Periodicity Search of the Geminga-like Pulsars

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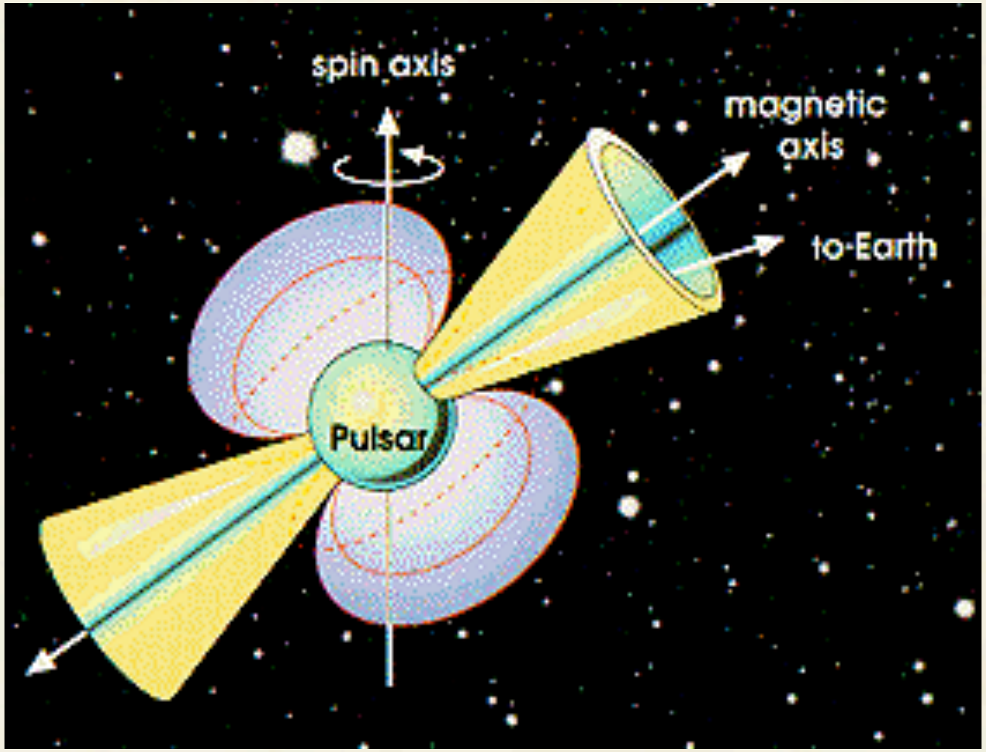
Outline :

- **Periodicity as a multiwavelength tool**
- **Our method to perform periodicity search**
- **Candidates of the next Geminga**
- **The contribution of the Fermi Observatory**

(Workshop in Hong-Kong Univ. 06/22, 2010)

Periodicity as a Multiwavelength Tool

- Gamma radiation is produced by interactions of energetic particles.
High-energy particles, as they lose energy, can radiate in lower-energy bands.
- Periodic variability at multiple wavelengths is a definitive identifier.
- Variability studies have shown that pulsars have low variability (except for their pulsations).
- Pulsars (rotating neutron stars) are the prototype of this approach.



Periodicity as a Multiwavelength Tool

The approach:

search out a periodic signal at one wavelength, then fold data for other wavelength bands at the expected period.

- **At some level, gamma-ray sources will have X-ray counterparts. If the X-ray counterpart can be found, the better X-ray position information allows deep searches at longer wavelengths.**
- **The classic example is Geminga. Bignami, Caraveo, Lamb, and Halpern got the detection of X-ray pulsations from this isolated neutron star in 1992.**

LETTERS TO NATURE

Discovery of soft X-ray pulsations from the γ-ray source Geminga

J. P. Halpern* & S. S. Holt†

LETTERS TO NATURE

Pulsed high-energy γ-radiation from Geminga (1E0630+178)

D. L. Bertsch*, K. T. S. Brazier†, C. E. Fichtel*, R. C. Hartman*, S. D. Hunter*, G. Kanbach†, D. A. Kniffen‡, P. W. Kwok*, Y. C. Lin§, J. R. Mattox*¶, H. A. Mayer-Hasselwander†, C. v. Montigny†, P. F. Michelson§, P. L. Nolan§, K. Pinkau†, H. Rothermel†, E. J. Schneid||, M. Sommer†, P. Sreekumar* & D. J. Thompson*

- **In addition to the identification, periodic sources allow exploration of physical processes.**

Period v. Period derivative diagram for known Pulsars

Before the launch of Fermi observatory:

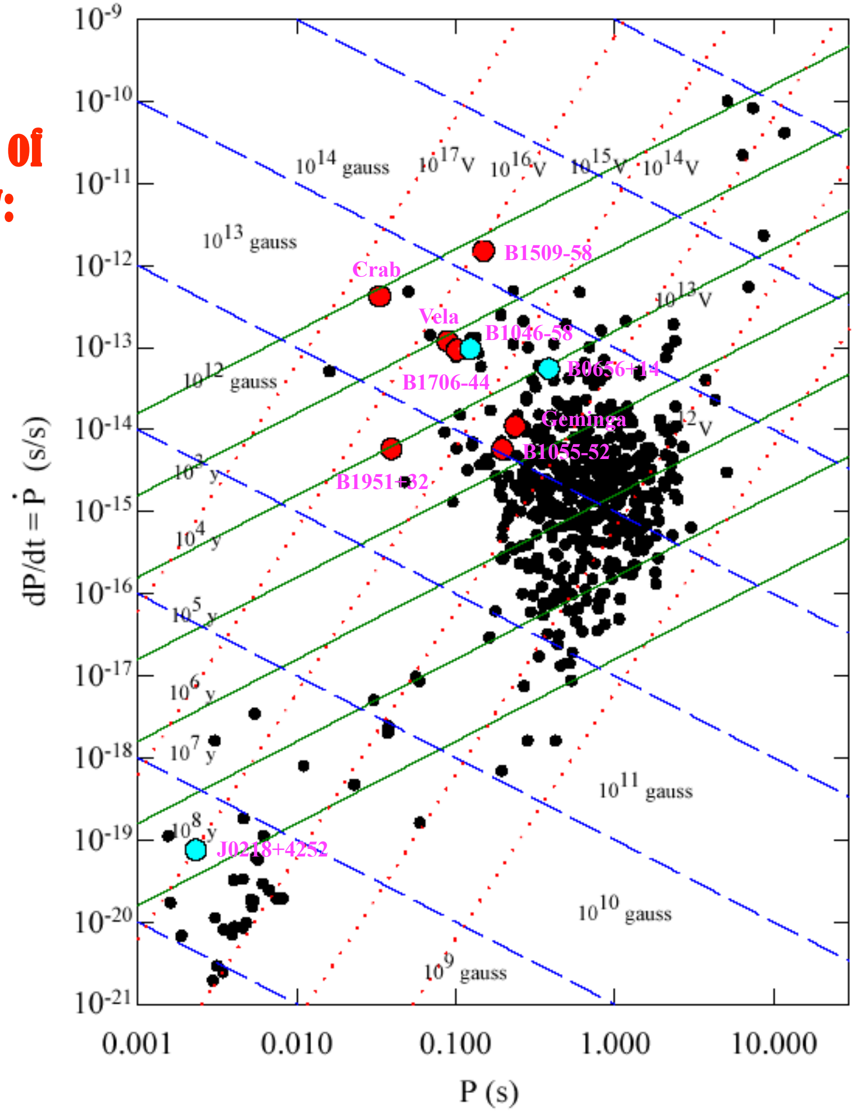


FIGURE 3. Period v. period derivative for a large sample of pulsars. Small dots: no gamma-ray emission. Large dark dots: seven high-confidence gamma-ray pulsars. Large light dots: three lower-confidence gamma-ray pulsars. Solid lines: timing age. Dotted line: open field line voltage. Dashed line: surface magnetic fields. (Thompson, 2001)

Characteristic age:

$$T = P/2\dot{P} \text{ year}$$

Spin-down energy:

$$\dot{E} = 4\times10^{46}\frac{\dot{P}}{P^3} \text{ erg/s}$$

Magnetic field:

$$B \sim 3.2\times10^{19}\sqrt{P\dot{P}} \text{ gauss}$$

Open field line voltage:

$$\Phi_{open} = 4\times10^{20}P^{-3/2}\dot{P}^{1/2} \text{ volt}$$

The current of relativistic particles flow:

$$\dot{N} \sim 1.7\times10^{38}\dot{P}^{1/2}P^{-3/2} \propto \sqrt{\dot{E}} \text{ s}^{-1}$$

