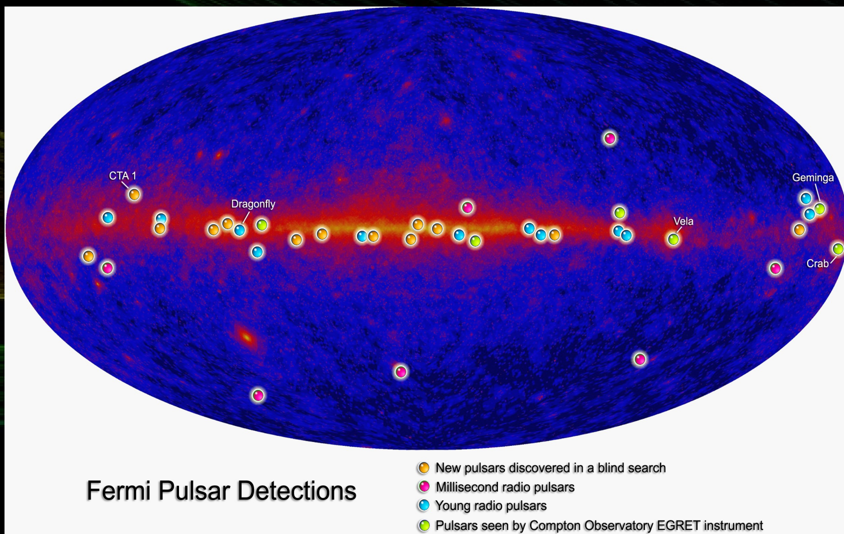
Millisecond Pulsars and Fermi Unidentified Sources

○*Takata, J.*

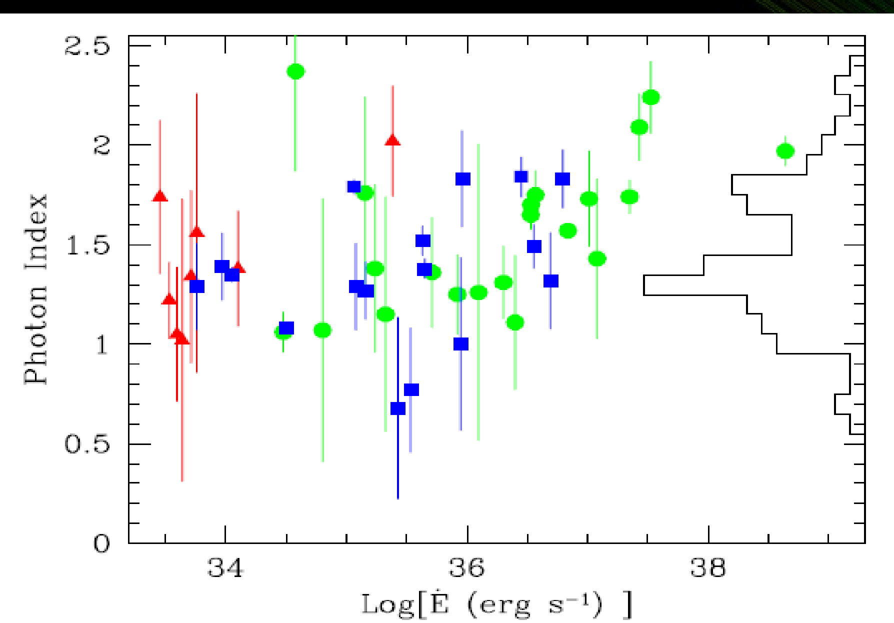
Wang, Y.

Cheng, K.S.
(The University of Hong Kong)

Introduction



(from NASA/Fermi/LAT Collaboration)



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

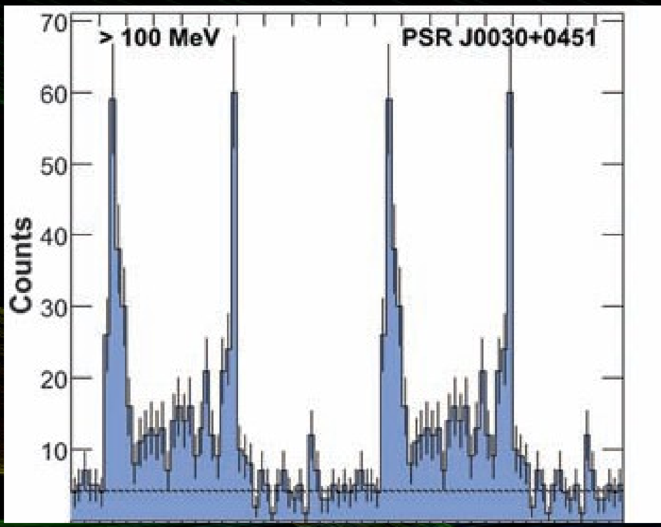
- Statistical arguments

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

2) Over 600 Fermi sources are unidentified

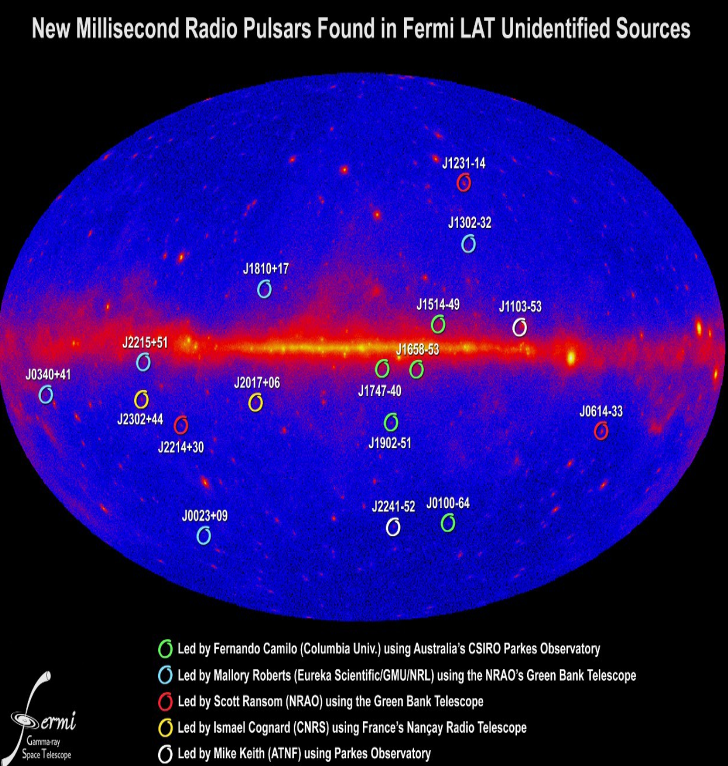
-Association between high Galactic un-identifid sources and millisecond pulsars (eg. Kaaret & Philip 1996; Cottam, Jean Faucher-Gigu`ere & Loeb 2010)

(Abdo et al. 2009)



- 9 millisecond pulsars with $L_{\gamma} \sim 10^{33\text{-}34}$ 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 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

