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低纬度未证认 γ 射线源的起源问题的探讨

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摘 要

对银道面附近 ($|b| \leq 5°$) 未证认的伽玛射线源和年龄小于 10^6 年的银河系年轻脉冲星之间的成协的可能性进行了统计研究. 结果表明, 年轻脉冲星可能说明大多数未证认 EGRET 源, 它们和超新星遗迹以及 OB 星协在位置上成协. 其表现为: 有 2/3 是年轻射电宁静脉冲星, 1/3 是年轻射电脉冲星. 对这些未证认 γ 射线源的变化性的研究发现, 它们中的大部分都是不变的. 同时我们预期, GLAST 的空间探测将可能在银道面附近 ($|b| \leq 5°$) 中检测到 $\approx 80\dot{N}_{100}$ 颗射电脉冲星和 $\approx 1100\dot{N}_{100}$ 颗未证认 γ 射线源, 这里 $\dot{N}_{100}$ 是以 100 年为单位的中子星生成率。

关 键 词 γ 射线: 理论 — 脉冲星 — 恒星: 中子星 — 恒星: 统计

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Possible Origin of Low Latitude Unidentified Gamma-ray Sources

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Abstract

We present a statistical study on possible association between the unidentified γ-ray point sources at the Galactic plane ($|b| \leq 5°$) and the Galactic young pulsars with ages of less than

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10^6 yr. Our results suggest that young pulsars may account for the majority of unidentified EGRET sources that are positionally associated with supernova remanants and OB star associations, in such a way that two thirds are young radio quiet pulsars and one third are young radio pulsars. We have studied the variability of these unidentified γ-ray sources and found that most of them may be non-variable. Furthermore, we expect that GLAST may detect $\approx 80\dot{N}_{100}$ radio pulsars and $\approx 1100\dot{N}_{100}$ unidentified γ-ray point sources in the Galactic plane with $|b| \leq 5°$, where $\dot{N}_{100}$ is the birth rate of neutron stars in units of 100 years.

Key words gamma rays: theory—pulsars: general—stars: neutron—stars: statistics

1 Introduction

The third EGRET catalog (Hartman et *al.* 1999) lists 170 unidentified point sources, where 55 unidentified point sources are at low Galactic latitudes ($|b| < 5°$). Many authors have studied the possible association of the unidentified γ-ray point sources with known objects (see Montmerle 1979; Kaaret & Cottam 1996; Yadigaroglu & Romani 1997). Recently, Romero, Benaglia & Torres(1999) have studied the possible association of the unidentified EGRET sources listed in the third (3EG) catalog with Wolf-Rayet and Of stars, SNRs and OB associations (considered as pulsar tracers). They found that 6 unidentified γ-ray sources of the 3EG catalog are positionally coincident with WR stars, 4 with Of stars, 22 with SNRs and 26 with OB associations. Obviously, at present, the number of the counterparts of the unidentified γ-ray sources increases significantly, compared to that of Yadigaroglu & Romani (1997). In such case, are there still most unidentified EGRET sources in the Galactic plane young pulsars or Geminga-like pulsars? Motivated by this question, we will use the outer gap model of γ-ray pulsars proposed by Zhang & Cheng (1997) to examine the population predictions in detail and compare the results with the observed unidentified γ-ray sources in the Galactic plane.

2 Unidentified EGRET Sources and Possible Counterparts

In the Galactic plane with $b \leq 10°$, there are 74 unidentified EGRET sources listed in third catalog (Hartman et *al* 1999). In order to find their counterparts in the Galactic plane, Romero et *al.* (1999) have studied the level of two-dimensional positional coincidences between these EGRET sources and different populations of Galactic objects such as WR and Of stars, SNRs and OB associations (considered as pulsar tracers). They found that the counterparts of these EGRET sources are 6 WR stars, 4 Of stars, 22 SNRS and 26 OB associations and there is overwhelming statistical evidence for the association of the unidentified EGRET sources with SNRs and OB star forming region. From their analysis, we can see that (i)39 unidentified EGRET sources have their counterparts, some of them more than one. And (ii)the Galactic latitudes of these 39 unidentified EGRET sources are within $b \leq 5°$. In Table 1, we list 38 unidentified EGRET

Tab. 1 Unidentified γ-ray point sources whose positions are coincident with OB associations and SNRs.

