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Search for Nearby Host Galaxies of Short Gamma-Ray Bursts Detected and Well Localized by BATSE/IPN

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Abstract—We have collected the observational data accumulated before the Swift experiment to check the possible connection of short gamma-ray bursts (GRBs) with low-redshift galaxies. The BATSE/IPN experimental data on well-localized short GRBs and the SDSS DR5 and PSCz catalogs of galaxies are used. The PSCz sky coverage has allowed us to search for host galaxies for a sample of 34 short GRBs. One or more galaxies have been found in the error boxes of six bursts, but the probability of a chance coincidence for each of them is high. No excess of nearby galaxies in the total sample has been detected. The 90% confidence limit corresponds to the fact that no more than 7% of the short GRBs could originate in nearby galaxies of the PSCz sample. The estimated upper limit of several percent may be considered to be valid in the volume $z = 0.015$–0.025. Based on the results of our search, we have estimated the lower limits for the isotropic energies $E_{\gamma\mathrm{iso}}$ of 31 short bursts from our sample. Their values lie within the range 1.0×10^{47}–2.7×10^{49} erg. The possible fraction of the flares from magnetars in our sample of short GRBs is discussed. The SDSS sky coverage is currently insufficient to perform a similar analysis.

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INTRODUCTION

It has been established through extensive observations in various spectral ranges that soft long (>2 s) gamma-ray bursts (GRBs) are produced during the collapse of massive stars. The progress in understanding the origin of short hard GRBs is not so rapid, partly because of their lower detection rate (Gehrels et al. 2008).

The Swift experiment being conducted now and other active experiments detect of the order of ten short GRBs per year. Their possible host galaxies can be established only in a few cases. At the same time, before the launch of Swift (before 2004), several hundred short GRBs were detected in the BATSE experiment (Paciesas et al. 1999) with a typical localization error of the order of several degrees and several tens of GRBs were localized using IPN (Hurley et al. 1999a, 1999b, 2006) with an accuracy of ∼1 arcmin. These data allow the possible connection between short GRBs and low-redshift galaxies to be checked.

Recent Swift, HETE-2, and Chandra observations with simultaneous optical observations have revealed a clear connection between several short GRBs and moderate-redshift galaxies (Berger et al. 2005; Gehrels et al. 2005; Fox et al. 2005). These are elliptical and spiral galaxies at $z \sim 0.2$; the isotropic energy $E_{\gamma\mathrm{iso}}$ of the bursts ranges from 1.1×10^{48} to 3.0×10^{51} erg. This discovery argues for the model of short GRB production during the coalescence of binary neutron stars or black holes (Eichler et al. 1989). The results of Shaefer (2006) and Berger et al. (2007) prove that short GRBs originate even at higher redshifts.

However, Tanvir et al. (2005) found a correlation between the error boxes of short GRBs and galaxies in the local Universe, indicating that from 10 to 25% of these bursts originate at redshifts $z < 0.025$. A sample of several hundred short GRBs detected by BATSE (Paciesas et al. 1999) and the IRAS PSCz galaxy catalog (Saunders et al. 2000) were used.

At the same time, a giant flare was detected from the soft gamma-ray repeater SGR 1806-20 (Hurley et al. 2005; Palmer et al. 2005). This showed that a substantial fraction of the short GRBs could be produced by extragalactic magnetars, i.e., could be quite different in nature. The energy of these flares

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is (2–7) × 10^{46} erg (Frederiks et al. 2007). Several groups attempted to reveal such a sub-population among the short GRBs. Popov and Stern (2006), who searched for bursts from nearby spiral galaxies in the BATSE sample, and Lazzati et al. (2005), who analyzed the spectra of 76 BATSE bursts, concluded that the number of bursts from soft gamma-ray repeaters in the samples of short GRBs does not exceed a few percent. Nakar et al. (2006) and Ofek (2007), who used the IPN data on GRBs, suggest ∼15% as an upper limit. Nakar et al. (2006) searched for nearby galaxies in the error boxes of six short GRBs detected by IPN and did not find any of them. Ofek (2007) used a sample of several tens of short GRBs detected by IPN in searching for coincidences with 316 bright spiral galaxies and found only one coincidence that could be a chance one.

We use all of the BATSE and IPN data on well-localized short GRBs to search for host galaxies and a population at low redshifts. The SDSS DR5 and PSCz catalogs are used as the samples of nearby galaxies.