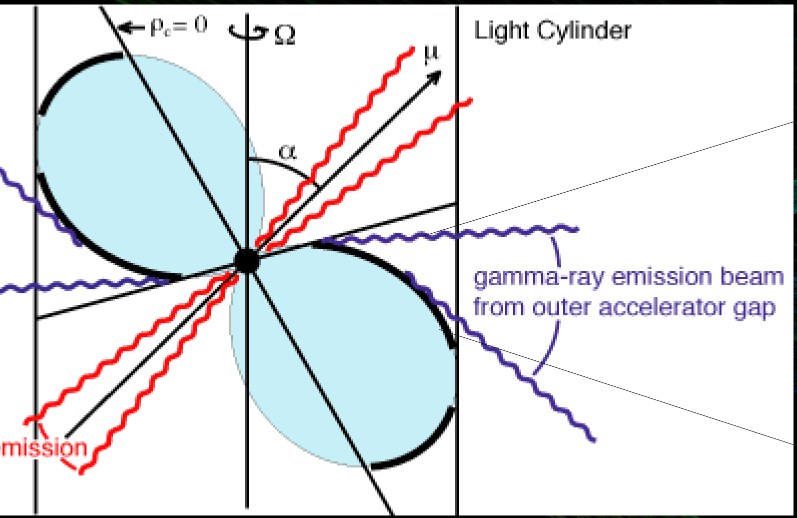
- A Monte-Carlo study

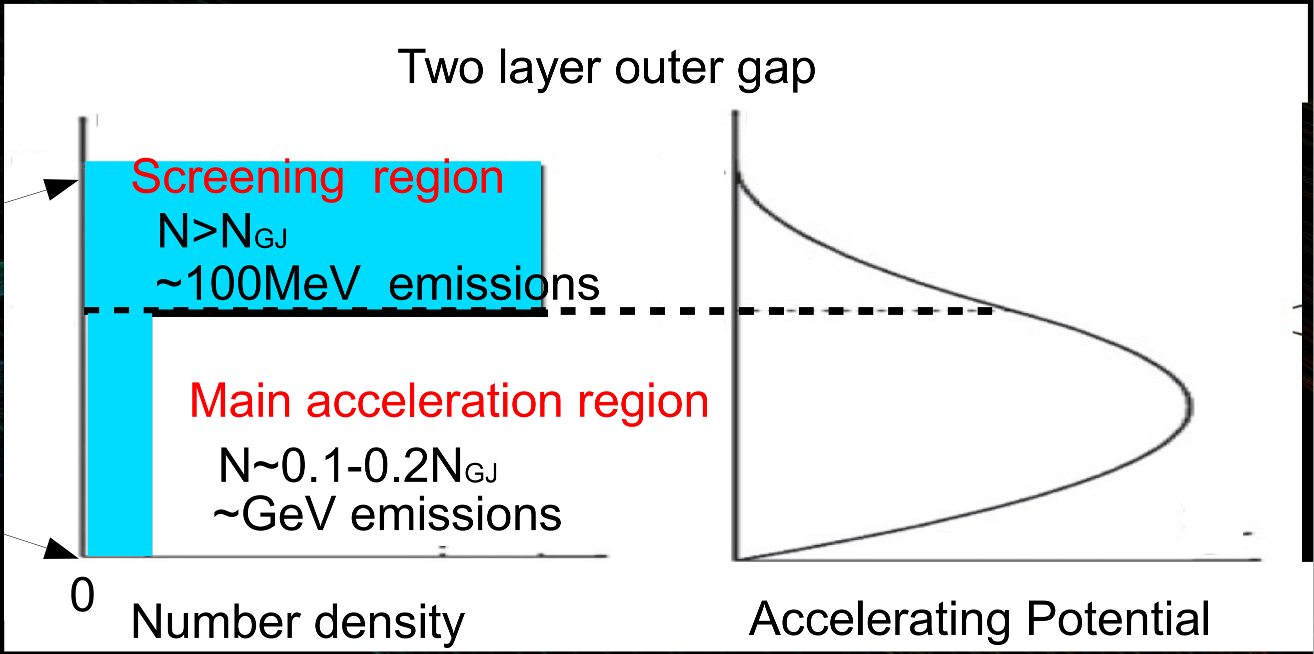
  -Population of the radio-loud and radio-quiet gamma-ray pulsars

- 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 $\propto T^{1/2}$

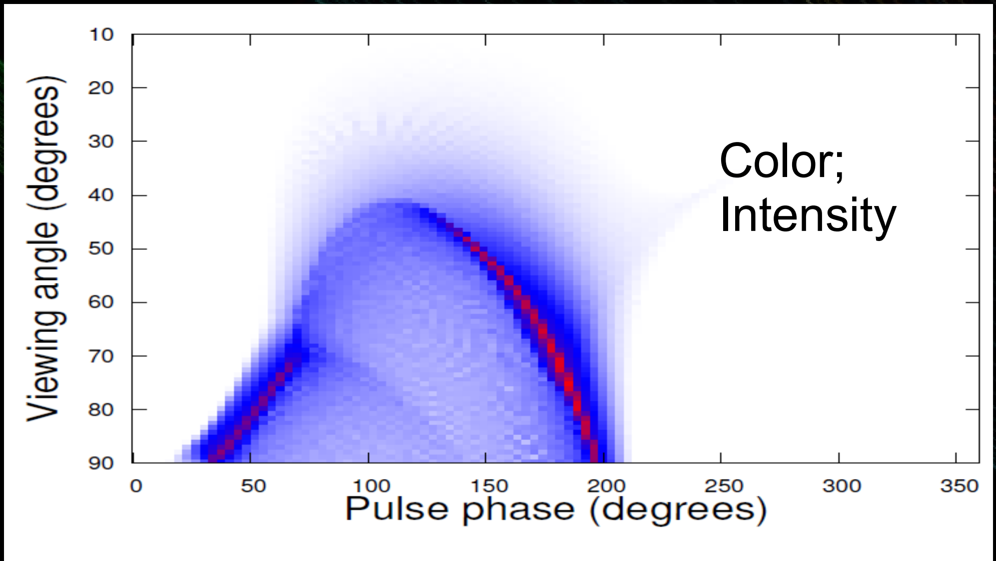
  -Because Fermi has not identified the radio-quiet millisecond pulsar, we applied the sensitivity of the radio-quiet canonical pulsars for that of the radio-quiet millisecond pulsars.

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.