Name (3EG J)	$l/(^\circ)$	$b/(^\circ)$	F_γ [a]	α	r/kpc OB	r/kpc SNR	Age/yr [b] SNR	I_i [d]
0229+6151	134.20	1.15	37.9±6.2	2.29±0.18	2.01	···	···	0.48±0.34
0542+2610	182.02	-1.99	14.7±3.2	2.67±0.22	···	1.80$^{(1)}$	$\approx 10^5$	1.17±0.83
0617+2238	189.00	3.05	51.4±3.5	2.01±0.06	1.34	1.50$^{(2)}$	$6\cdot10^3$	0.62±0.40
0631+0642	204.71	-1.30	14.2±3.4	2.06±0.15	···	1.20$^{(3)}$	$(3-15)\cdot10^4$	2.00±1.43
0634+0521	206.18	-1.41	15.0±3.5	2.03±0.26	1.48	1.20$^{(3)}$	$4\cdot10^4$	0.49±0.35
0824-4610	263.28	-4.89	63.9±7.4	2.36±0.07	0.49	0.50$^{(4)}$	$1.1\cdot10^4$	1.10±0.78
0827-4247	260.84	-2.46	42.6±7.4	2.10±0.12	···	2.00$^{(5)}$	$3.7\cdot10^3$	0.45±0.31
0841-4356	263.29	-1.10	47.5±9.3	2.15±0.09	···	0.50$^{(4)}$	$1.2\cdot10^4$	1.15±0.82
0848-4429	264.50	-0.46	20.1±7.7	2.05±0.16	1.41	···	···	1.04±0.74
1013-5915	283.93	-2.34	33.4±6.0	2.32±0.13	···	3.80$^{(2)}$	10^4	0.45±0.32
1027-5817	284.94	-0.52	65.9±7.0	1.94±0.09	2.14	···	···	0.53±0.38
1048-5840	287.53	0.47	61.8±6.7	1.97±0.09	2.64	···	···	0.36±0.26
1102-6103	290.12	-0.92	32.5±6.2	2.47±0.21	2.16	1.90$^{(2)}$	$6.3\cdot10^4$	0.72±0.51
1308-6112	305.01	1.59	22.0±6.1	3.14±0.59	1.76	···	···	0.80±0.57
1410-6147	312.18	-0.35	64.2±8.8	2.12±0.14	1.51	1.90$^{(2)}$	$1.5\cdot10^4$	0.44±0.31
1420-6038	313.63	0.37	44.7±8.6	2.02±0.14	1.51	···	···	0.85±0.61
1639-4702	337.75	-0.15	53.2±8.7	2.50±0.18	1.59	12.3$^{(6)}$	$\approx 10^5$ [c]	0.76±0.54
1655-4554	340.48	-1.61	38.5±7.7	2.19±0.24	1.35	···	···	0.47±0.34
1714-3857	348.04	-0.09	43.6±6.5	2.30±0.20	···	7.5$^{(4)}$	$\approx 8\cdot10^3$ [c]	0.73±0.52
1718-3313	353.20	2.56	18.7±5.1	2.59±0.21	1.23	···	···	0.97±0.70
1734-3232	355.64	0.15	40.3±6.7		1.31	≈ 2.7	$\approx 3\cdot10^4$ [c]	0.97±0.70
1744-3011	358.85	-0.52	63.9±7.1	2.17±0.08	···	2.6$^{(2)}$	$9.7\cdot10^3$	0.72±0.51
1746-2851	0.11	-0.04	119.9±7.4	1.70±0.07	···	8.5	10^4-10^5	0.71±0.51
1800-2338	6.25	-0.18	61.3±6.7	2.10±0.10	···	3.0$^{(2)}$	$5.8\cdot10^4$	0.60±0.43
1809-2328	7.47	-1.99	41.7±5.6	2.06±0.08	1.94	···	···	0.96±0.69
1823-1314	17.94	0.14	42.0±7.4	2.69±0.19	1.48	···	···	1.15±0.82
1824-1514	16.37	-1.16	35.2±6.5	2.19±0.18	1.48	≈ 2.4	$\approx 5\cdot10^5$ [c]	1.10±0.78
1826-1302	18.47	-0.44	46.3±7.3	2.00±0.11	1.48	···	···	1.04±0.74
1837-0423	27.44	1.06	19.1	2.71±0.44	···	2.0$^{(8)}$	$\approx 3.5\cdot10^4$	3.58±2.55
1856+0114	34.60	-0.54	67.5±8.6	1.93±0.10	···	3.0$^{(3)}$	10^4	1.10±0.79
1903+0550	39.52	-0.05	62.1±8.9	2.38±0.17	···	5.5$^{(3)}$	10^3	0.85±0.61
2016+3657	74.76	0.98	34.7±5.7	2.09±0.11	1.17	12.0$^{(3)}$	$\approx 6\cdot10^3$	0.85±0.61
2020+4017	78.05	2.08	123.7±6.7	2.08±0.04	1.17	1.5$^{(2)}$	10^4	0.39±0.28
2021+3716	75.58	0.33	59.1±6.2	1.86±0.10	1.17	···	···	0.87±0.62
2022+4317	80.63	3.62	24.7±5.2	2.31±0.19	1.17	···	···	0.87±0.62
2027+3429	74.08	-2.36	25.9±4.7	2.28±0.15	1.17	···	···	1.90±1.36
2033+4118	80.27	0.73	73.0±6.7	1.96±0.10	1.17	···	···	0.50±0.36
2227+6122	106.53	3.18	41.3±6.1	2.24±0.14	0.77	···	···	1.26±0.90

