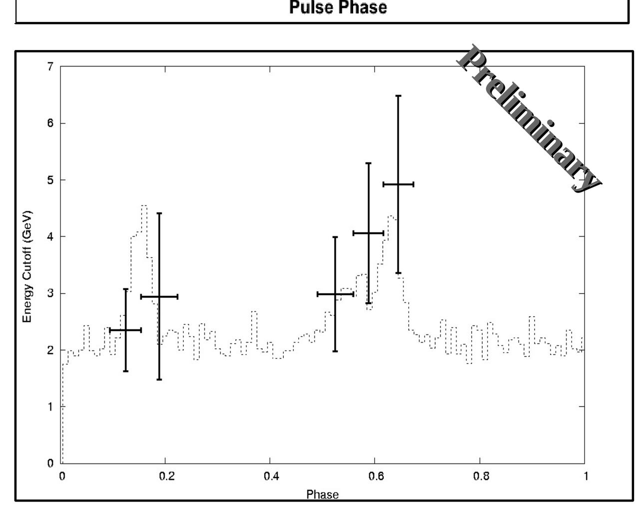


PSR J1952+3252

Phase Averaged Spectra
F(>100 MeV) = (1.76 ± 0.19) x 10^{-7} $cm^{-2}s^{-1}$
Index = (1.75 ± 0.12)
CutOff = (4.5 ± 1.2) GeV
Power Law is excluded by ~6σ

Phase Resolved Spectra
- No emission is detected outside of φ = (0.1-0.7)
- The second peak has a larger cutoff than the first peak region.





Discussion

Minimum Emission Altitude: $r > (E_{max}B/1.76\ GeV)^{2/7} P^{-1/7} R_*$ [2]

PSR J1057-5226: $E_{max} \sim 2 \times E_{cutoff}$ = 2.6 GeV → r >1.45R_*
PSR J1709-4429: $E_{max} \sim 2 \times E_{cutoff}$ = 9.8 GeV → r >3.2R_*
PSR J1952+3252: $E_{max} \sim 2 \times E_{cutoff}$ = 9.0 GeV → r >2.1R_*

Geometry: Using the measured Δ and ζ and predicted geometry by [11]:

	Δ	ζ_{meas}(°)	α_{TPC}(°)	ζ_{TPC}(°)	$f_{\Omega,TPC}$	α_{OG}(°)	ζ_{OG}(°)	$f_{\Omega,OG}$
J1057-5226	0.20	67	60	50	0.85	78	67	0.55
J1709-4429	0.25	53	45-50	53	1.05	47-49	53	0.7-1.0
J1952+3252	0.49	-	55-90	55-90	1.0-1.25	60-90	70-85	0.75-1.1

Luminosity and Efficiency: $L_\gamma = 4\pi f_\Omega(\alpha, \zeta_E)\, d^2 F_{E,Obs}$ $\eta = L_\gamma / E'_{sd}$

PSR J1057-5226: d=(0.7 ± 0.2) kpc → L_γ = (1.7 ± 0.9) x10^{34} f_Ω ergs s^{-1} η =0.56±0.31 f_Ω
PSR J1709-4429: d=(1.4 - 3.6) kpc → L_γ = (2.9 - 19.0) x10^{35} f_Ω ergs s^{-1} η= 0.09-0.57 f_Ω
PSR J1952+3252: d=(2.0 ± 0.6) kpc → L_γ= (6.4 ± 3.2) x10^{34} f_Ω ergs s^{-1} η = 0.02±0.01 f_Ω

Conclusions

- The high cutoff energy of pulsed emission for all three pulsars → low altitude emission models are excluded [3] and high altitude models like Outer Gap (OG)[7] or two-pole caustic (TPC) [4] models are favored.
- Both OG and TPC models offer a range of possible solutions for the emission geometry and agrees with the measured viewing angle, ζ_{meas}.
- EGRET observations point to a very high efficiency for PSR J1057-5226[9] , confirmed by these recent much more sensitive LAT measurements.
- EGRET did not see any evidence of cutoff for PSR J1952+3252 emission[6], but LAT clearly measures a cutoff at 3.5 GeV.
- PSR J1709-4429 spectra was best fitted by Broken Power Law shape using EGRET data[10], LAT data favors Power Law with Simple Exponential Cutoff but the fit is not dramatically different from a Broken Power Law.

References

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