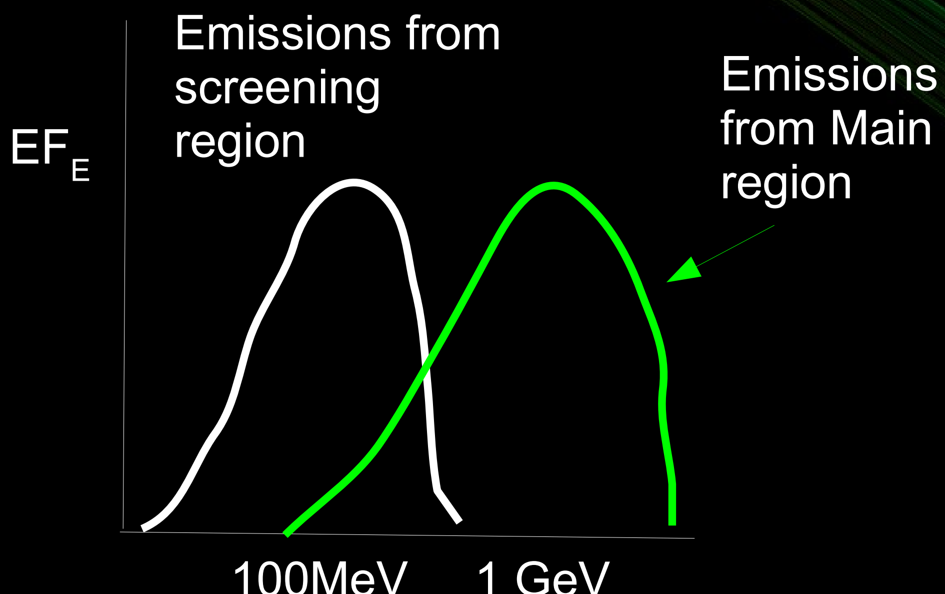
Results

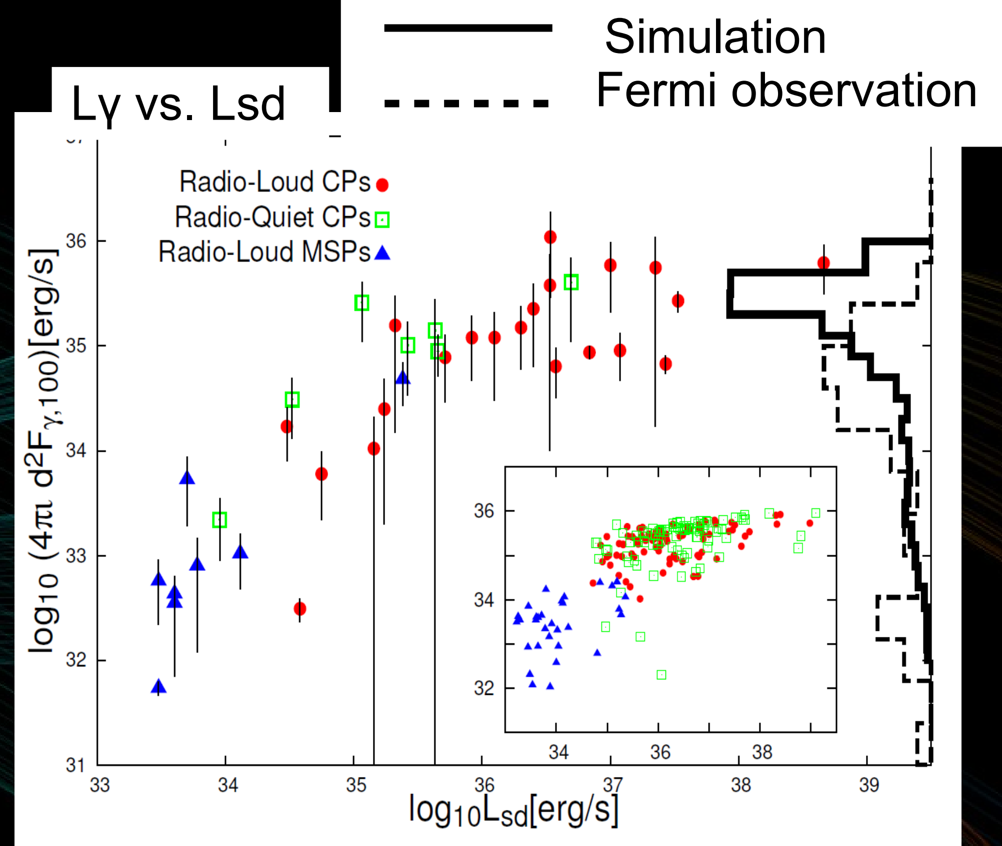
- Two peaks in the distribution of photon index (E>100MeV)

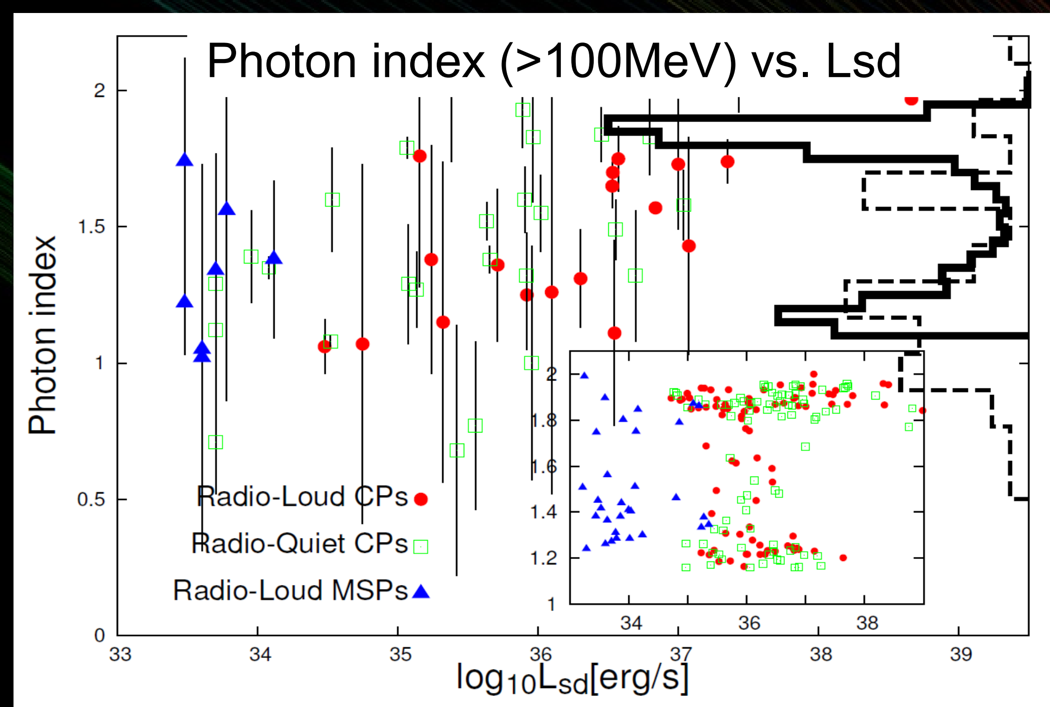
  -1.8~2; emissions from main region (E~1GeV)+ screening region(E~100MeV).

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

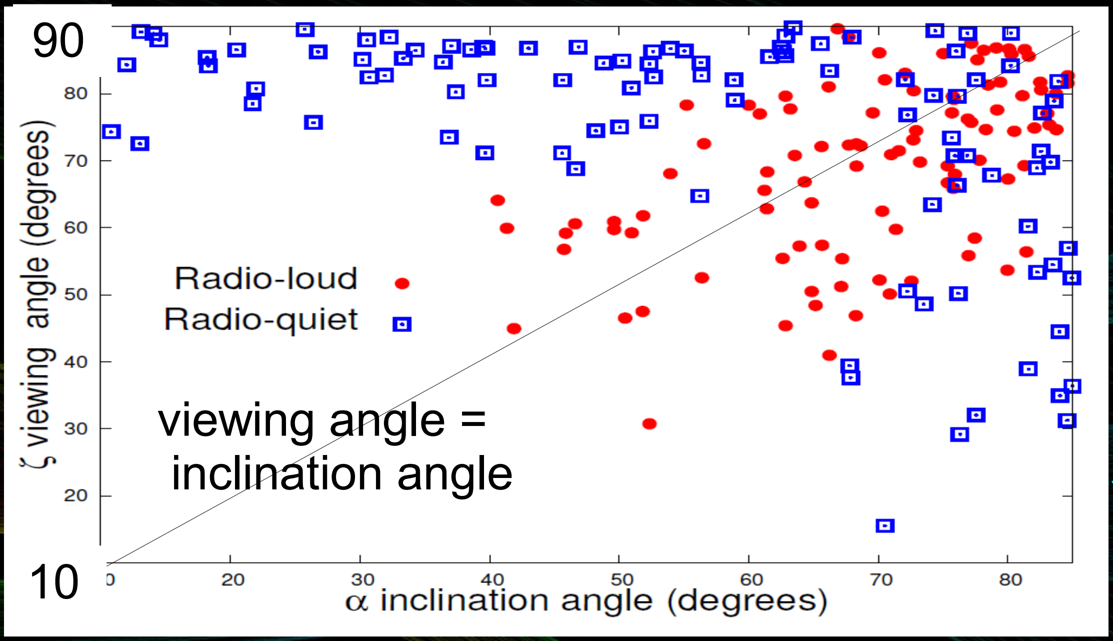
  >> (or <<) 90degree.