a: F_γ is in units of $10^{-8}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. b: the estimated ages of SNRs. c: we use the formula given by Leahy & Wu (1989). d: I_i is the ratio of the fluctuation index of ith unidentified source to mean fluctuation index of known γ-ray pulsars (see text).

References:(1) Anderson *et al.* 1996; (2) Yadigaroglu & Romani, 1997; (3) Biggs & Lyne 1996; (4) Green 1984; (5) Pavlov *et al* 1999; (6) Koralesky *et al.* 1998; (7) Leahy 1989; (8) Reich *et al.* 1984.

sources listed in 3EG catalog and possible counterparts which are given by Romero et al. (1999). For these unidentified EGRET sources, their names, Galactic longitudes and latitudes, fluxes and spectral indexes have been given, with the only exception of 3EG J1746-2851, whose spectral index is not determined. When we estimate its γ-ray energy flux, we will assume that the spectral index is 2.0.

Both SNRs and OB associations may contain pulsars, and some of these pulsars have been detected at radio band and/or X-ray energy range, and others may have weak radio emission so that they have not been detected or do not exist in the SNRs and OB associations. However, at least some of SNRs and OB associations should associate with the pulsars, so we will focus on them as counterparts of unidentified EGRET sources. Therefore, we have a sample which have 38 SNRs and OB associations. Because an unidentified EGRET source in Table 1 may be coincident with both an OB association and a SNR, we consider two possible cases of the observed sample. Case 1: we assume that the observed sample consists of 26 OB associations and 12 SNRs. In this case, the OB associations which are the counterparts of the unidentified EGRET sources are selected first and then SNRs are selected. Case 2: we assume that the observed sample is composed of 22 SNRs and 16 OB associations, which means that SNRs are selected first.

3 The Model and Monte Carlo Simulations

We will briefly describe our Monte Carlo simulation (see Cheng & Zhang (1998) and Zhang, Zhang & Cheng (2000) for details). At present, six known γ-ray pulsars have their ages of less than 10^6 yr, and the pulsars in the SNRs and OB associations which are the counterparts of the unidentified EGRET sources have also ages less than of 10^6 yr. Therefore, we assume that the maximum age is 10^6 yr in our simulations.

The assumed initial values of the parameters of pulsars at birth including the distributions of initial period, position, velocity and magnetic field are based on the statistical results of observed radio pulsars. Once the initial properties of a pulsar at birth are given, the pulsar period at time t can be estimated by $P(t) = (P_0^2 + (16\pi^2 R_{\rm NS}^6 B^2/3Ic^3)t)^{1/2}$, where, $R_{\rm NS}$ is the neutron star radius and I is the neutron star moment of inertia. The period derivative ($\dot{P}$) can be determined by $P\dot{P} = (8\pi^2 R_{\rm NS}^6/3Ic^3)B^2$. Furthermore, the pulsar position at time t is determined following its motion in the Galactic gravitational potential. Using the equations given by Paczynski (1990) for given initial velocity, the orbit integrations are performed by using the 4th order Runge Kutta method with variable time step on the variables R, $V_{\rm R}$, z, $V_{\rm Z}$ and ϕ. Then the sky position and the distance of the simulated pulsar can be calculated.