Neutron stars

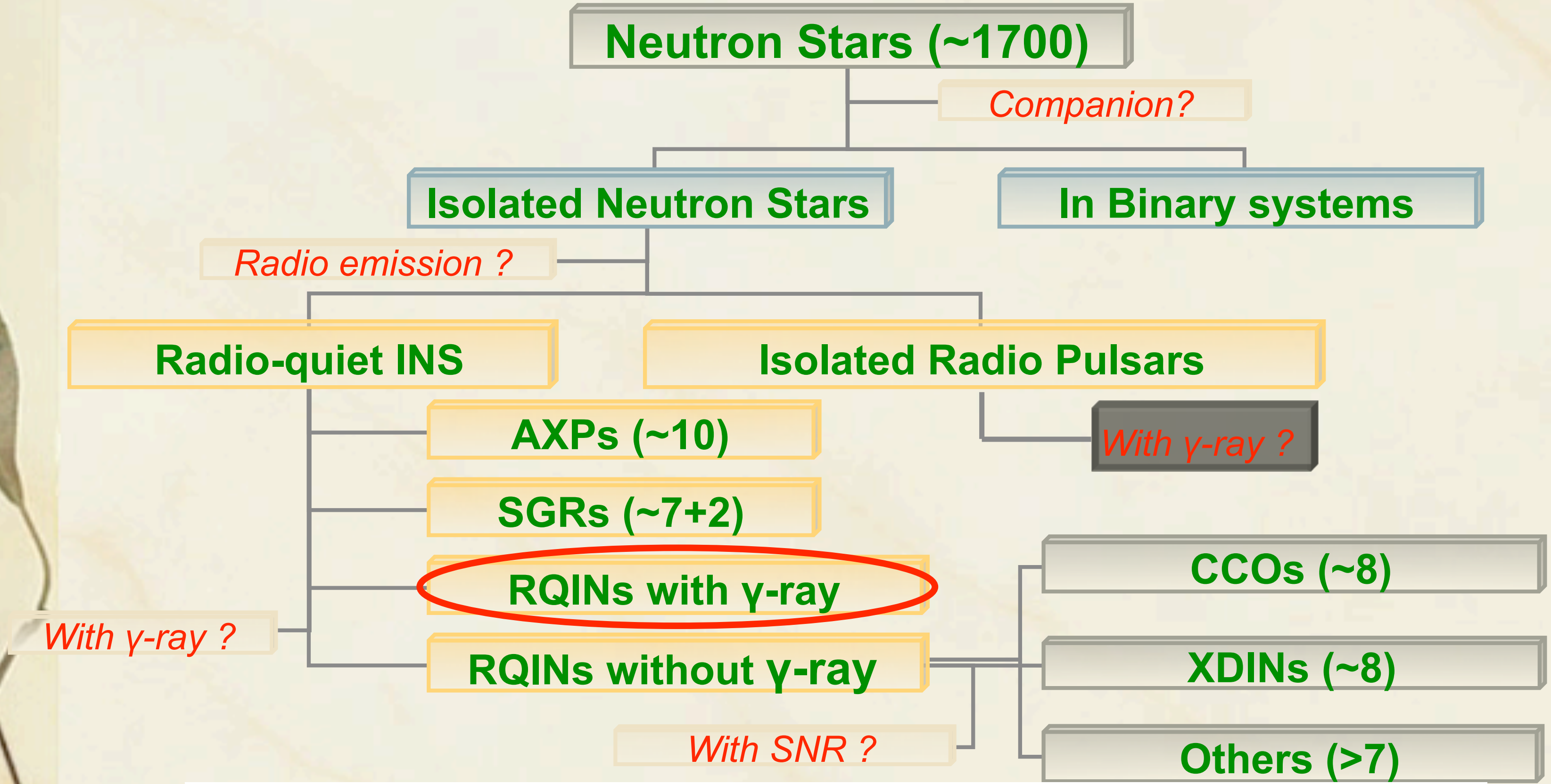


TABLE 4

SUMMARY PROPERTIES OF THE KNOWN GAMMA-RAY PULSARS (D.J. Thompson et al, 1999)

Name	P (s)	τ (y)	$\dot{E}$ (erg s^{-1})	F_E (erg cm^{-2} s^{-1})	d (kpc)	L_{HE} (erg s^{-1})	η ($E > 1$ eV)
Crab …………	0.033	1300	4.5×10^{38}	1.3×10^{-8}	2.0	5.0×10^{35}	0.001
B1509−58……	0.150	1500	1.8×10^{37}	8.8×10^{-10}	4.4	1.6×10^{35}	0.009
Vela …………	0.089	11,000	7.0×10^{36}	9.9×10^{-9}	0.5	2.4×10^{34}	0.003
B1706−44……	0.102	17,000	3.4×10^{36}	1.3×10^{-9}	2.4	6.9×10^{34}	0.020
B1951+32……	0.040	110,000	3.7×10^{36}	4.3×10^{-10}	2.5	2.5×10^{34}	0.007
Geminga………	0.237	340,000	3.3×10^{34}	3.9×10^{-9}	0.16	9.6×10^{32}	0.029
B1055−52……	0.197	530,000	3.0×10^{34}	2.9×10^{-10}	1.5	6.2×10^{33}	0.207

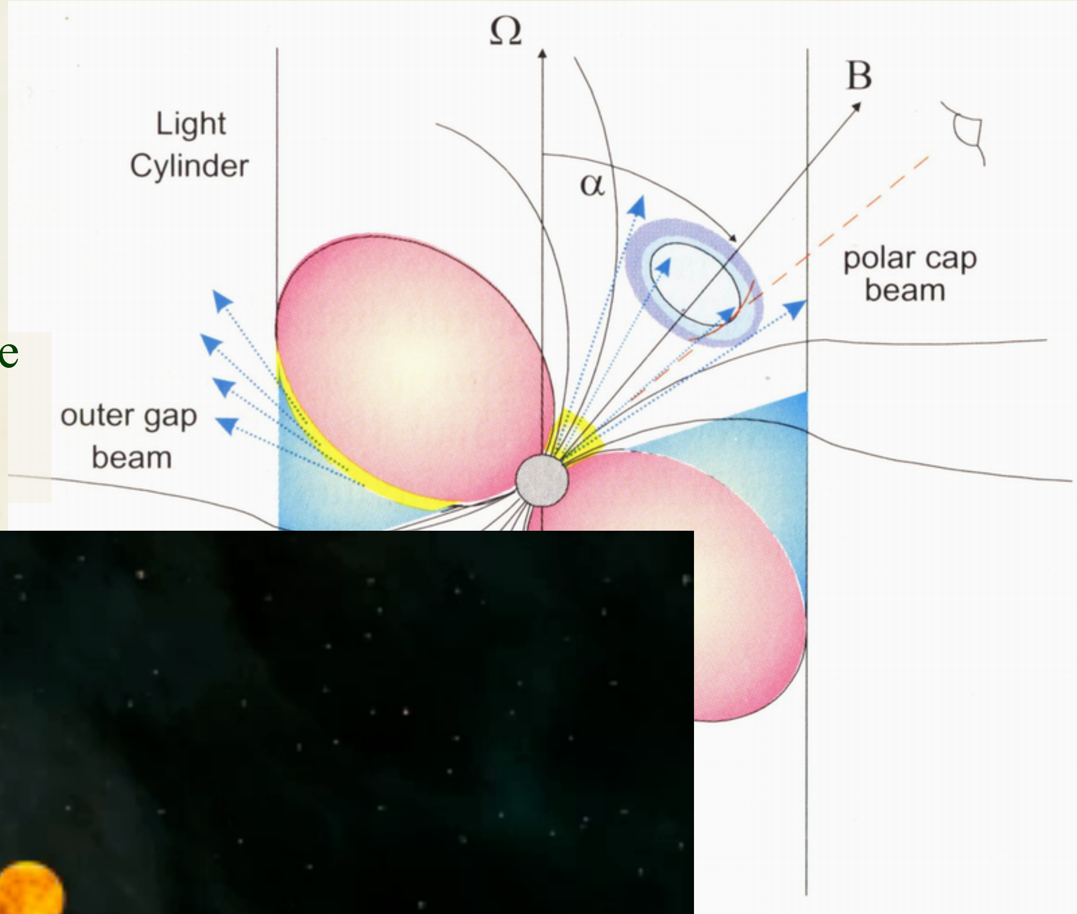
Possible γ-ray Emission Mechanism of Pulsars

Outer Gap Models
(Romani & Yadigaroglu 1995; Cheng & Zhang 1998)

- Particle acceleration in outer gap (where Ω•B = 0) generates gamma rays

Polar-Cap Models

- Long-standing interpretation of radio pulse emission; beam directed along magnetic dipole axis (Radhakrishnan & Cooke 1969)