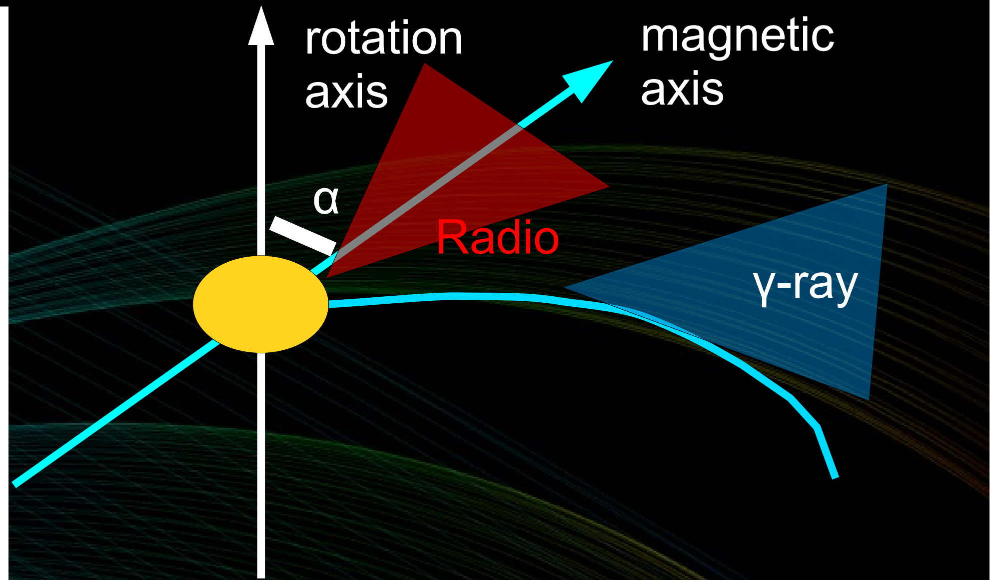


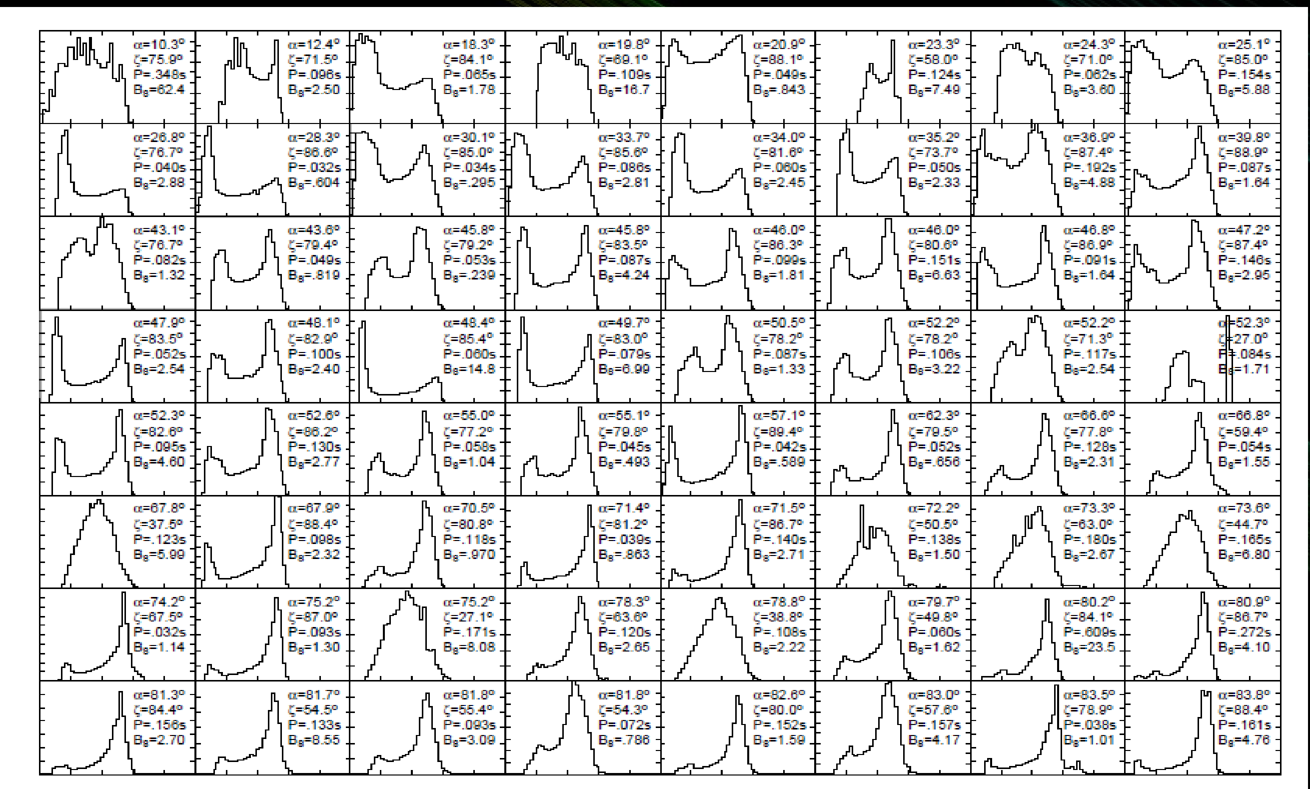




Canonical pulsars





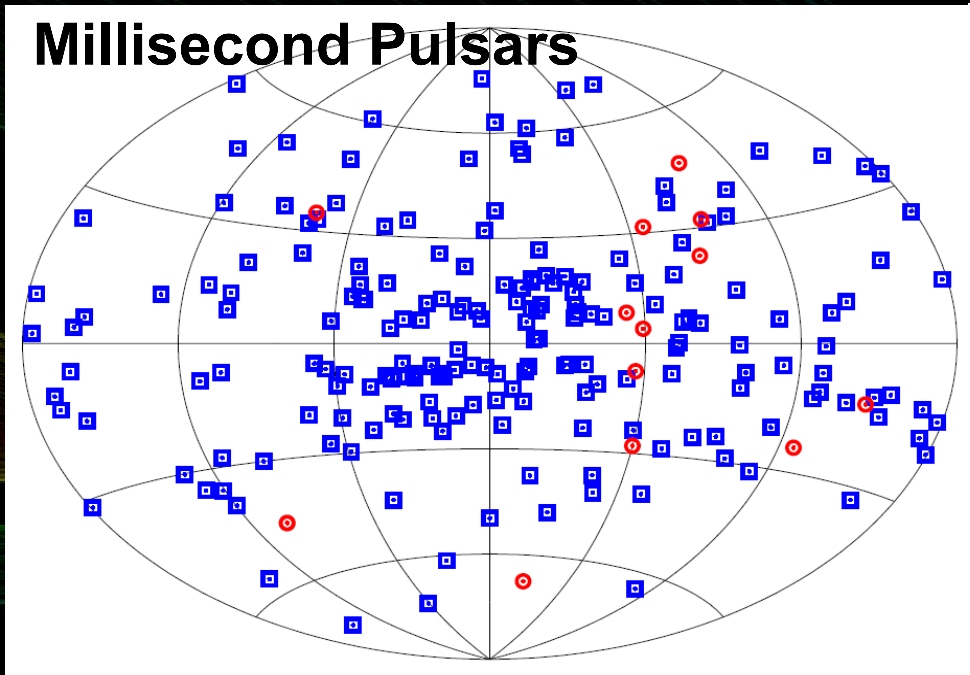


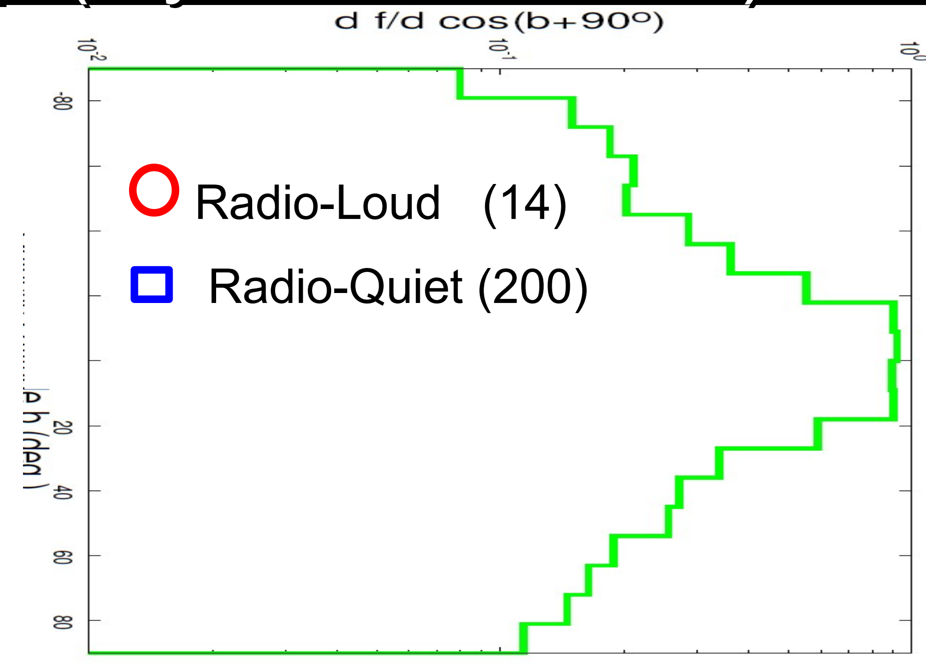
Pulse profile of simulated pulsars