In order to generate a pulsar population detectable at the radio band, we need to consider radio selection effects: the pulsar must satisfy that its radio flux is greater than the radio survey flux threshold and its broadened pulse width is less than the rotation period (e.g. Sturner & Dermer 1996). Briefly, the minimum detectable average flux density, $S_{\rm min}$, of a pulsar's survey depends mainly on receiver and sky background noise temperatures, the broadened pulse width, pulsar's period etc. The pulsar which satisfies $L_{400}/d^2 \geq S_{\rm min}$ is considered to be a radio-detectable pulsar, where L_{400} is the radio luminosity at 400 MHz and d is the distance to the pulsar. The radio beaming fraction can be expressed as (Emmering & Chevalier 1989) $f_{\rm r}(\omega) = (1-\cos\omega)+(\pi/2-\omega)\sin\omega$, where a random distribution of magnetic inclination angles is assumed and ω is the half-angle of the radio emission cone. Here we will use the model of Lyne & Manchester (1988) corrected by Biggs (1990), i.e. $\omega = 6^\circ.2 \times P^{-1/2}$. Then, following Emmering & Chevalier (1989), a sample pulsar with a given period P is chosen in one out of $f_{\rm r}(P)^{-1}$ cases using the Monte Carlo method.

We use the γ-ray pulsar model given by Zhang & Cheng (1997) to describe the high energy γ-ray emission from the rotation-powered pulsars. In this model, the fractional size of the outer gap, which is the ratio of the average vertical separation of the outer gap boundaries in the plane of $(\Omega,\ \mu)$ to the radius of the light cylinder, can be determined as

$$f_{\rm s} \approx 5.5 \cdot P^{26/21} B_{12}^{-4/7} \tag{1}$$

It should be emphasized that $f_{\rm s} \leq 1$. If $f_{\rm s} > 1$, it means that there is not sufficient $\rm e^{\pm}$ pairs near the neutron star surface and then the keV X-rays from a hot polar cap will escape from the star. Gamma-rays are produced inside the outer gap by synchro-curvature radiation of the primary $\rm e^{\pm}$ pairs (for details see Zhang & Cheng 1997). The expected γ-ray luminosities can be expressed as $L_\gamma \approx 3.6 \times 10^{31} f^3 B_{12}^2 P^{-4}$ ergs $\rm s^{-1}$. Therefore, the energy flux of γ-rays with energy greater than 100 MeV can be expressed as

$$S_\gamma^{\rm th}(E_\gamma > 100{\rm MeV}) = \frac{1}{\Delta\Omega_\gamma d^2} L_\gamma(> 100{\rm MeV}), \tag{2}$$

where $\Delta\Omega_\gamma$ is the solid angle into which the pulsar radiation is beamed and d is the distance to the pulsar.

The beaming solid angle is not well known. In our recent three dimensional outer gap model (Cheng, Ruderman & Zhang 2000), however, the solid angle should be the function of the fractional size of the outer gap. The γ-ray beaming fraction can be approximated as (Zhang *et al.* 2000)

$$f_\gamma \approx \left(\frac{\alpha}{90^\circ}\right)^a \frac{(1-b\cdot f_s)}{(1+b\cdot f_s)}, \tag{3}$$

where α is the magnetic inclination angle of the pulsar, $a \sim 0.5$ and $b \sim 0.5$. Parameter a indicates the dependence of the beaming fraction on the magnetic inclination. Parameter b indicates an approximate position of the emission region in units of radius of the light cylinder. Small (large) b means that the emission is mainly produced near (far away from) the first open field line in the outer gap. It can be seen that the beaming fraction is determined if pulsar's parameters such as period, magnetic field and magnetic inclination are given.

We now consider the γ-ray selection effects. In the third catalog, the faintest source in the catalog with significance $\sqrt{TS} \geq 4$ has a flux of $(6.2\pm1.7)\cdot 10^{-8}\ \rm cm^{-2}\ s^{-1}$ (Hartman *et al.* 1999).

In our analysis, we include the criterion of likelihood $(TS)^{1/2}$ greater than 5 ($\approx 5\sigma$) when we choose the flux threshold. In Table 1, the statistical significances of 6 unidentified sources are less than 5. Here we will use

$$S_\gamma(>100\mathrm{MeV}) \geq 1.2 \times 10^{-10} \ \mathrm{erg\ cm^{-2}s^{-1}} \tag{4}$$

as the minimum detectable γ-ray energy flux, which corresponds roughly to the faintest sources with $(TS)^{1/2} > 5$ in Table 1. In order to take γ-ray beaming effects into account, a sample γ-ray pulsar is chosen in one out of f_γ^{-1} cases using the Monte Carlo method. The pulsars which satisfy Eq.(4) and beaming condition will be detectable as γ-ray pulsars.