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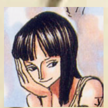
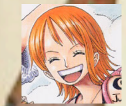
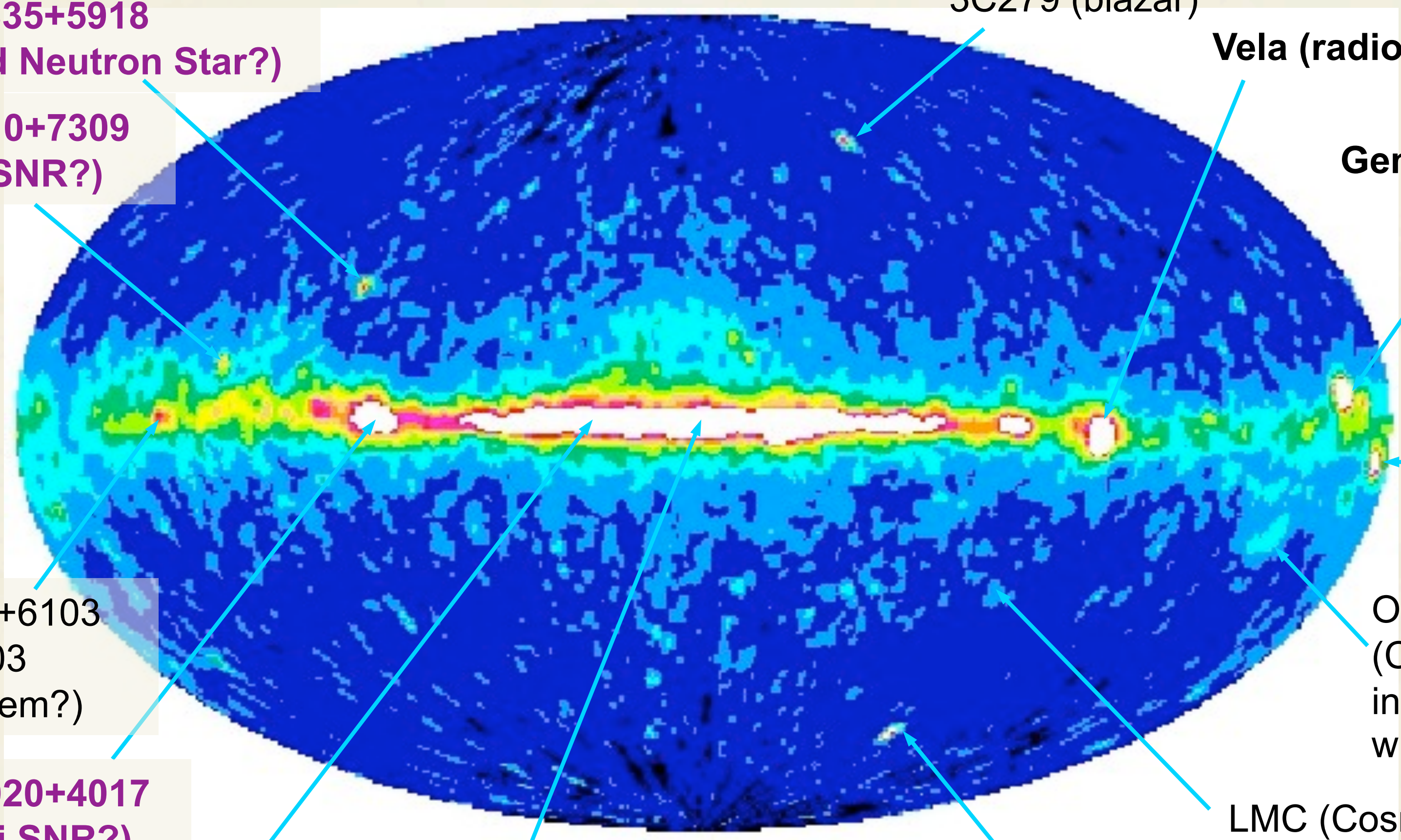


Unidentified EGRET sources



According to Lamb and Macomb, 1997; there are around 30 sources in the sky with GeV fluxes above $4x10^{-8}$ photons cm^{-2} s^{-1}. Some of them which lie almost exclusively along the Galactic plane are currently unidentified.

EGRET All Sky Map (>1 GeV)



(Thompson, 2004)

Unidentified EGRET sources

From Roberts and Romani (2001), they present a catalog of 2-10 keV ASCA GIS images of fields containing bright sources of GeV emission. The images cover ~85% of the 95% confidence position contour for 28 of the 30 sources.

According to the unidentified sources of Robert’s catalog and the constraint of available data sets, we can work on periodicity search for the X-ray counterparts of those radio-quiet ϒ-ray pulsar candidates.

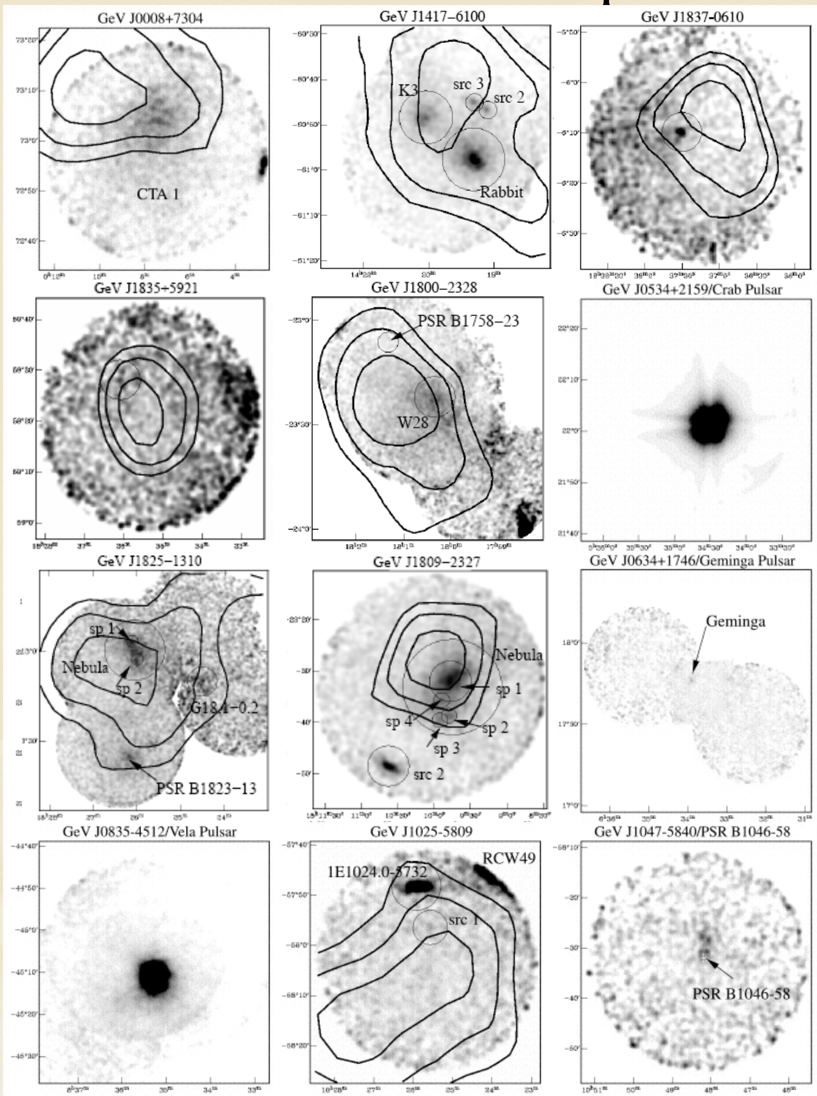


Fig. Roberts, Romani, Kawai – ASCA searches, evidence of pulsar wind nebulae.

How can we detect the marginal pulsation?

Unidentified GeV sources which might be next Geminga

The only way is blind search and data cross-checking

- Based on 5 independent significant trial periods which are selected by H-test from each X-ray data, we search related periods in other data of the same point source by the condition that **the characteristic age of the pulsar is larger than 1000 years**.