THE DATA AND THE SEARCH PROCEDURE

IPN used the detection time of a GRB to establish its celestial coordinates by triangulation. The detection of a burst by two or more instruments gives an annular error box on the celestial sphere that intersects the BATSE circular error box (whose radius is several degrees), thereby reducing the resulting error box approximately by a factor of 30. If a GRB is detected by three or more IPN instruments, then triangulation gives one or two very small error boxes.

In 1990–2000, IPN obtained data on 39 GRBs classified as short ones (Table 1). Most of these GRBs were also detected in the BATSE experiment; all bursts are considerably brighter than its detection threshold. The limiting depth of the sample changed with time, because different spacecraft with different sensitivities constituted IPN at different times. We use the BATSE 3σ error circle whose radius is $r_{3\sigma} = 3\sqrt{\sigma^2_{\rm stat} + \sigma^2_{\rm sys}}$, where $\sigma_{\rm sys} = 1\overset{\circ}{.}6$ is the systematic error and $\sigma_{\rm stat}$ is the statistical error (Paciesas et al. 1999). The IPN 3σ error ring is centered at a point with right ascension α and declination δ and radii $R \pm \delta R$ (Table 1). According to our estimates, eight, five, twenty, and six of the 39 bursts have error boxes smaller than 0.003, 0.003–0.1, 0.1–1, and 1–10 sq. deg, respectively.

We used the SDSS DR5 (Adelman-McCarthy et al. 1999) and PSCz (Saunders et al. 2000) catalogs as galaxy surveys. SDSS DR5 is the deepest survey with estimated redshifts up to $z \sim 0.5$, covering 1/4 of the sky. PSCz presents data on galaxies up to $z \sim 0.1$, covering 84% of the sky. At low Galactic latitudes, the PCSz (IRAS) survey is more complete than any other close surveys.

None of the 39 short GRB error boxes under consideration is completely covered by the SDSS DR5 survey. Ten error boxes are covered partially and only three are covered by more than half. The survey does not provide sufficient data for our search.

The error boxes of GRB 931205, 971218, 980310B, 981226, and 010119 are not covered by the PSCz survey, but this survey can be used for a search in the remaining completely covered 34 error boxes. The redshift distribution of PSCz galaxies peaks at $z \sim 0.015$ (62.5 Mpc) and may be considered conditionally complete in this volume. However, the catalog contains galaxies up to $z \sim 0.1$. We deal with the estimated expected number of chance coincidences of galaxies with an error box of a certain area and the probabilities without allowance for the z distribution, unless stated otherwise.

We estimated the probability of a random coincidence of a galaxy at $z \leq 0.025$ with an error box of no more than 0.1 sq. deg to be no more than 2×10^{-3}. For a closer galaxy, the probability has such a value for a larger error box. The probability was estimated by assuming a Poisson distribution using the ratio of the error box size to the size of the PSCz coverage region.

As the first step, we considered error boxes with sizes $S_{\rm errorbox} \leq 0.1$ sq. deg. Nine of the thirteen error boxes are covered by the PSCz survey, but there are no PSCz galaxies in any of them. Subsequently, we considered error boxes with $S_{\rm errorbox} \leq 1$ sq. deg and the entire sample of 34 error boxes. There are three and nine PSCz galaxies, respectively, in the error boxes under consideration, while the expected number of chance coincidences are 3.4 and 12.8, respectively.

The total number of galaxies in the sample of 34 error boxes is smaller than that expected for a chance coincidence. Using a cumulative Poisson distribution, we estimated that the 90% confidence level corresponds to 7% of the bursts originating in nearby PSCz galaxies. The constraint of several percent is valid for the volume $z \sim 0.015$–0.025.

Galaxies were found only in six of the 34 error boxes (Table 2). The redshift of these galaxies ranges from 0.001 to 0.046. Table 2 lists the probabilities of a chance coincidence estimated by taking into account z. In all cases, these probabilities are much higher than 2×10^{-3}, which does not allow a firm conclusion about whether a given galaxy is the host one to be reached. The most probable actual host galaxy can be J/078/801 for GRB 950210.