4 Simulations and Results

Using the procedure of Monte Carlo simulations described by Cheng & Zhang (1998), we can produce a sample of γ-ray pulsar populations with ages of less than 10^6 yr and γ-ray energy fluxes above the minimum detectable flux (Eq.(4)). This simulated population consists of both radio pulsars (population I) and radio-quiet pulsars (population II). The details of the simulation procedure are described in Cheng & Zhang (1998). In order to model the pulsar populations, we generate pulsars with random ages of less than 10^6 yr with $\dot{N}_{100} = 1$. Initial period, position, magnetic field, and velocity of each pulsar are determined from known distributions. At time t, period and period derivative of a pulsar are calculated using Eqs. mentioned above, and the pulsar position is estimated following the pulsar's motion in the Galactic gravitational potential. Then we can produce the total young γ-ray pulsar population which consists of young pulsars satisfying γ-ray selection effects, along with the relevant simulated quantities such as period, period derivative, and γ-ray energy flux. Galactic longitude and latitude of each simulated pulsar are recorded and the number of pulsars is labeled as N_γ. Adding radio selection effects and following the same simulation steps as those in generating total young γ-ray pulsar sample, we generate population I. In the population I, the pulsars must satisfy both radio selection and γ-ray selection conditions (the number of these pulsars in population I is represented by $N_{\gamma 1}$). In order to generate population II, we exclude the simulated pulsars in population I from the total young γ-ray pulsar population. In other words, the pulsars in population II satisfy the γ-ray selection condition but do not satisfy the radio selection condition. The number of the radio-quiet pulsars is approximated by $N_{\gamma 2} = N_\gamma - N_{\gamma 1}$. When comparing simulated results with observed results, the distances and γ-ray energy fluxes have been compared and the KS test has been made.

In our simulations, we compare first the simulated results (i.e. population I) with the observed data of 6 known γ-ray pulsars using the KS test. The maximum deviations of period, period derivative, distance and γ-ray energy flux distributions from the observed distributions are 0.36, 0.46, 0.38, and 0.40, respectively. It can be seen that three out of four of the cumulative distributions cannot be rejected at better than 80% confidence level and the second at better than 90% confidence level. Therefore, we conclude that our model may explain the statistical properties of the γ-ray pulsars.

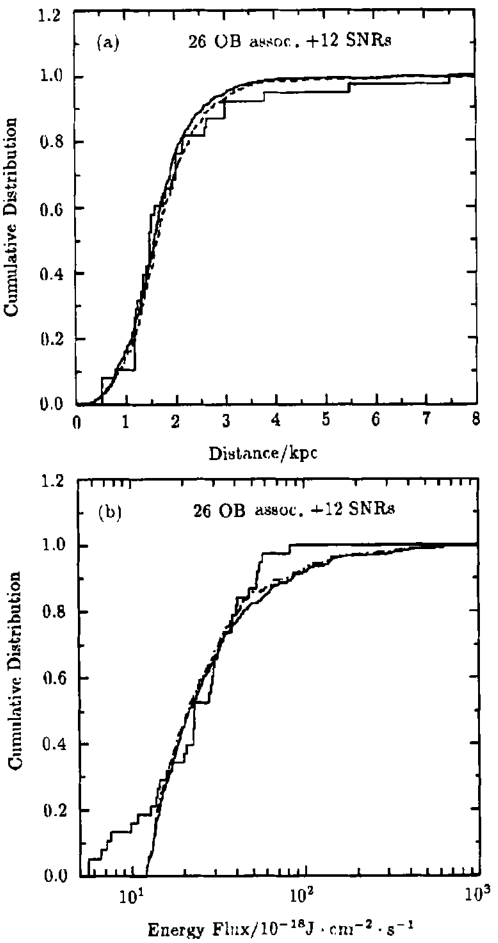

Fig. 1 Comparisons of our model results with the observed data of unidentified EGRET sources which are spatially coincident with OB associations and SNRs (26 OB associations plus 12 SNRs). (a) Cumulative distribution of distance and (b) cumulative distribution of γ-ray energy flux. The histogram represents the observed data, the solid and dashed curves represent the simulated population I and II respectively.