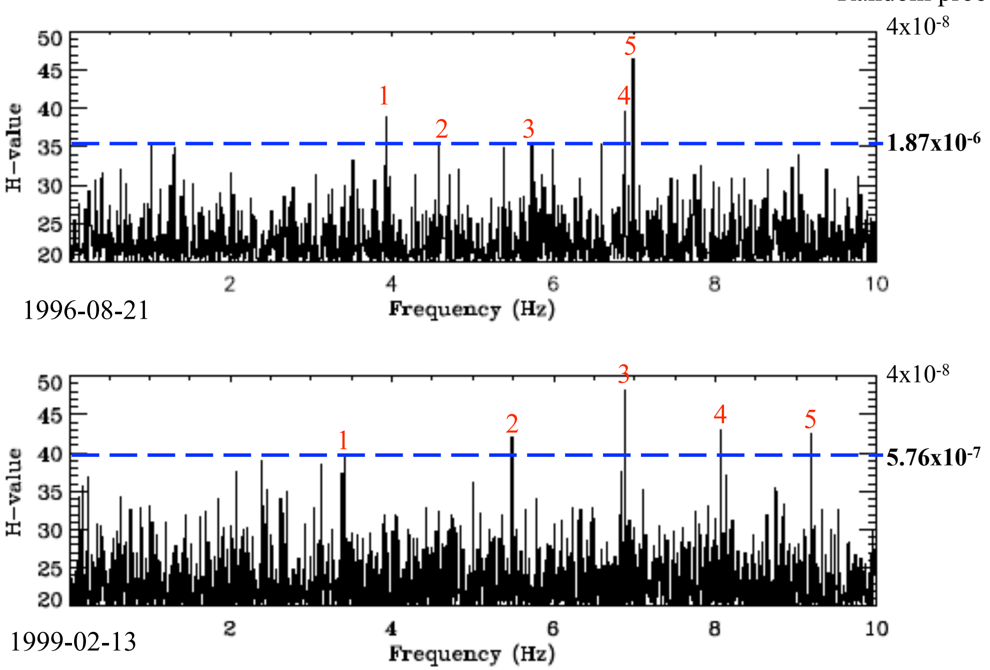


Fig a. Blind search in 2 ASCA data of AX J1420.1-6049

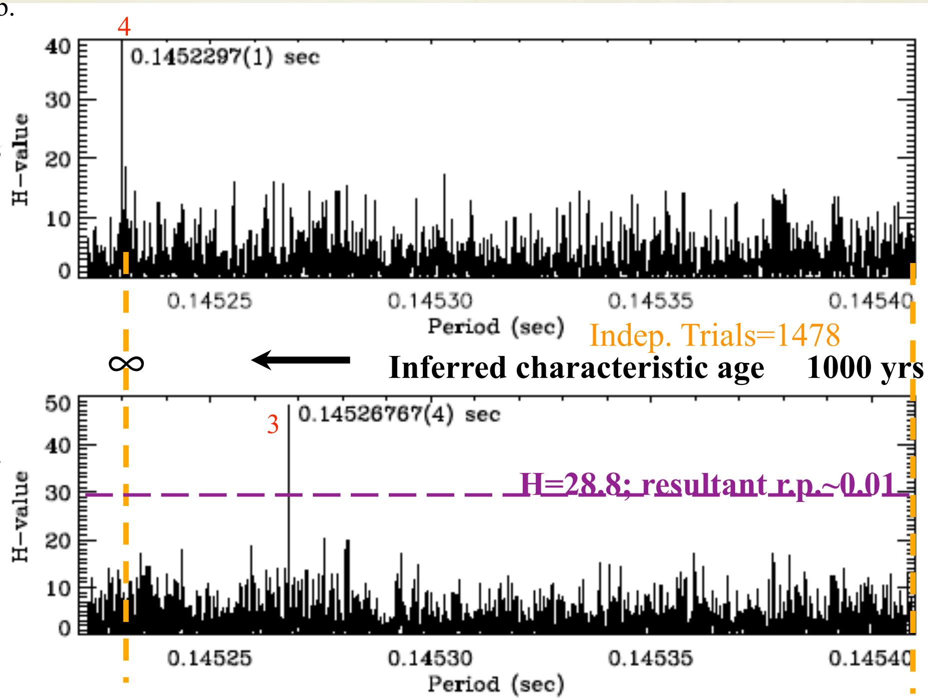


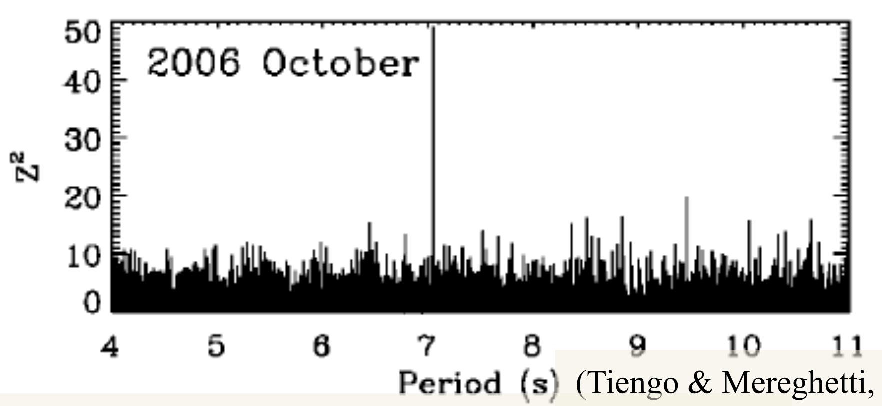
Fig b. Candidate period of AX J1420.1-6049 from data cross-checking

How can we detect the marginal pulsation?

- Furthermore, in order to let our choice to be more convincible, we only consider that (the Chance Probability of the Prominent Feature in the First Data Set) X (the Chance Probability of the Related Period in the Second Data set) < **0.01**.
- We also tested this method with weak pulsar candidates.
  We examined some CCOs and XDINSs with only marginal evidences of periodicity detection.

Tiengo & Mereghetti (2007) reported the marginal period **7.055s** of RX J1856.5-3754 with the chance prob. of 6×10^{-4}. (Epoch: 54032.44076 MJD)

FIG. 2.—Distributions of the Z^2-statistics for the *XMM-Newton* observations of RX J1856.5−3754.



(Tiengo & Mereghetti, 2007)

We obtain the consistent period with the **r.p. ~ 4×10^{-4}** using **5 XMM** observations to eliminate the fake results induced by random noise.

Table. Possible pulsed candidates of RX J1856.5-3754

RX J1856.6-3754	period (s)	T_c (year)	dp/dt (10^{-13} s/s)	Epoch(MJD)	E.P.
P1	7.054898	71820	15.56	52373.00618-53113.30249	3.92×10^{-4}

The New Geminga-like pulsars

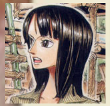
我要成為宇宙王!!

Vela-like pulsar: age ~ 10^4 yrs; Geminga-like pulsar: age > 10^5 yr

Table 2: Rotational ephemerides for the new pulsars. For all timing solutions, the reference epoch is MJD 54754. The given frequency and frequency derivative are barycentric. The numbers in parentheses indicate the error in the last decimal digit(s). For LAT PSR J0357+32, marked with (†), the measured frequency derivative, and thus the derived parameters, may be significantly affected by positional error (see text).We also list the number of photons, n_γ, obtained with the cuts used in this work (see text) over the 5 month observational period. The (1–100 GeV) photon number flux, F_{35}, is given, as presented in the *Fermi* Bright Source List (*39*), except for LAT PSR J2238+59, which was not in the Bright Source List but whose flux was derived from the same data set and analysis approach. (Abdo et al., 2009)

LAT PSR	n_γ	F_{35} (10^{-8} cm^{-2} s^{-1})	f (Hz)	$\dot{f}$ (-10^{-12} Hz s^{-1})	τ (kyr)	$\dot{E}$ (10^{34} erg s^{-1})	B (10^{12} G)
J0007+7303	1509	6.14(27)	3.1658891845(5)	3.6133(3)	13.9	45.2	10.8
J0357+32	294	0.64(10)	2.251723430(1)	0.0610(9)†	585.0	0.5	2.3
J0633+0632	648	1.60(17)	3.3625440117(3)	0.8992(2)	59.3	11.9	4.9
J1418-6058	3160	5.42(38)	9.0440257591(8)	13.8687(5)	10.3	495.2	4.4
J1459-60	1089	1.26(21)	9.694596648(2)	2.401(1)	64.0	91.9	1.6
J1732-31	2843	3.89(33)	5.087952372(2)	0.677(1)	120.0	13.6	2.3
J1741-2054	889	1.31(17)	2.417211371(1)	0.098(7)	392.1	0.9	2.7
J1809-2332	2606	5.63(31)	6.8125455291(4)	1.5975(3)	67.6	43.0	2.3
J1813-1246	1832	2.79(24)	20.802108713(5)	7.615(4)	43.3	625.7	0.9
J1826-1256	4102	2.47(27)	9.0726142968(4)	9.9996(3)	14.4	358.2	3.7
J1836+5925	2076	8.36(31)	5.7715516964(9)	0.0508(6)	1800.0	1.2	0.5
J1907+06	2869	3.74(29)	9.378101746(2)	7.682(1)	19.4	284.4	3.1
J1958+2846	1355	1.29(18)	3.4436636006(8)	2.6351(5)	20.7	35.8	8.1
J2021+4026	4136	10.60(40)	3.769079109(1)	0.7780(7)	76.8	11.6	3.9
J2032+4127	2371	3.07(26)	6.9809351235(8)	0.9560(4)	115.8	26.3	1.7
J2238+59	811	0.96(11)	6.145017519(3)	3.722(2)	26.3	90.3	4.1

The new sight provided by Fermi

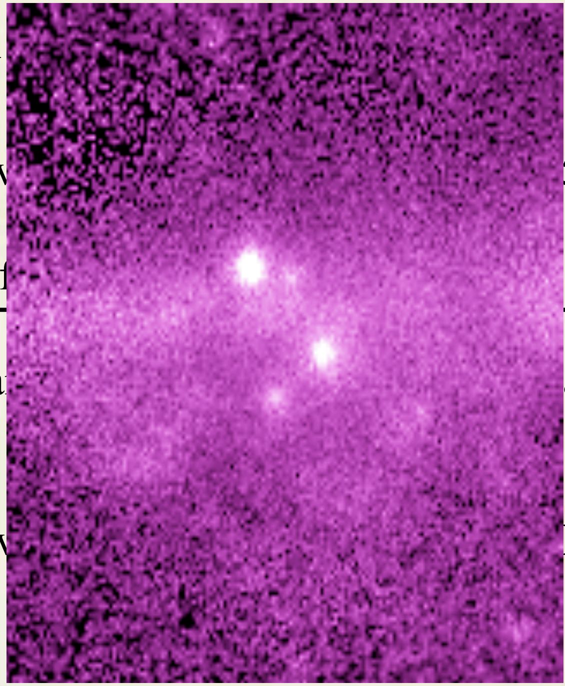


Based on the pulsed detections of Fermi data, we suggest that the origin of Geminga-like pulsars being radio-quiet is geometric, instead of intrinsic.