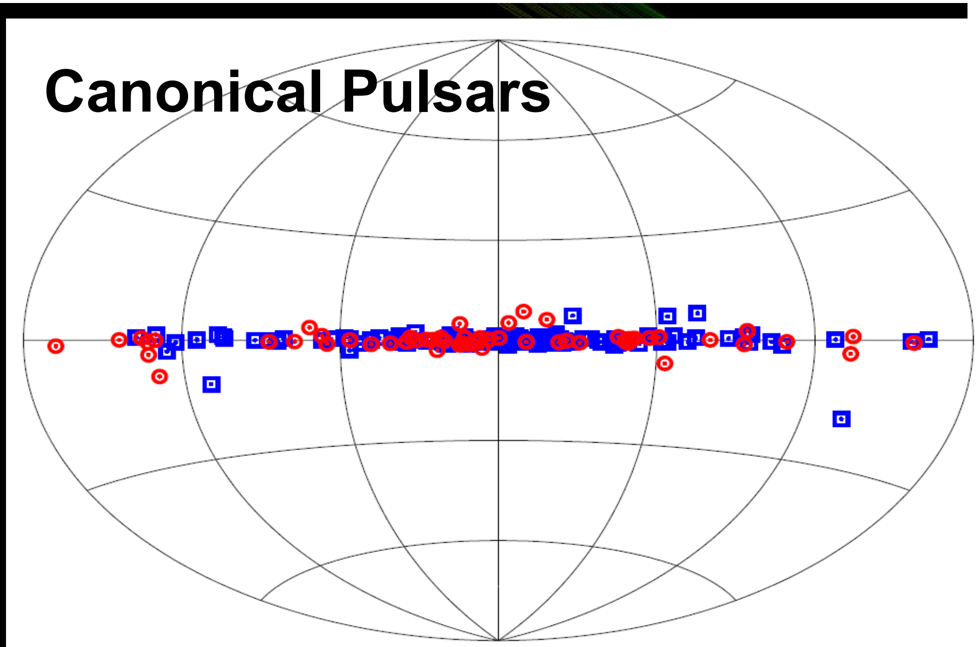
- The gamma-ray pulsars with ζ~90degrees are preferentially discovered.

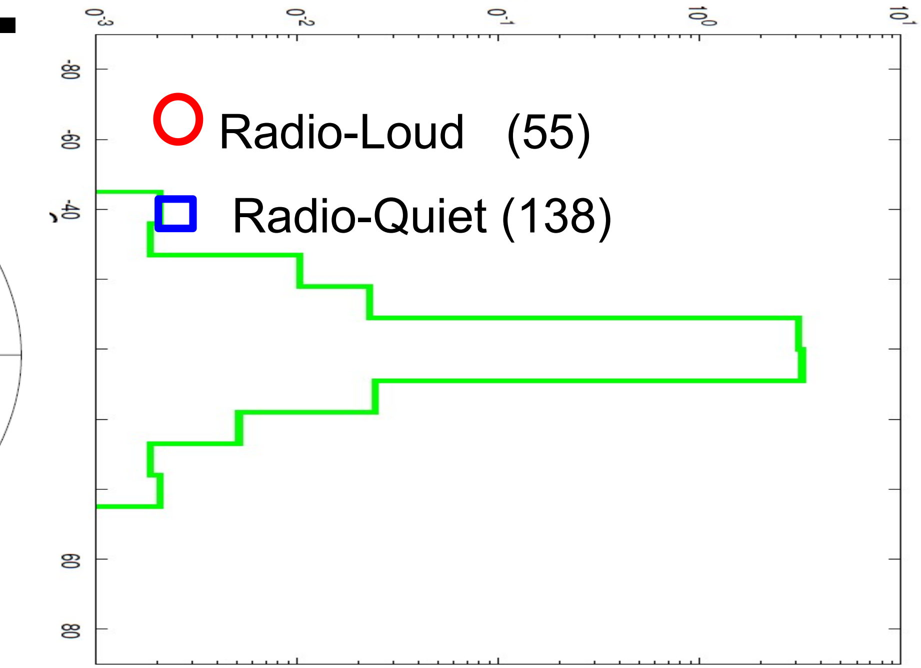
  -->double peak structure

Galactic Distribution (5 yr observations)