Furthermore, we use our model to consider the correlation between the unidentified EGRET sources and young pulsars. We assume that all unidentified EGRET sources which have counterparts consist of young pulsars, including radio pulsars and radio-quiet pulsars, so we perform Monte Carlo simulations to get a simulated sample: the total young γ-ray pulsar population. In order to compare the γ-ray energy fluxes of the simulated pulsars with the observed ones, we use the distance and the γ-ray energy flux as two independent variables and then examine the simulated results through the KS tests for these two variables against the observed values. The observed sample corresponds to case 1 described in Section 2, which consists of 26 OB associations and 12 SNRs. For such a sample, the hypothesis that the simulated pulsars and the observed unidentified EGRET sources were drawn from the same parent population cannot be rejected at the > 80 % or > 90 % confidence level if the maximum deviation from the observed data is < 0.170 or < 0.194. For the total young γ-ray pulsar population, the KS test indicates that the maximum deviation is 0.152 for the distance and 0.158 for the γ-ray energy flux. Furthermore, if we assume that the unidentified EGRET sources consist of the radio - quiet pulsars (population II), the KS test indicates that the maximum deviation is 0.153 for the distance and 0.169 for the γ - ray energy flux. The comparisons of the simulated results with the observed data are shown in Figs. 1 a -1 b. From the above analysis, we find that the hypothesis that the simulated pulsars and the observed unidentified EGRET sources were drawn from the same population cannot be rejected at 80% confidence level for the total young γ-ray pulsar population and for population II. For the observed sample called case 2, the distances of SNRs are taken from the literature except for G16.8-1.1 and G355.6+0.0. We have estimated the distances to these two

SNRs from σ- D relationship using the equation given by Leahy & Wu (1989). The maximum deviations from the observed data for the distance and the γ-ray energy flux are 0.210 and 0.158 for population I and 0.174 and 0.169 for population II. Therefore, for the observed sample of 38 unidentified 3EG sources positionally consistent with 22 SNRs and 16 OB associations (case I), we cannot conclude that the simulated pulsars and the observed unidentified EGRET sources were drawn from the same population.

Our model predicts that there are $\approx 32\dot{N}_{100}$ young pulsars with ages less than 10^6 yr which emit high energy γ-rays in Galactic plane with $|b| \leq 5°$. For all these young pulsars, $\approx 22\dot{N}_{100}$ are radio quiet pulsars and $\approx 10\dot{N}_{100}$ are radio pulsars. It is believed that the birth rate of neutron stars in our Galaxy is from 1 to 2 per 100 years, so the expected young pulsars in $|b| \leq 5°$ are from ≈ 32 to ≈ 64. Therefore, our model suggests that most unidentified 3EG sources positionally coincident with SNRs or OB star forming regions might be young pulsars. It should be pointed out that the above expectation depends on the detector's sensitivity. For example, if the minimum detectable radio energy flux of pulsar survey is decreased, then more radio pulsars will be detected, and the ratio given above may change. Furthermore, if the minimum detectable γ-ray energy flux decreases, then more young pulsars which emit high energy γ-rays will be detected.

5 Discussion and Conclusions

Based on the study of Romero *et al* (1999) on the association of unidentified EGRET sources with Galactic objects such as SNRs, OB associations as well as WR and Of stars and the γ-ray pulsar model (Zhang & Cheng 1997), we have studied statistical properties of these unidentified EGRET sources using the Monte Carlo method. Our results indicate that the unidentified EGRET sources whose counterparts are OB associations and SNRs may have the same parent population as the young pulsars (see Fig.1).

Now we study the variability of 38 unidentified γ-ray sources listed in Table 1. We use the weighted fluctuation index μ used by Romero *et al.* (1994) for blazar variability, i.e. $\mu = 100\sigma_S/ < S >$, where $< S >= [\Sigma_{i=1}^{n}\sigma_i^{-2}S_i][\Sigma_{i=1}^{n}\sigma_i^{-2}]^{-1}$ is the weighted mean flux density of a source and σ_S is the standard deviation of the set of n measurements. In 3EG catalog, there are many observations at different viewing periods for one source. When the source has just an upper flux limit in 3EG catalog, we assume that the flux is $F_\gamma = (F_\gamma^{\rm upper} - F_\gamma^{\rm lim})/2$ with errors of the same magnitude, where $F_\gamma^{\rm lim} \approx 6.2 \times 10^{-8}$ cm^{-2} s^{-1}. First, we estimate the index for the 6 known γ-ray pulsars. Averaging the μ values of these pulsars, we have $< \mu >_{\rm pulsar}= 77.0 \pm 50.0$. Further we estimate the index $\mu_i^{\rm un}$ of the 38 unidentified γ-ray sources. Then we define a parameter $I_i = \mu_i^{\rm un}/ < \mu >_{\rm pulsar}$. A source can be considered as variable when its parameter I is greater than $1 + 1\sigma$, otherwise the source classifies as non-variable. We list the values of this parameter for 38 unidentified sources in Table 1. In Fig. 2, we present the distribution of these unidentified sources with this parameter. From Table 1 and Fig. 2, 26 of 38 unidentified sources have values of I_i which are less than 1 and $I_i \le 1 + 1\sigma$ for 35 sources. There are 3 sources that are clearly differentiated from the rest. The most variable of these sources has a spectral index of 2.71, clearly incompatible with a pulsar interpretation. All variable sources are also positionally consistent with SNRs. These facts suggest an interpretation based on isolated black holes for such sources. More research should be done on them in the future. Therefore it seems that most of the 38 unidentified sources are non-variable. However it should be noted that the standard error of mean fluctuation index of known γ-ray pulsars is large, so we cannot confirm the above conclusion using current observed data.