Table. List of GLAST instrument parameters compared to those of EGRET.

Parameter	EGRET	GLAST (Fermi)
Energy Range	20 MeV to 30 GeV	20 MeV to 300 GeV
Energy	10%	
Effectiv	500 cm^2	
Field of	0.5 sr	
Angula	at 100 Me	
Sensitiv	0^{-7} ph cm^{-}	
Source	30 arcmi	

EGRET observed

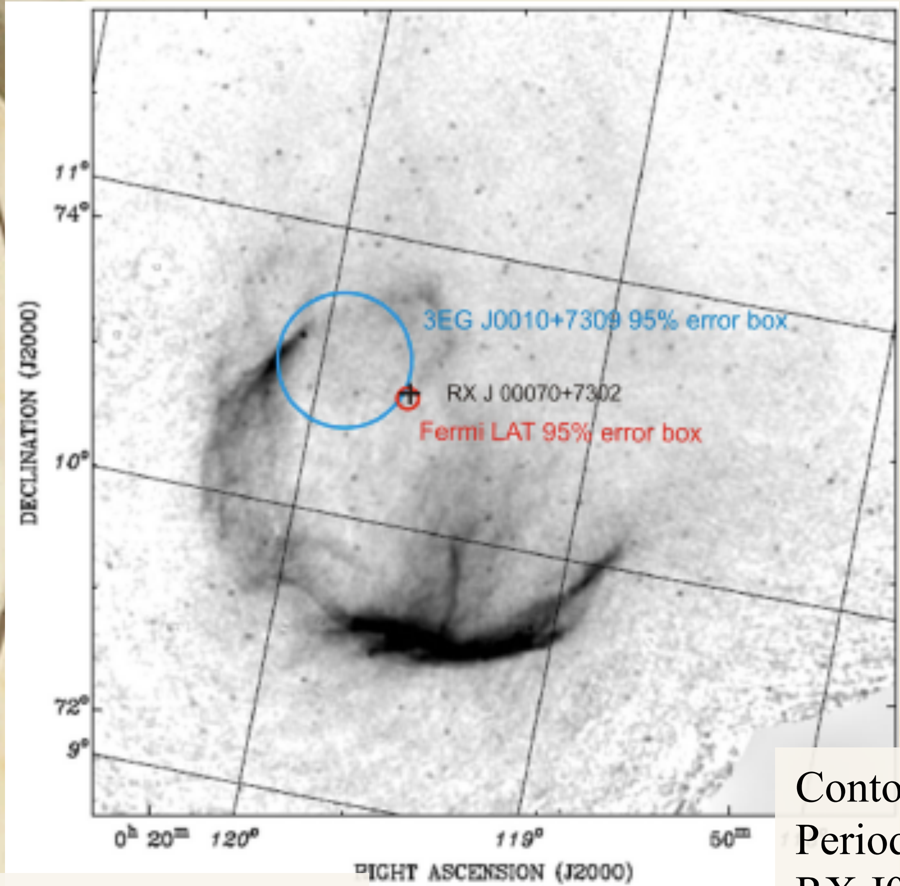


Fermi observed

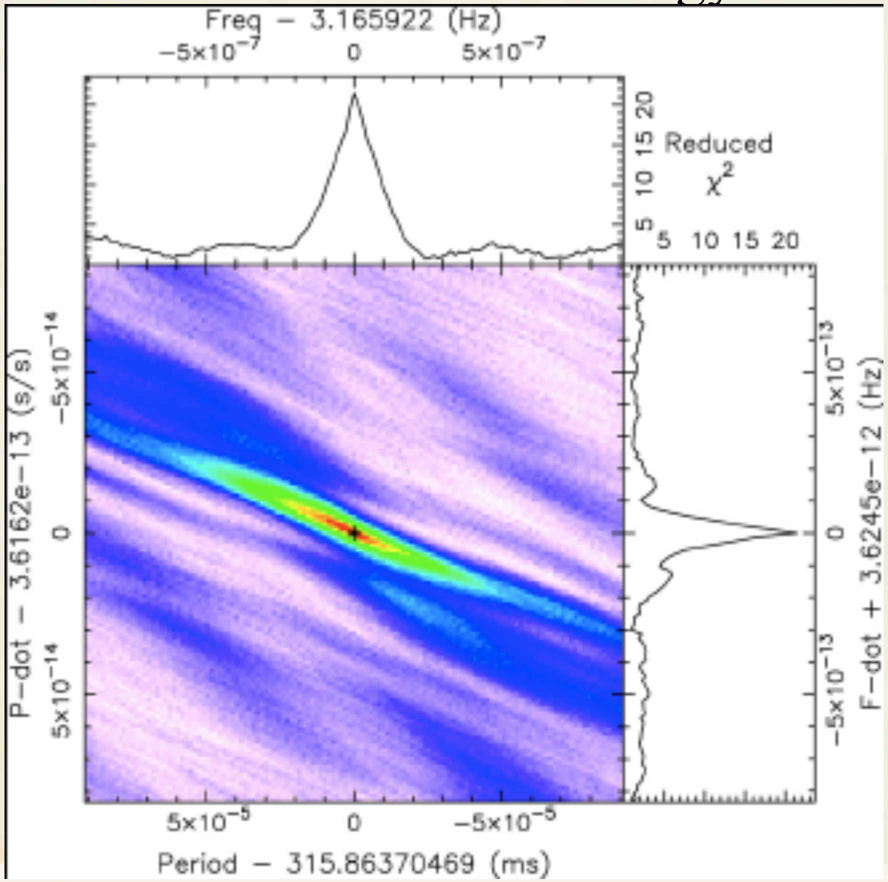
Connection of the γ–ray pulsars and their X-ray counterparts

Period of the Fermi pulsars may give us hint to detect the periodicity for their X-ray counterparts without using blind search and therefore strengthen the identification of the source in different energy bands.

EX: Pulsar centered in CTA 1

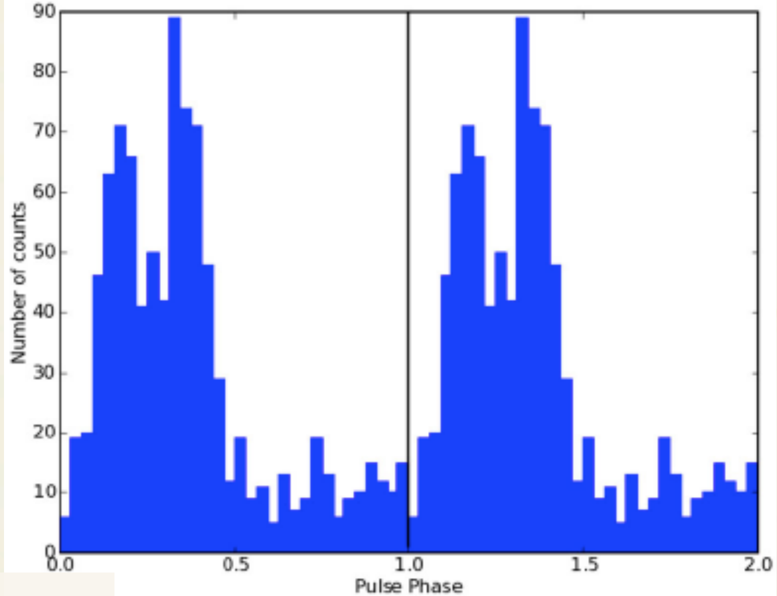


(Abdo et al., 2008)