Table 1. Short GRBs detected by IPN. The localization data and the estimated size of the error box are given

GRB date and time		BATSE localization, circle			IPN localization, ring				Error box, sq. deg
					α_1	δ_1	R_1	δR_1	
		α	δ	σ_{stat}	α_2	δ_2	R_2	δR_2	
June 26, 1991	$07^h15^m13^s$	133.38	7.72	1.27	134.557	18.501	10.164	2×10^{-2}	0.478
Apr. 14, 1992	23 22 41	112.5	−73.72	1.57	331.028	−9.164	87.724	7×10^{-3}	3.4×10^{-4}
					189.386	2.413	89.759	4×10^{-3}	
Sep. 3, 1992	00 49 17	61.97	−68.37	0.75	338.732	−0.549	88.165	0.01	0.219
Jan. 6, 1993	15 37 39	6.08	2.0	0.53	345.556	12.984	21.048	0.021	0.376
Mar. 29, 1993	03 09 25	179.25	−8.65	0.94	148.09	−13.723	35.582	1×10^{-2}	0.128
Apr 28, 1993	01 07 12	129.85	−55.45	1.68	143.9	−12.085	46.202	5×10^{-3}	0.138
Sep. 5, 1993	03 26 30	310.95	−1.22	0.63	335.615	17.389	28.629	5.8×10^{-3}	0.113
					335.616	17.397	28.635	7×10^{-3}	
Oct. 17, 1993	01 17 49	181.44	−83.11	0.65	162.389	−24.11	58.979	0.003	0.061
Dec. 5, 1993	14 59 51	15.56	66.49	2.22	347.108	35.133	38.364	1.8×10^{-2}	0.59
July 17, 1994	03 24 29	109.80	12.93	0.71	130.246	−40.076	54.328	6×10^{-3}	0.118
Jan. 8, 1995	02 04 20	17.71	−12.94	3.58	320.718	−47.219	57.551	1.5×10^{-2}	0.704
Feb. 10, 1995	02 20 21	154.55	−27.48	1.15	155.444	25.748	53.632	8×10^{-3}	0.187
Feb. 11, 1995	02 24 57	9.51	52.65	1.08	335.804	−25.124	85.83	6×10^{-3}	0.127
June 20, 1995	00 44 33	45.72	6.13	1.49	21.969	64.638	61.737	1.9×10^{-2}	0.500
Aug. 5, 1995	03 44 14	79.86	−39.38	1.75	337.035	−80.272	48.132	2×10^{-2}	0.359
Mar. 19, 1996	14 26 33	94.84	−47.72	2.01	352.443	−73.674	48.164	5×10^{-2}	1.549
Aug. 3, 1996	18 45 22	338.02	−50.13	1.93	340.865	−40.801	12.019	1.4×10^{-2}	0.439
Oct. 17, 1996	11 16 43	37.16	−10.68	2.89	354.974	−32.029	40.759	2.6×10^{-2}	0.94
July 4, 1997	01 08 16	74.82	−16.00	4.14	154.193	25.359	89.853	3×10^{-3}	0.152
Dec. 9, 1997	23 10 36	241.35	62.21	0.77	171.404	11.832	70.341	4×10^{-3}	3×10^{-3}
					265.214	−21.285	83.818	0.172	
Dec. 18, 1997	14 34 59	41.62	61.47	0.95	351.223	−11.657	83.434	1.6×10^{-2}	0.019
Feb. 28, 1998	06 44 07	24.51	13.43	4.67	340.357	−12.77	55.236	0.013	0.752
Mar. 10, 1998	00 36 29	75.19	−60.72	8.84	338.174	−12.983	85.921	2.6×10^{-2}	2.795
Mar. 10, 1998	13 57 41	242.41	−60.47	1.24	338.051	−12.993	81.321	3×10^{-3}	0.074
Oct. 5, 1998	18 00 26	275.24	44.05	1.22	260.54	−24.703	71.356	4.1×10^{-2}	0.929
Dec. 26, 1998	10 47 04	267.15	−24.4	1.84	347.077	7.778	81.38	3×10^{-3}	0.081
Feb. 8, 1999	04 12 44	296.10	−39.40	2.29	332.365	−7.147	46.571	2.6×10^{-2}	0.878
May 16, 1999	23 54 23	253.55	−3.64	0.77	324.654	7.122	76.968	0.004	1.3×10^{-3}
					214.006	−20.457	40.158	0.04	
July 12, 1999	07 45 19	126.52	8.65	3.63	148.289	−8.391	28.976	0.006	0.026
					83.755	28.947	43.539	0.042	
Oct. 7, 1999	01 49 27	234.18	−3.39	1.50	164.315	5.059	68.655	4.1×10^{-2}	1.104
Dec. 11, 1999	04 34 41	215.26	11.72	6.10	215.198	−21.141	28.297	0.132	9.244
Jan. 8, 2000	16 48 07	236.35	−78.82	0.71	164.295	−35.974	49.485	1.5×10^{-2}	0.29
Mar. 26, 2000	05 18 56	333.36	−26.36	2.36	316.827	41.054	68.837	5×10^{-3}	1.6×10^{-3}
					291.959	−31.367	36.005	8.1×10^{-2}	
May 13, 2000	11 21 35	338.91	−45.11	2.08	310.984	−27.576	32.37	9.9×10^{-2}	3.055
May 25, 2000	10 24 13	280.22	−39.44	2.75	312.719	−26.83	30.209	0.115	4.571
June 7, 2000	02 24 49	–	–	–	310.465	32.541	79.268	0.005	1.4×10^{-3}
					310.927	21.249	81.687	0.015	
July 27, 2000	19 42 36	–	–	–	139.729	−33.865	62.002	0.006	1.6×10^{-3}
					134.829	−24.842	58.463	0.007	
Dec. 4, 2000	08 01 10	–	–	–	25.338	74.774	62.454	0.013	1.6×10^{-3}
					333.554	45.945	64.67	0.022	
Jan. 19, 2001	10 19 35	–	–	–	324.62	−68.945	85.955	0.006	8.4×10^{-4}
					352.7	60.273	69.372	0.025	