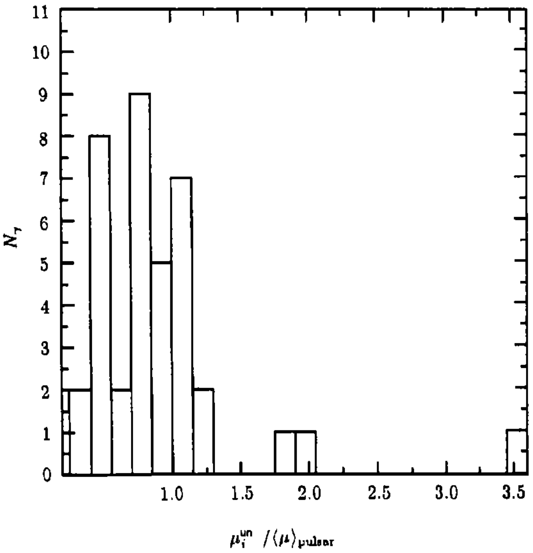

Fig.2 The distribution of the 38 unidentified EGRET sources with the parameter $I_i = \mu_i^{\rm un}/ < \mu >_{\rm pulsar}$. μ means the fluctuation index which is defined in text

It is interesting to give some expectations using our model for GLAST threshold. For the point sources, the GLAST sensitivity for the γ-rays with energy greater than 100 MeV is $\approx 4 \times 10^{-9}$ cm^{-2} s^{-1} (Kamae *et al.* 1999), which means that the ratio of GLAST threshold to EGRET threshold is $\approx 4 \times 10^{-2}$. Assuming that the minimum detectable energy flux of the GLAST is 4.8×10^{-12} erg cm^{-2} s^{-1}, we have produced two samples of γ-ray pulsar populations with the pulsar ages less than 10^6 years. One consists of the γ-ray pulsars in which only γ-ray selection effects are taken into account, and the other consists of the young pulsars which are detectable in both radio and γ-ray energy ranges. The normalized distributions of the distance, period, period derivative and beaming solid angle are shown in Fig. 3. Our results indicate that (i) the GLAST may detect $\approx 80\dot{N}_{100}$ radio pulsars and (ii) if most unidentified γ-ray point sources in $|b| \le 5°$ are young pulsars, then the GLAST may detect $\approx 1100\dot{N}_{100}$ Galactic γ-ray point sources.

The observations of γ-ray pulsars indicate that the pulsar spectrum is not too steep; the maximum value of the spectral indices for the known γ-ray pulsars is about 2.19 (the Crab pulsar). From Table 1, however, 33 out of the unidentified 3EG sources which are coincident with OB associations and SNRs have spectral indices of less than 2.5, so it is difficult to say whether the unidentified γ-ray sources in the Galactic plane can be explained in form of the young pulsar origin only by spectral analysis (Zhang & Cheng 1998).