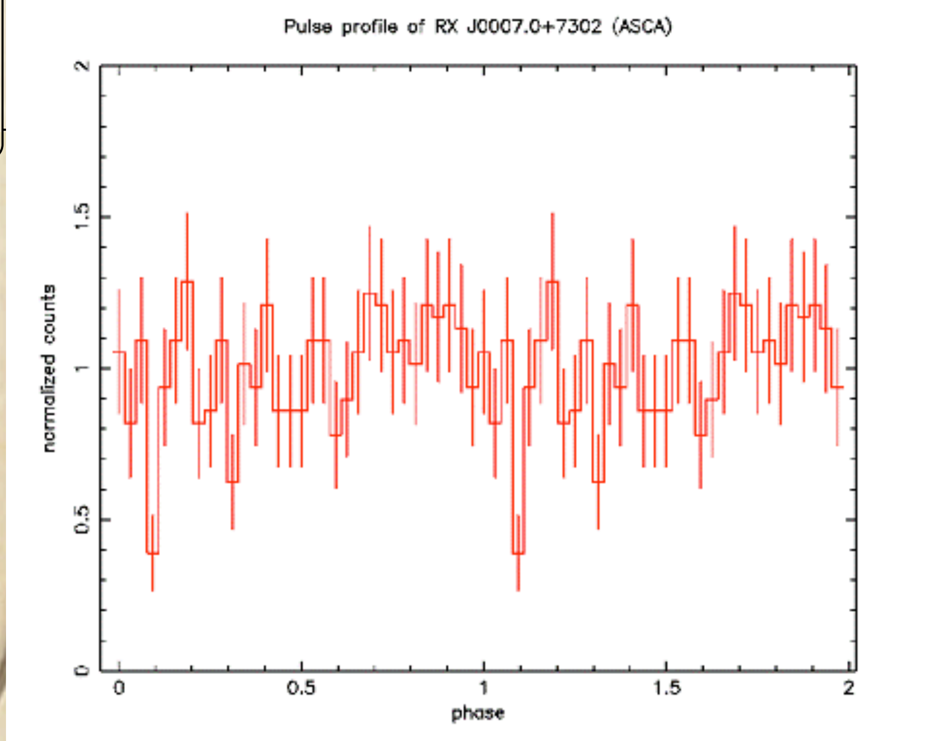
Contours of detection significance over a range of period and Period derivative using photons within a radius of 1º around RX J0007.0+7302. The initial indication of a signal in this P, dP/dt region was found with a novel technique.

Frequency (Hz)	3.165922467(9)
Frequency derivative (s^{-2})	$-3.623(4) \times 10^{-12}$
Period (ms)	315.8637050(9)
Period derivative ($s\ s^{-1}$)	$3.615(4) \times 10^{-13}$
Epoch [MJD (TDB)]	54647.440 938
R.A. (J2000.0)	$00^h\ 07^m\ 01^s.56$
DEC. (J2000.0)	+73° 03′ 08′′.1
Galactic longitude	119°.65947(3)
Galactic latitude	+10°.463348(3)

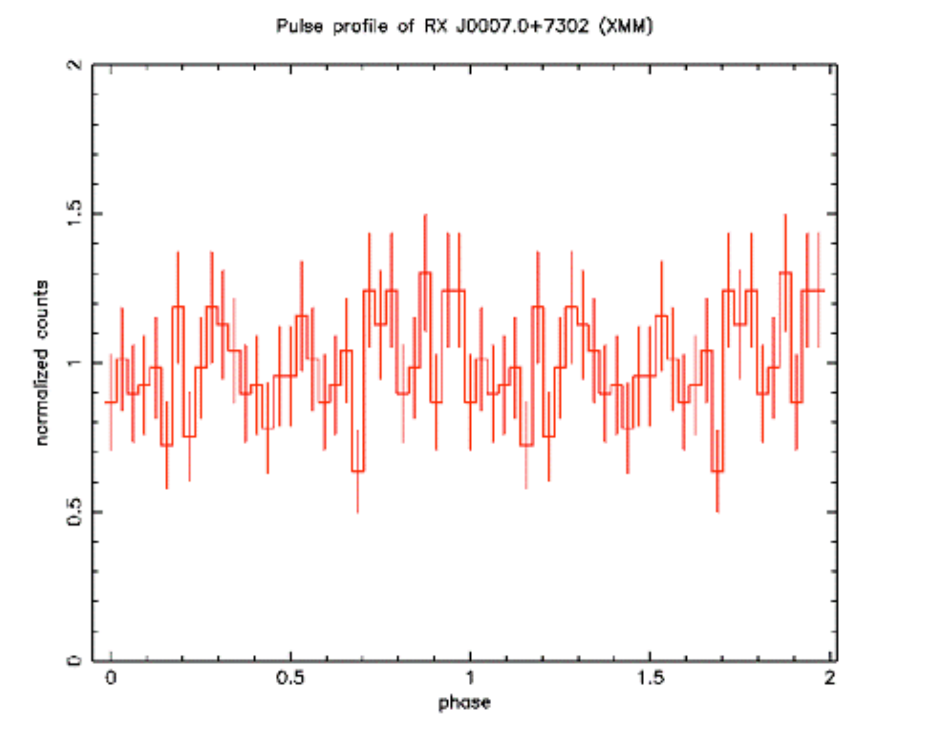


(Abdo et al., 2008)

Pulse profile of RX J0007.0+7302 (ASCA)



Pulse profile of RX J0007.0+7302 (XMM)



X-ray pulsation of the Geminga-like pulsars

Applying for the better data is necessary to verify the pulsed detection for the possible X-ray counterparts to radio-quiet γ-ray pulsars.

XMM-Newton Master Log & Public Archive (xmmmaster) Bulletin

Search radius used: 15.00 '

Select All	Related Links	Services	obsid / Dataset ID	status	name	ra	dec	time	duration [s]	pi lname	pi fname	public date	data in heasarc	Search Offset ['] from (target)
	Chan ROSAT RXTE ASCA Abstract	O R N S D H	0604940201	processed	CTA1	00 07 05.34	+73 02 02.9	2009-03-07 13:05:37	6128	Caraveo	Patrizia	2010-06-03	N	1.093 (RX J0007.0+7302)
	Chan ROSAT RXTE ASCA Abstract	O R N S D H	0604940101	processed	CTA1	00 07 05.16	+73 02 02.2	2009-03-07 15:06:44	120282	Caraveo	Patrizia	2010-06-03	N	1.102 (RX J0007.0+7302)
	Chan ROSAT RXTE ASCA Abstract	O R N S D H	0011430201	archived	CTA1	00 07 02.50	+73 01 51.1	2002-02-21 18:56:32	41594	Slane	Patrick	2003-07-04	Y	1.265 (RX J0007.0+7302)

Suzaku Master Catalog (suzamaster) Bulletin

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Select All	Related Links	Services	name	ra	dec	time	obsid	exposure [s]	processing date	public date	Search Offset ['] from (target)
	XIS	O R N S D H	RXJ0007.0+7302	00 07 33.98	+72 59 03.5	2010-01-08 14:40:15	404011010	105373.90000	2010-01-22 10:52:09	2011-01-26	4.675 (RX J0007.0+7302)

Proposal for *SUZAKU* Observations — AO 4

Cover Page

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Proposal Title
X-RAY OBSERVATIONS OF GAMMA-RAY PULSAR AND ITS WIND NEBULA IN CTA1

Subject Category	GALACTIC POINT SOURCES	Program Type	REGULAR
Number of Targets 3	Total Time 180.00	TOO Proposal? N	Merging? Y