Table 2. PSCz galaxies coincident with the error boxes of short GRBs

GRB date and time		Localization, sq. deg	PSCz galaxy	z	Probability of chance coincidence	$E_{\gamma\text{iso}}$, erg
Feb. 10, 1995	$02^h20^m21^s$	0.187	H/061/505	0.015	0.017	3.0×10^{47}
			J/078/801	0.0087	0.008	$1.0 \times 10^{47\star}$
Oct. 17, 1996	11 16 43	0.94	G/015/005	0.07	0.29	$5.3 \times 10^{48\star}$
Oct. 7, 1999	01 49 27	1.104	F/093/007	0.028	0.21	$9.4 \times 10^{48\star}$
Dec. 11, 1999	04 34 41	9.244	E/107/018	0.02	0.75	$3.0 \times 10^{48\star}$
			E/107/028	0.025	0.82	4.6×10^{48}
			E/110/019	0.027	0.85	5.4×10^{48}
May 13, 2000	11 21 35	3.055	K/177/013	0.001	0.15	$2.2 \times 10^{47\star}$
May 25, 2000	10 24 13	4.571	J/139/011	0.046	0.75	1.2×10^{49}
			K/147/006	0.017	0.42	$1.6 \times 10^{48\star}$

Note. The last column gives the values of $E_{\gamma\text{iso}}$ for a given GRB estimated by assuming the galaxy to be the host one. The values of $E_{\gamma\text{iso}}$ marked by an asterisk may be considered as the estimated lower limits for these GRBs and an addition to Table 3.

Considering the possibility that the galaxies listed in Table 2 are the host ones, we can estimate the isotropic energy of a given GRB $E_{\gamma\text{iso}}$ in this case: $E_{\gamma\text{iso}} = (4\pi d_{\mathrm{L}}^2 F)$, where d_{L} is the luminosity distance and F is the fluence. We assume that $\Omega_\Lambda = 0.7$, $\Omega_M = 0.3$, and $H = 70$ km s^{-1} Mpc^{-1} and use the BATSE (25–1000 keV) fluences (Paciesas et al. 1999). These estimates are lower limits for $E_{\gamma\text{iso}}$ for the bursts under consideration.

We also estimated the lower limits for $E_{\gamma\text{iso}}$ for the remaining bursts without any galaxies found in their error boxes by taking into account the fact that the PSCz catalog is conditionally complete up to $z \sim 0.015$. The calculations were made for 25 of the 28 bursts (Table 3) for which the brightness data are available. We used data from the BATSE and KONUS catalogs (Mazets et al. 2002).

The lower limits for $E_{\gamma\text{iso}}$ lie within the range 1.0×10^{47}–2.7×10^{49} erg and agree with the values for the short GRBs for which the distances were determined during the Swift experiment.

Popov and Stern (2006) estimated that giant flares from magnetars could be detected by the BATSE detectors up to distances of 50 Mpc. The lower brightness threshold of our sample is at least a factor of 4 higher and, hence, the flares from magnetars are seen no farther than 25 Mpc ($z = 0.006$). Within this volume, no galaxies were detected in the investigated error boxes (Table 2). This suggests that the fraction of the flares from magnetars in the investigated sample of short GRBs is no more than a few percent.