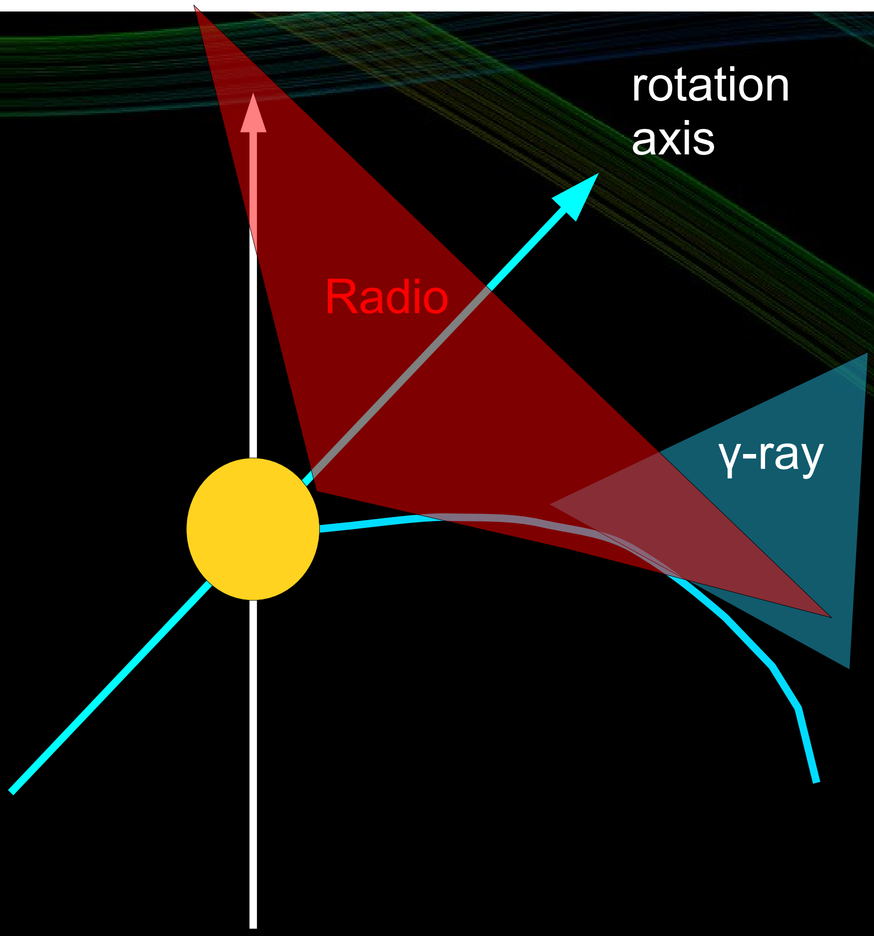






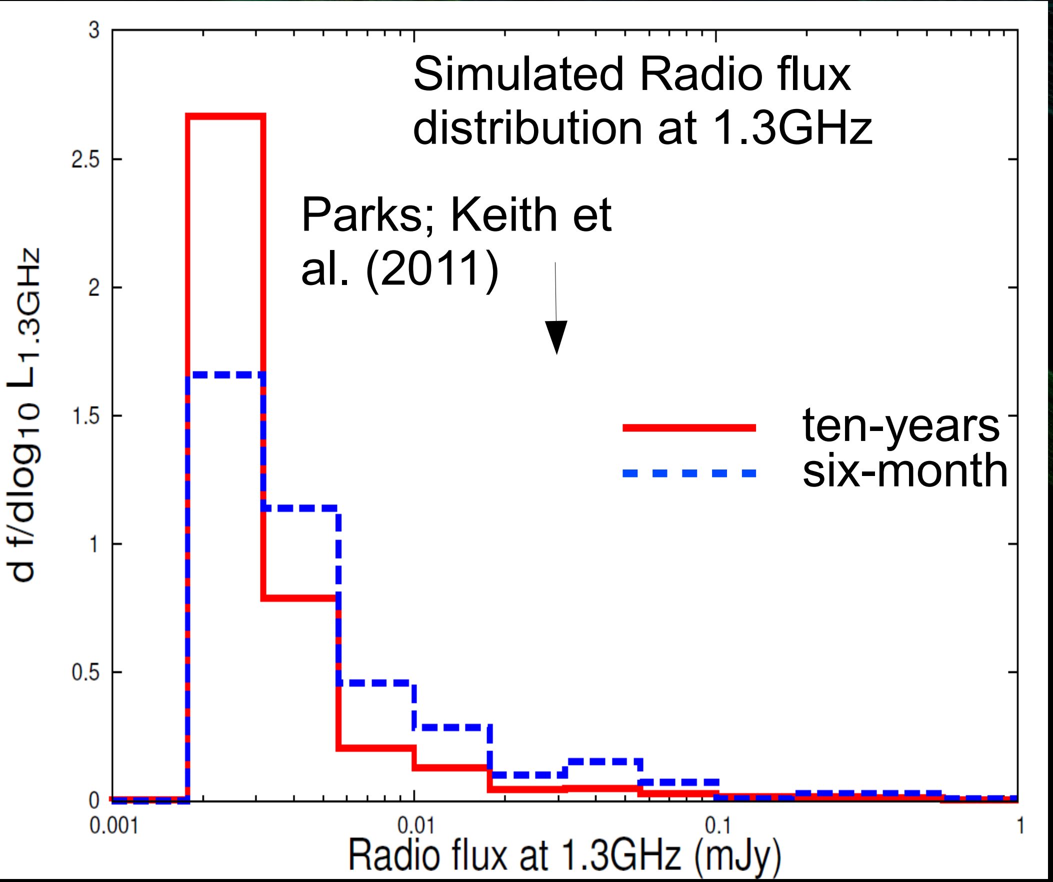


MSPs	six-months		five-years		ten-years	
	$N_{\text{Radio-Loud}}$	$N_{\text{Radio-Quiet}}$	$N_{\text{Radio-Loud}}$	$N_{\text{Radio-Quiet}}$	$N_{\text{Radio-Loud}}$	$N_{\text{Radio-Quiet}}$
Threshold Radio flux x 1	10	52	14	200	16	284
Threshold Radio flux = 0 (beaming effect)	106	11	321	41	438	62



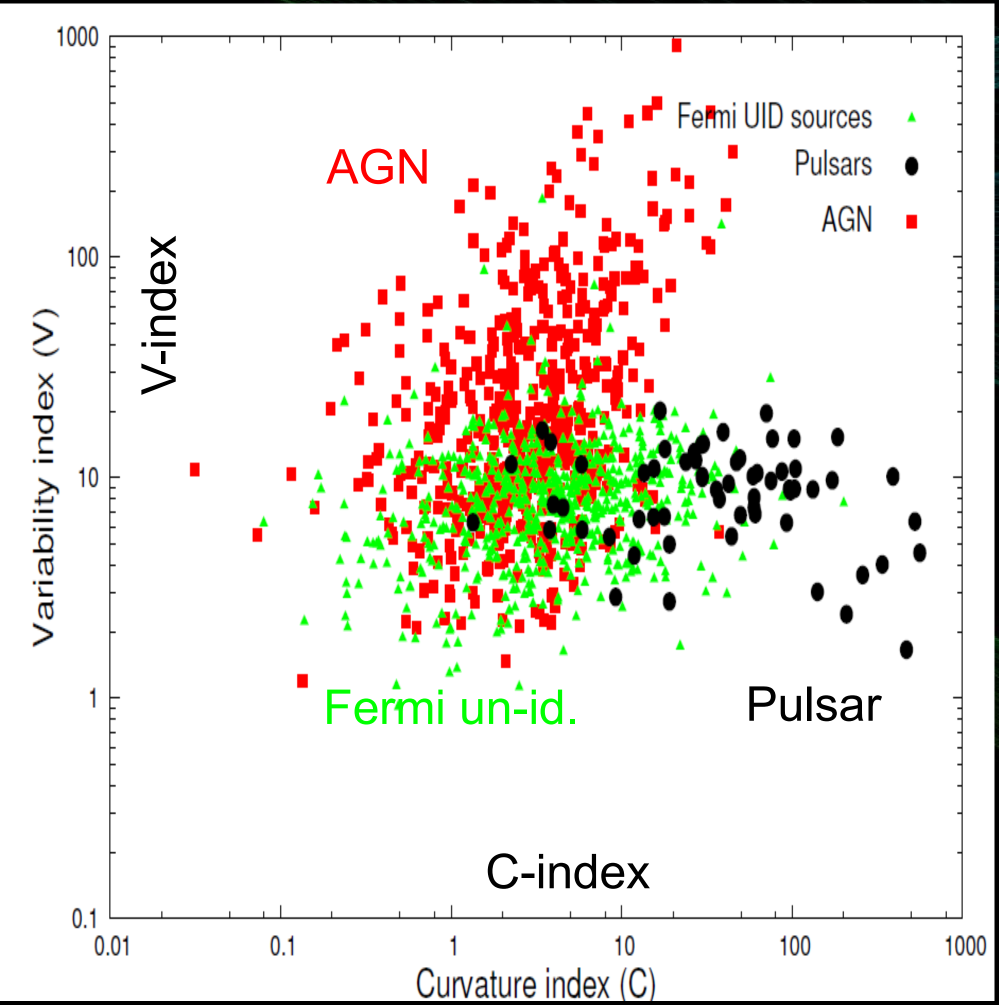
- Wide radio cone of millisecond pulsar (Kramer & Xikouris, 2000)
- Beaming effect (threshold flux=0) implies intrinsically $N_{R\text{-}L}/N_{R\_Q}$~7-10.