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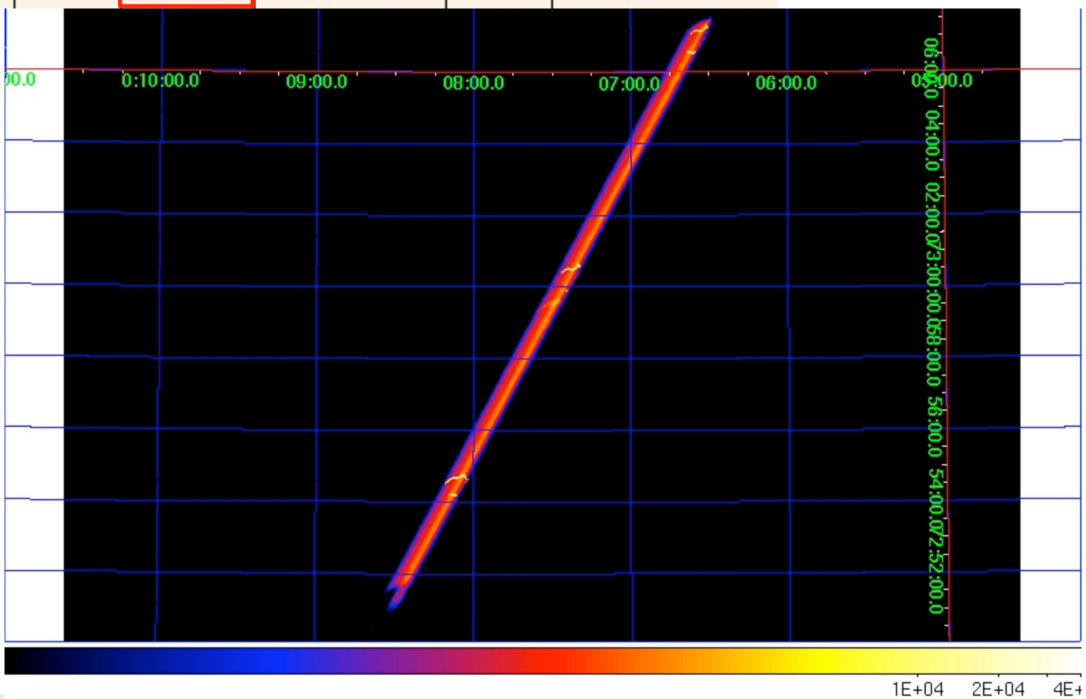
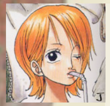
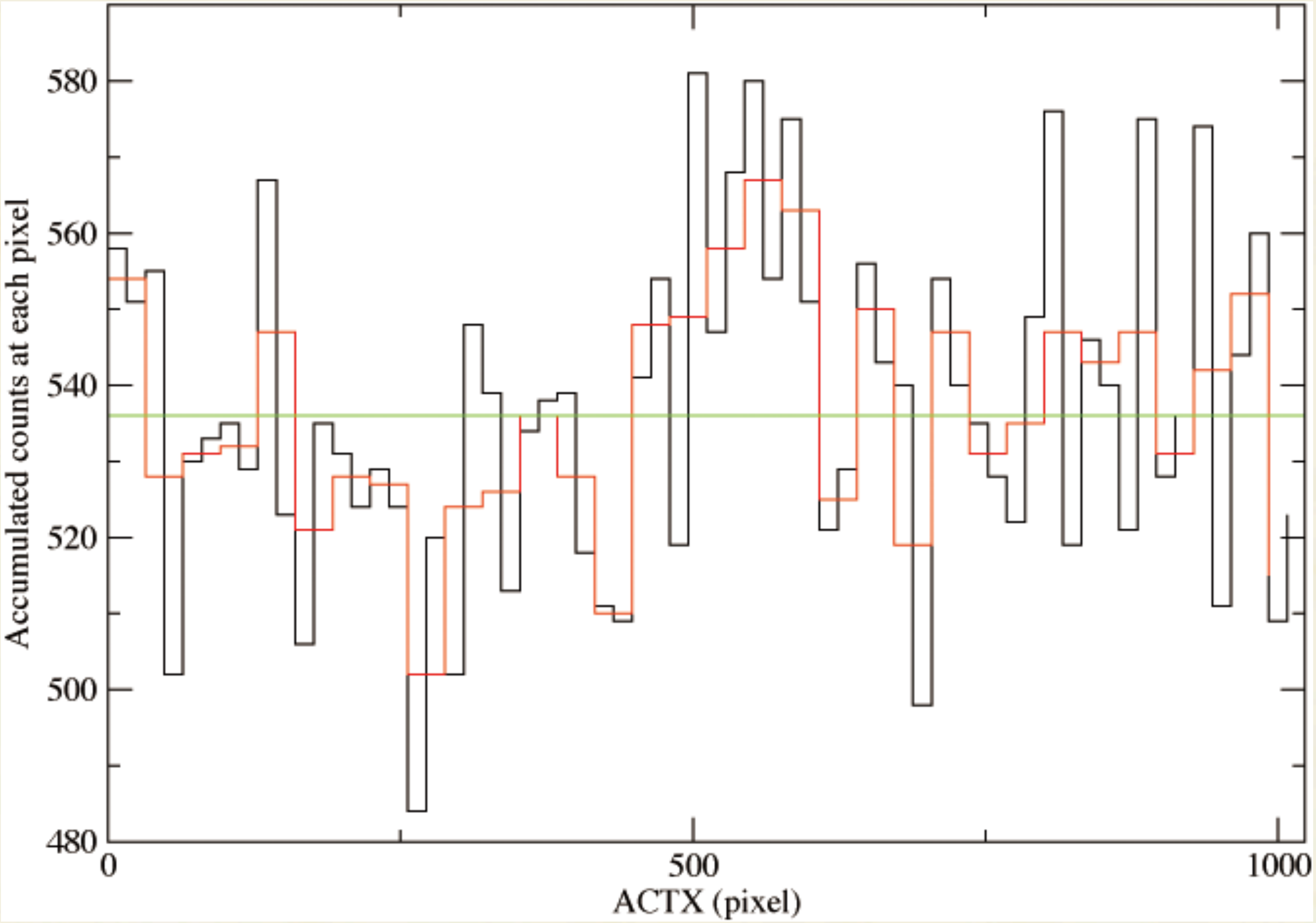
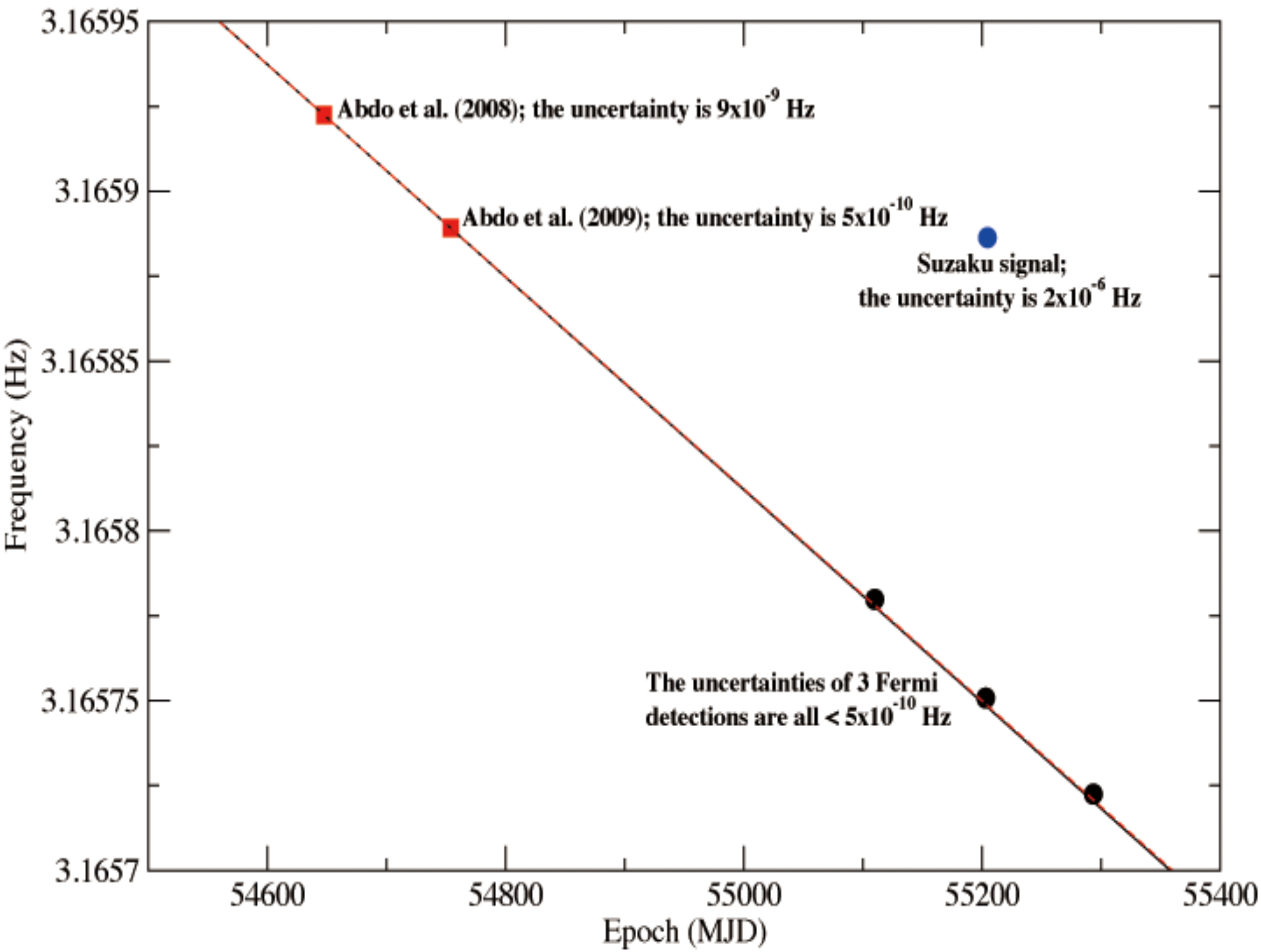


