Millisecound Pulsars

and

Fermi Unidentified Sources

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Introduction

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 unidentified sources and millisecond pulsars
  (e.g. Kaaret & Philip 1996; Cottam, Jean Faucher-Giguère & Loeb 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
- 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 $\propto T^{1/2}$

-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.
**γ-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.

EF

Emissions from screening region

Emissions from Main region

Photon index (>100MeV) vs. Lsd

Simulation
Fermi observation
The gamma-ray pulsars with $\zeta \sim 90^\circ$ are preferentially discovered. --> double peak structure

- The gamma-ray pulsars with $\zeta \sim 90^\circ$ degrees are preferentially discovered. --> double peak structure
Galactic Distribution (5 yr observations)

**Millisecond Pulsars**
- Radio-Loud: 14
- Radio-Quiet: 200

**Canonical Pulsars**
- Radio-Loud: 55
- Radio-Quiet: 138
### MSPs

<table>
<thead>
<tr>
<th>Threshold Radio flux x 1</th>
<th>six-months</th>
<th>five-years</th>
<th>ten-years</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N_{\text{Radio-Loud}})</td>
<td>10</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>(N_{\text{Radio-Quiet}})</td>
<td>52</td>
<td>200</td>
<td>284</td>
</tr>
</tbody>
</table>

Threshold Radio flux = 0 (beaming effect)

- Wide radio cone of millisecond pulsar (Kramer & Xikouris, 2000)
- Beaming effect (threshold flux=0) implies intrinsically \(N_{\text{R-L}}/N_{\text{R-Q}}\sim 7-10\).
• With the present sensitivity of the radio surveys, most millisecond pulsars remain as radio-quiet.

• Most of gamma-ray millisecond pulsars may not be identified so far.

• They could contribute to Fermi unidentified sources.

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<tr>
<td>Threshold Radio flux = 0 (beaming effect)</td>
<td>106</td>
<td>11</td>
<td>321</td>
</tr>
</tbody>
</table>

Simulated Radio flux distribution at 1.3GHz

Parks; Keith et al. (2011)
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.
Simulated canonical pulsars

Simulated millisecond pulsars

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. 
  \(\sim 1.8-2\) for \(\alpha \sim 90\text{degs}\) and \(\sim 1.2-1.4\) for smaller (or larger) \(\alpha\) than 90degrees.

- Fermi will have preferentially detected the pulsars with viewing angle\(\sim 90\text{deg.}\) → 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
- 3-dimensional model
  - Dependency of the emission characteristics on the inclination angle and Earth viewing angle.

![Graph showing color vs. intensity versus viewing angle and pulse phase](image1)

![Graph showing flux vs. viewing angle](image2)