MSPs	six-months		five-years		ten-years	
	$N_{Radio-Loud}$	$N_{Radio-Quiet}$	$N_{Radio-Loud}$	$N_{Radio-Quiet}$	$N_{Radio-Loud}$	$N_{Radio-Quiet}$
Threshold Radio flux x 1	10	52	14	200	16	284
Threshold Radio flux = 0 (beaming effect)	106	11	321	41	438	62



- 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.**

Fermi unidentified sources



- Curvature index and Variability index

(Abdo, et al. 2010)

C-index characterizes spectral shape

(cut off or single power law?)

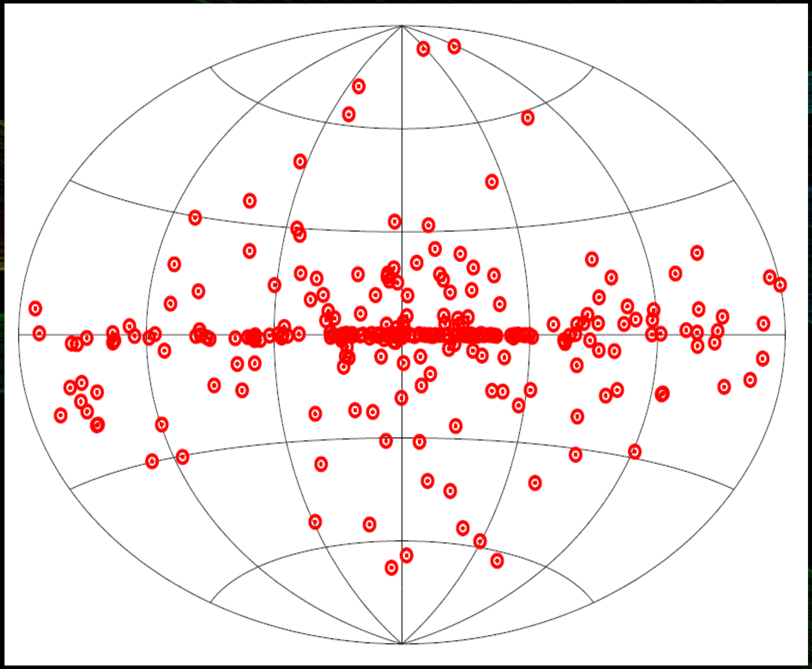
V-index characterizes stability.