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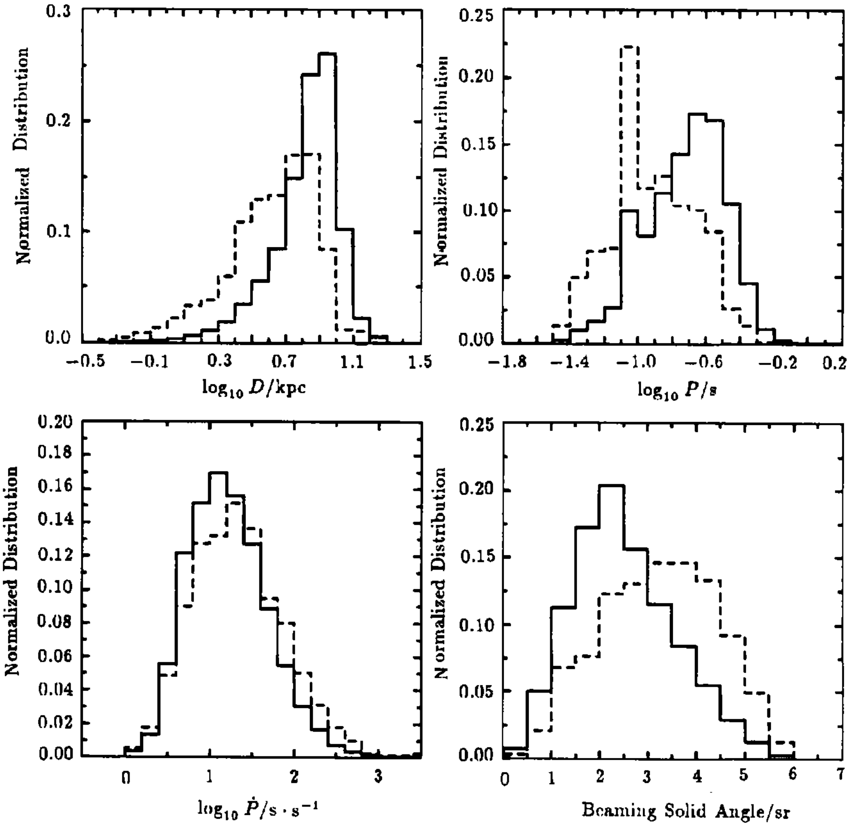

Fig. 3 The normalized distributions of distance, period, period derivative and beaming solid angle for the simulated young pulsars with their ages less than 10^6 years. Solid histograms show the distributions of the pulsars in which γ-ray selection effects are taken into account. Dashed histograms show the distributions of the pulsars which are detectable in both radio and γ-ray energy ranges

References

Anderson D A. 1996, Ap. J., 468: L55

Bailes M, Kniffen D A. 1992, Ap. J., 391: 659

Biggs J D. 1990, M.N.R.A.S., 245: 514

Biggs J D, Lyne A G. 1996, M.N.R.A.S., 282: 691

Cheng K S, Zhang L. 1998, Ap. J., 498: 327

Cheng K S, Ruderman M, Zhang L. 2000, Ap. J., 537: 964

Combi J A, Romero G E, Benaglia P. 1998, Astron. Astrophys., 333: L31

Emmering R T, Chevalier R A. 1989, Ap. J., 345: 931

Gaensler B M, Johnston S. 1995, M.N.R.A.S., 277: 1243

Gorham P W *et al.* 1996, Ap. J., 458: 257

Green D A. 1984, M.N.R.A.S., 209: 449

Hartman R C *et al.* 1999, Ap. J. Suppl. Ser., 123: 79

Kaaret P, Cottam J. 1996, Ap. J., 462: L35

Kamae T, Ohsugi T, Thompson D J *et al.* 1999, preprint astro-ph/9901187, (the information of GLAST are available on the WWW at http://www-glast.stanford.edu)

Koralesky B *et al.* 1998, A. J., 116: 1323

Leahy D A. 1989, Astron. Astrophys., 216: 193

Leahy D A, Wu X J. 1989, Publ. Astron. Soc. Pac., 101: 607

Montmerle T. 1979, Ap. J., 231: 95

Paczynski B. 1990, Ap. J., 348: 485

Pavlov G G, Zavlin V E, Trümper J. 1999, Ap. J., 511: L45

Reich W, Fürst E, Sofue Y. 1984, Astron. Astrophys., 133: L4

Romani R W. 1996, Ap. J., 470: 469

Romani R W, Yadigaroglu I A. 1995, Ap. J., 438: 314

Romero G E, Benaglia P, Torres D F. 1999, Astron. Astrophys., 348: 868

Romero G E, Combi J A, Colomb F R. 1994, Astron. Astrophys., 288: 731

Sturner S J, Dermer C D. 1996, Ap. J., 461: 872

Yadigaroglu I A, Romani R W. 1995, Ap. J., 372: L99

Yadigaroglu I A, Romani R W. 1997, Ap. J., 476: 347

Zhang L, Cheng K S. 1997, Ap. J., 487: 370

Zhang L, Cheng K S. 1998, Astron. Astrophys., 335: 234

Zhang L, Zhang Y J, Cheng K S. 2000, Astron. Astrophys., 357: 957