Millisecond Pulsars and Fermi Unidentified Sources

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Introduction



(from NASA/Fermi/LAT Collaboration)



1) Fermi has identified over 60 gamma-ray pulsars (Abdo et al. 2010).

Statistical arguments

- Galactic population
- Emission properties (e.g. Photon
- index vs. Spin down power)

2) Over 600 Fermi sources are unidentified

-Association between high Galactic unidentifid sources and millisecond pulsars (eg. Kaaret & Philip 1996; Cottam, Jean Faucher-Gigu`ere & Loeb 2010)

(Abdo et al. 2009)



• 9 millisecond pulsars with $L_{\gamma} \sim 10^{33-34}$ erg/s~10%L_{sd} (Abdo et al. 2009, 2010)

Discovery of new radio millisecond pulsars in Fermi unidentified sources
(e.g. Ray 2010, Ransom et al. 2011; Keith et al. 2011)

New Millisecond Radio Pulsars Found in Fermi LAT Unidentified Sources



Led by Fernando Camilo (Columbia Univ.) using Australia's CSIRO Parkes Observatory
 Led by Mallory Roberts (Eureka Scientific/GMU/NRL) using the NRAO's Green Bank Telescope
 Led by Scott Ransom (NRAO) using the Green Bank Telescope
 Led by Ismael Cognard (CNRS) using France's Nançay Radio Telescope
 Led by Mike Keith (ATNF) using Parkes Observatory

(New Radio MSPs , Ray 2010)

Millisecond pulsars become an important class of Galactic gamma-ray sources.

- How many millisecond pulsars could contribute to Fermi unidentified sources ?
- Radio quiet millisecond pulsars?

Monte-Carlo Simulation

A Monte-Carlo study

-Population of the radio-loud and radio-quiet gamma-ray pulsars

- Method- Bailes & Kniffen (1992); Sturner & Demer (1996); Faucher-Gigu`ere & Kaspi (2006)
- Empirical model of the radio emission from the polar cap
- Major Radio Surveys Parks (Manchester et al. 2001) etc.
- Fermi sensitivity scale 6month threshold flux (Abdo et al. 2009) to longer observation with ∝ T^{1/2}

-Because Fermi has not identified the radio-quiet millisecond pulsar, we applied the sensitivity of the radio-quiet canonical pulsars for that of the radio-quiet millisecond pulsars.

y-ray emissions



- Two-layer outer gap (Wang, Takata & Cheng 2010)
- 3-dimensional model;

 -flux
 -cut-off energy
 -photon index (Ec>E>100MeV)
 -pulse profile
- Viewing angle and inclination angle are random.



Results

- Two peaks in the distribution of photon index (E>100MeV)
 - -1.8~2; emissions from main region (E~1GeV)+ screening region(E~100MeV).

- 1.2~1.4; emission from only main region for a viewing angle

>> (or <<) 90degree.





36

38

39

38

Radio-Loud MSPs

34

33

35

 \log_{10}^{36} Lsd[erg/s]

Canonical pulsars





$ \begin{bmatrix} \alpha = 10.3^{\circ} \\ \zeta = 75.9^{\circ} \\ P = .3485 \\ B_{g} = 62.4 \\ H \end{bmatrix} \begin{pmatrix} \alpha = 12.4^{\circ} \\ \zeta = 71.5^{\circ} \\ P = .0905 \\ B_{g} = 2.50 \\ H \end{bmatrix} \begin{pmatrix} \alpha = 18.3^{\circ} \\ \zeta = 84.19 \\ P = .0905 \\ B_{g} = 1.78 \\ B_{g} = 1.78 \\ H \end{bmatrix} \begin{pmatrix} \alpha = 19.8^{\circ} \\ \zeta = 00.19 \\ P = .0905 \\ P = .0905 \\ B_{g} = 1.78 \\ H \end{bmatrix} \begin{pmatrix} \alpha = 19.8^{\circ} \\ \zeta = 00.19 \\ P = .0905 \\ P$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$
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Pulse profile of simulated pulsars

The gamma-ray pulsars with ζ ~90degrees are preferentially discovered.

-->double peak structure

Galactic Distribution (5 yr observations)



MSPs	six-m N _{Radio-Loud}	onths NRadio-Quiet	five-y N _{Radio-Loud}	ears N _{Radio-Quie}	ten-ye NRadio-Lou	ears Id NRadio-Quiet		
Threshold Radio flux x 1	10	52	14	200	16	284		
Threshold Radio flux = 0 . (beaming effect)	106	11	321	41	438	62		
Radio	rotation axis •Wide radio cone of millisecond pu (Kramer & Xikouris, 2000)							
	γ-ray	•Be imp	•Beaming effect (threshold flux=0) implies intrinsically N _{R-L} /N _{R_Q} ~7-10.					

MSPs	six-m N _{Radio-Loud}	NRadio-Quiet	five-y N _{Radio-Loud}	ears NRadio-Qu	ten-y iel NRadio-Lo	vears
Threshold Radio flux x 1	10	52	14	200	16	284
Threshold Radio flux = 0 . (beaming effect)	106	11	321	41	438	62
Simulated distribution Parks; Keith et al. (2011)	Radio flux at 1.3GHz	-years month P fa	With the adio surv ulsars re Most of ulsars n ar. They co	e prese veys, m emain a gamm nay no	ent sens lost milli ls radio- a-ray m t be ide	itivity of the second quiet. illisecond ntified so
Radio flux at 1.3G	Hz (mJy)	 1 U	nidentif	ied so	urces.	

Fermi unidentified sources



Curvature index and Variability index (Abdo, et al. 2010) C-index characterizes spectral shape (cut off or single power law?) V-index characterizes stability. Fermi Pulsars -C>5 -V<23

Galactic Distribution of (253) Fermi unidentified sources with C>5 and V<23



• Fermi unidentified (253) sources with C>5 and V<23 must be dominated by the Galactic sources.











Fermi unidentified sources with C>5 and V<23 will be dominated by

-the canonical pulsars for low latitude sources

- the millisecond pulsars for high latitude

Summary

• Photon index depends on the viewing geometry. ~1.8-2 for α ~90degs and ~1.2-1.4 for smaller (or larger) α than 90degrees.

• Fermi will have preferentially detected the pulsars with viewing angle~90deg. \rightarrow Most of the pulse profiles have double peak structure.

• The most gamma-ray millisecond pulsars would remain as the radio-quiet, even though the radio beams point to the Earth due to limited sensitivity.

• Many pulsars dominate Fermi unidentified sources with C>5 and V<23.

γ-ray emissions

- γ-ray emissions from outer gap
- Wang, Takata & Cheng (2010, 2011)
- 3-dimensional model

-Dependency of the emission characteristics on the inclination angle and Earth viewing angle.