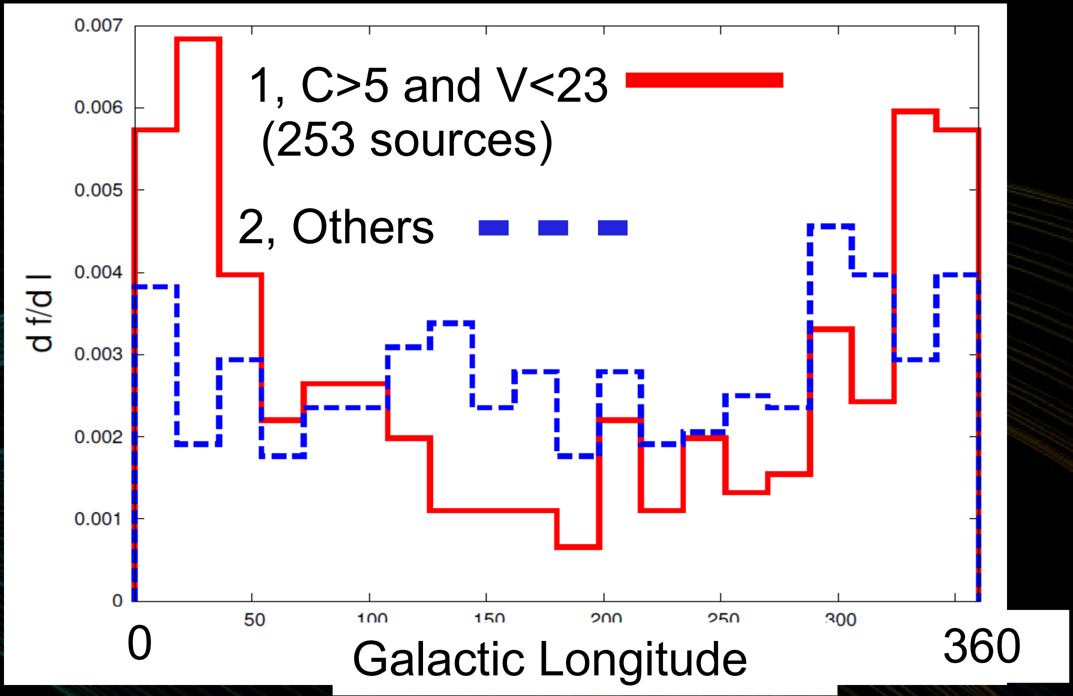
- *Fermi* Pulsars

-C>5

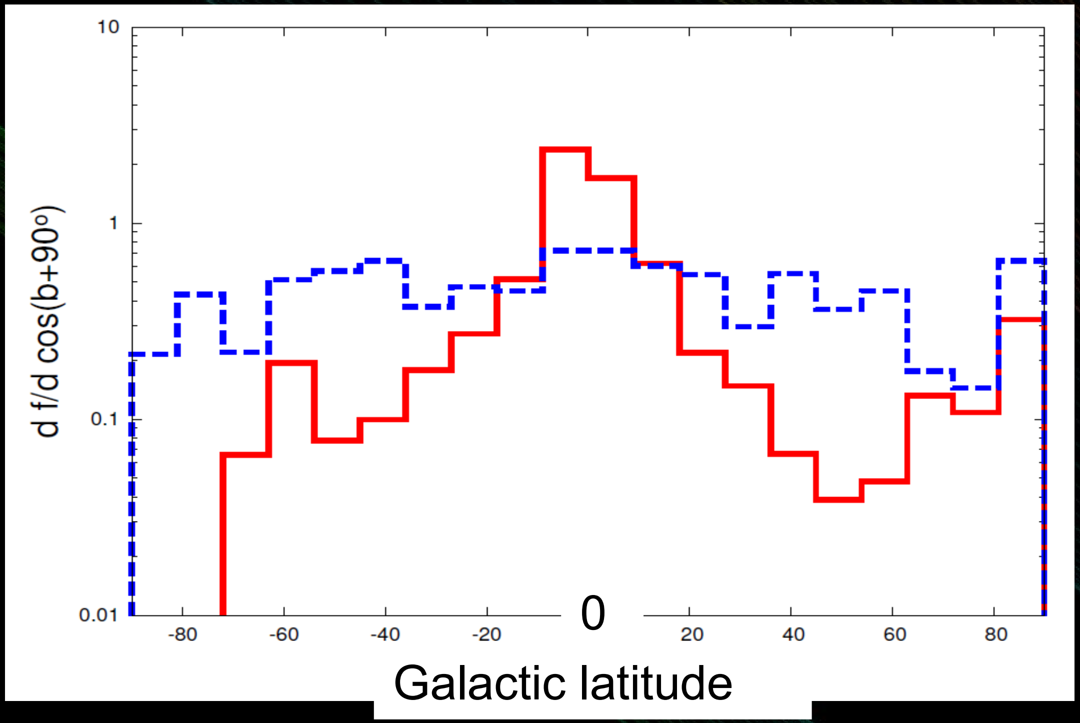
-V<23

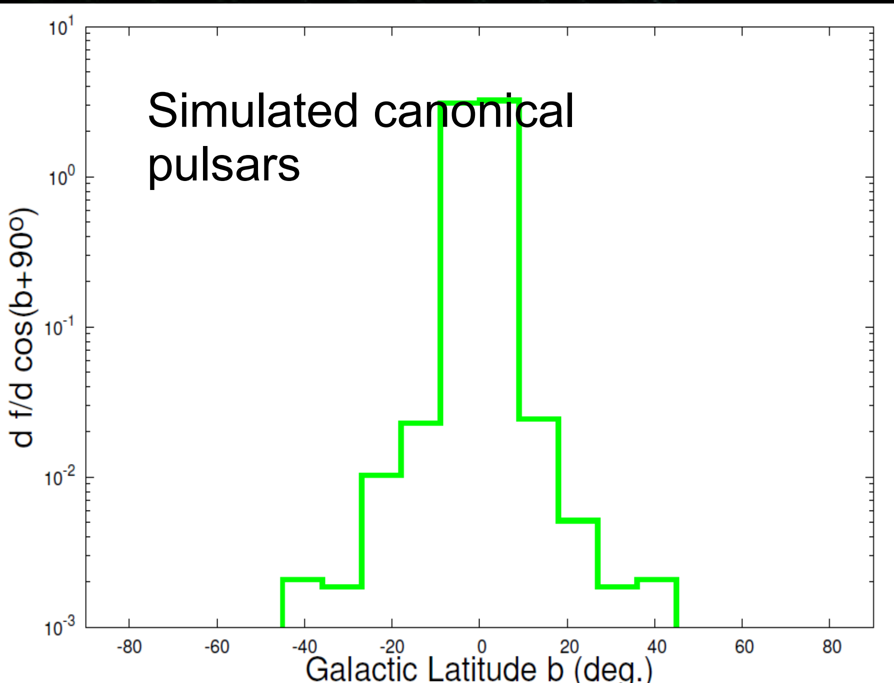
Galactic Distribution of (253) Fermi unidentified sources with C>5 and V<23

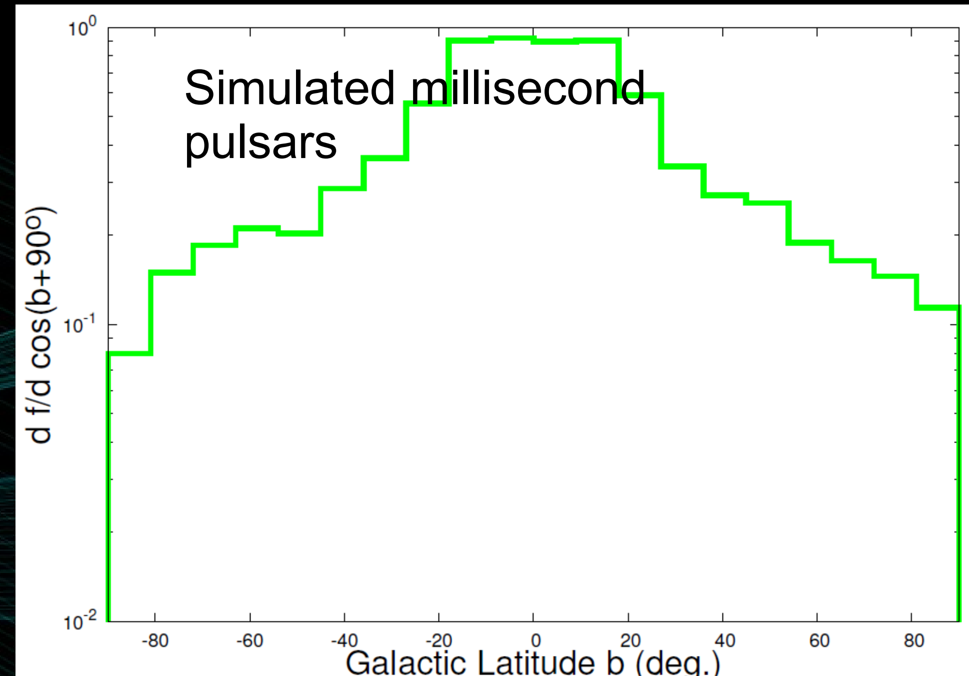


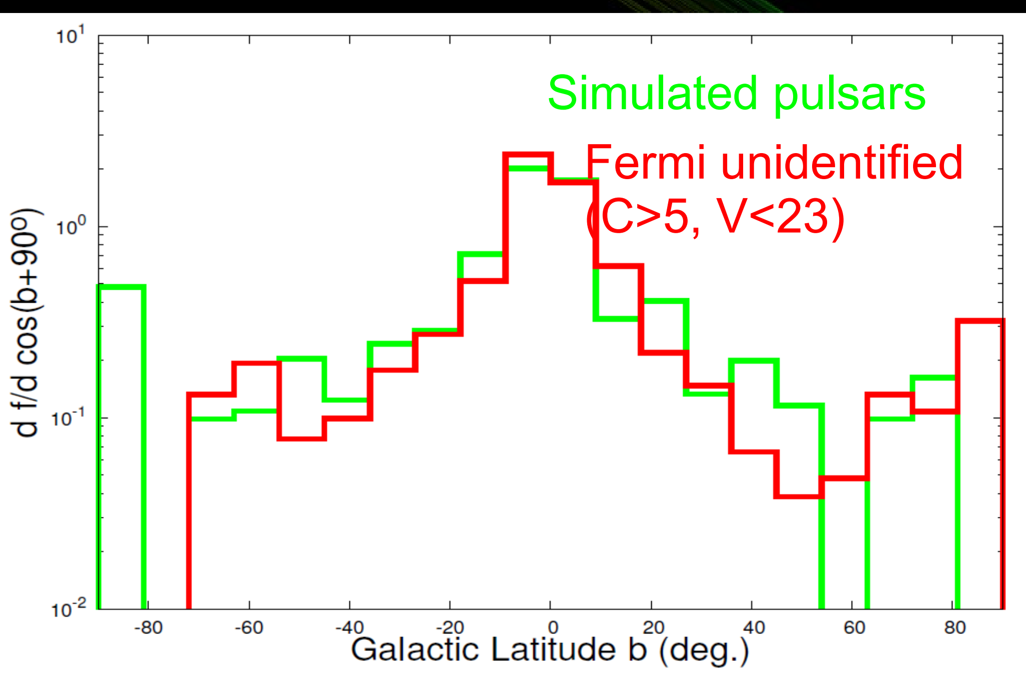


- Fermi unidentified (253) sources with C>5 and V<23 must be dominated by the Galactic sources.









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. → 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.