The X-ray counterpart in the Suzaku data



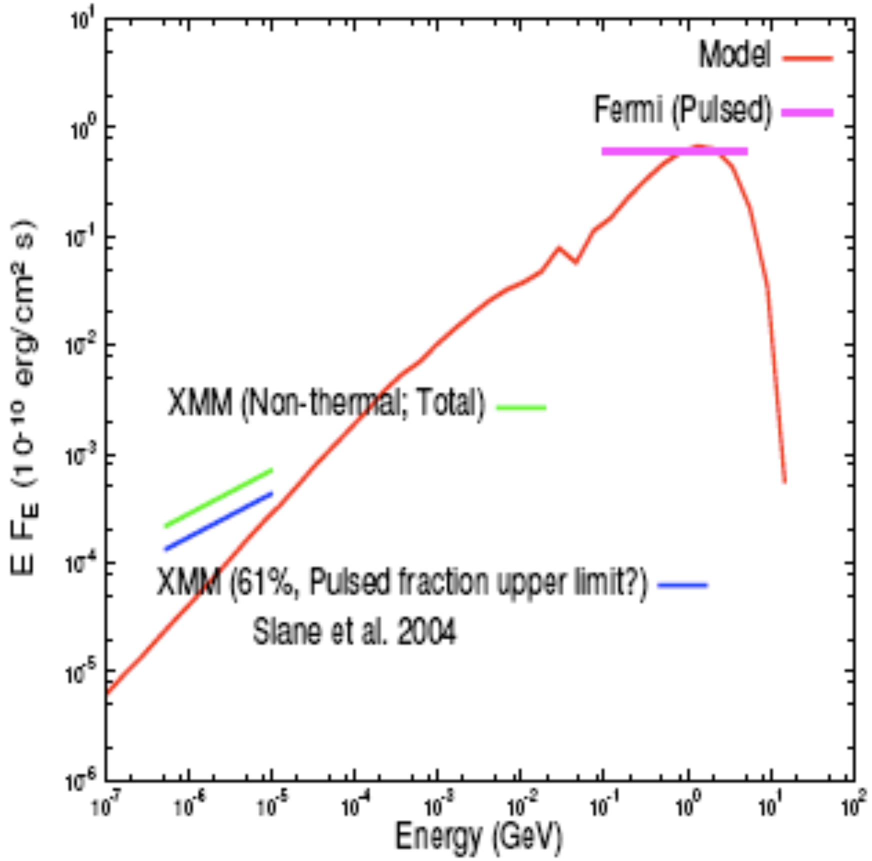
496-608 pixels ~**118”** represents the source region.
8 pixels inside the source region are treated as hot pixels and are removed.
58255 counts of the X-ray source within **0.2-12 keV** are obtained for timing analysis.
The black line marks the average counts distribution to bin with 16 pixels;
the red one marks the average counts distribution to bin with 32 pixels
and the green line marks the Median of **536**.





3.16595
3.1659
3.16585
3.1658
3.16575
3.1657
Frequency (Hz)
54600
54800
55000
55200
55400
Epoch (MJD)
Abdo et al. (2008); the uncertainty is 9x10^-9 Hz
Abdo et al. (2009); the uncertainty is 5x10^-10 Hz
Suzaku signal;
the uncertainty is 2x10^-6 Hz
The uncertainties of 3 Fermi
detections are all < 5x10^-10 Hz

he Geminga-like pulsars



The spectrum of γ-ray pulsar in CTA 1.
The red line shows the calculated pulsed spectrum.

Model result

Calculated spectrum (red line) in energy bands 0.5-10 keV is fitted by

$$F(E) = 2.62 \times 10^{-6} \left(\frac{E}{1\ \mathrm{keV}}\right)^{-1.17} \quad \mathrm{photos/cm^2/s/keV}.$$

The green line shows the spectrum of the non-thermal component for the total emission of the RXJ0007.0+7302. The blue line shows the 61% of the flux of the green line. According to the calculated pulsed spectrum of the pulsar supposed by Jumpei T., we can obtain ~135 counts from the pulsation of the neutron star with the circular region in the radius of 1'.5.

However, we obtained ~58000 counts from the source extraction.

Spectral Parameters

Parameter	CTA 1 *ASCA* GIS PL + Thermal	RX J0007.0+7302 *XMM-Newton* EPIC PL + BB	 PL + NSA
N_H (cm^{-2})	2.8 × 10^{21} (fixed)	±2.8 × 10^{21} (fixed)	2.8 × 10^{21} (fixed)
Γ (photons)	2.3 ± 0.2	1.5 ± 0.2	1.6 ± 0.2
$F_{X,PL}$[a] (ergs cm^{-2} s^{-1})	4.8 × 10^{-12}	2.0 × 10^{-13}	2.0 × 10^{-13}
kT (keV)	$0.28^{+0.3}_{-0.08}$	0.136 ± 0.012	0.053 ± 0.004
$F_{X,Th}$[b] (ergs cm^{-2} s^{-1})	1.1 × 10^{-11}	3.3 × 10^{-14}	3.5 × 10^{-14}
R (km)	...	$0.63d_{1.4}$	10 (fixed)
χ^2/dof	437.2/474	117.5/116	112.2/116

[a] Unabsorbed flux (0.5–10 keV), for power-law component. [b] Unabsorbed flux (0.5–10 keV), for thermal component.

(Slane et al. 2004)

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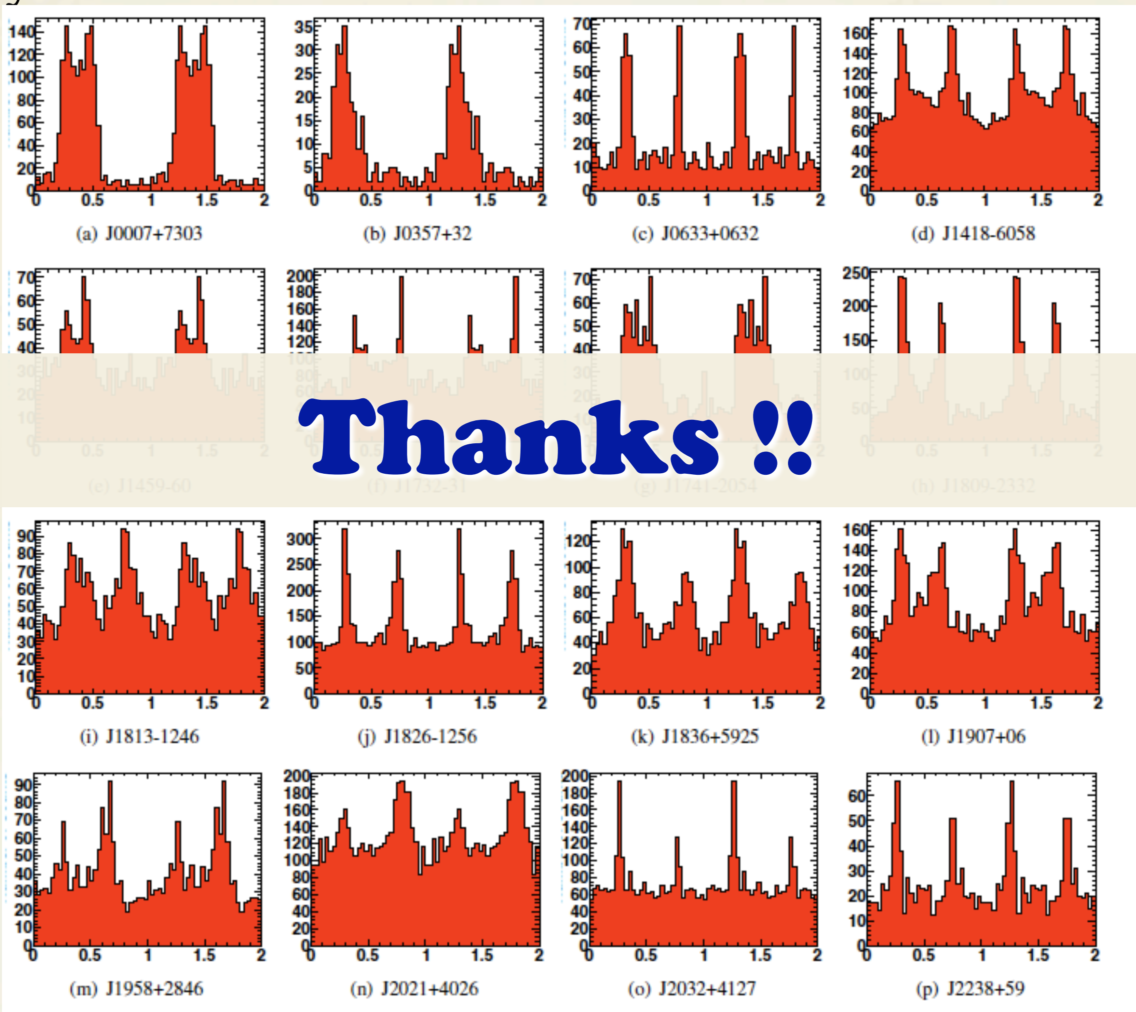
Connection of the γ-ray pulsars and their X-ray counterparts

The X-ray pulsation of the Geminga-like pulsars are still embedded in the diffuse X-ray emission of the SNR. To ensure the connection of the Geminga-like pulsar in different energy bands, the efforts of the periodicity searchwith the better data are still needed.



Thanks !!