CONCLUSIONS

(1) Based on PSCz data, we found no excess of nearby galaxies in the sample of error boxes for 34 short GRBs. The 90% confidence limit corresponds to the fact that no more than 7% of the short GRBs could originate in nearby galaxies of the PSCz sample. The estimated upper limit of several percent may be considered to be valid in the volume $z \sim 0.015$–0.025.

(2) Based on the results of our search, we estimated the lower limit for $E_\gamma$iso for 31 short GRBs from the analyzed sample (Tables 2 and 3). Its values lie within the range from 1.0×10^{47} to 2.7×10^{49} erg and agree with the results obtained for the bursts for which the distances were determined during the Swift experiment.

(3) One or more PSCz galaxies (Table 2) at redshifts from 0.001 to 0.046 fall within the error boxes of six of the 34 bursts, but the probability of a chance coincidence for each of them is high. The most probable actual host galaxy can be J/078/801 for GRB 950210.

(4) Giant flares from SGRs, if their admixture were in the analyzed sample, could be seen at redshifts $z < 0.006$. No such nearby galaxies were detected in any of the error boxes, suggesting that the admixture from SGRs accounts for no more than a few percent.

What fraction of the short GRBs can be associated with SGR flares and what fraction of the short GRBs originate in nearby galaxies remain open questions. Chapman et al. (2008) showed that only a double population consisting of GRB-producing SGRs and GRB-producing neutron star collisions corresponds

Table 3. Lower limits for $E_{\gamma\ \mathrm{iso}}$ of 25 short GRBs without any galaxies detected in their error boxes

GRB date	Observed fluence, erg cm^{-2}	Observed energy range, keV	Experiment	$E_{\gamma\ \mathrm{iso}}$, erg
June 26, 1991	1.50×10^{-6}	25–1000	BATSE	7.02×10^{47}
Apr. 14, 1992	1.09×10^{-5}	25–1000	BATSE	5.10×10^{48}
Mar. 29, 1993	2.83×10^{-6}	25–1000	BATSE	1.33×10^{48}
Apr. 28, 1993	1.78×10^{-6}	25–1000	BATSE	8.35×10^{47}
Sep. 5, 1993	3.37×10^{-6}	25–1000	BATSE	1.57×10^{48}
July 17, 1994	7.40×10^{-6}	25–1000	BATSE	3.46×10^{48}
Jan. 8, 1995	2.83×10^{-7}	25–1000	BATSE	1.32×10^{47}
Feb. 11, 1995	4.10×10^{-6}	25–1000	BATSE	1.92×10^{48}
June 20, 1995	1.04×10^{-6}	25–1000	BATSE	4.88×10^{47}
Aug. 5, 1995	5.05×10^{-6}	25–1000	BATSE	2.36×10^{48}
Mar. 19, 1996	2.97×10^{-6}	25–1000	BATSE	1.39×10^{48}
Aug. 3, 1996	4.49×10^{-7}	25–1000	BATSE	2.10×10^{47}
July 4, 1997	4.30×10^{-5}	25–1000	BATSE	2.01×10^{49}
Dec. 9, 1997	2.18×10^{-6}	25–1000	BATSE	1.02×10^{48}
Feb. 28, 1998	7.6×10^{-6}	15–2000	KONUS	3.55×10^{48}
Mar. 10, 1998	3.23×10^{-7}	25–1000	BATSE	1.51×10^{47}
Oct. 5, 1998	2.66×10^{-6}	25–1000	BATSE	1.24×10^{48}
Feb. 8, 1999	7.30×10^{-6}	25–1000	BATSE	3.41×10^{48}
May 16, 1999	5.8×10^{-5}	15–5000	KONUS	2.71×10^{49}
July 12, 1999	4.89×10^{-5}	25–1000	BATSE	2.29×10^{49}
Jan. 8, 2000	2.02×10^{-6}	25–1000	BATSE	9.43×10^{47}
Mar 26, 2000	3.5×10^{-6}	15–1000	KONUS	1.63×10^{48}
June 7, 2000	5.4×10^{-6}	15–3000	KONUS	2.52×10^{48}
July 27, 2000	1.9×10^{-5}	15–1000	KONUS	8.87×10^{48}
Dec. 4, 2000	1.7×10^{-6}	15–5000	KONUS	7.94×10^{47}

Note. The values for the six bursts with galaxies detected in their error boxes are given in Table 2.

to the observed local distribution of GRBs and their overall statistics. The least conservative limit is admitted by the results of Tanvir et al. (2005)—25% of the flares from SGRs in the samples of short GRBs. However, the searches for nearby host galaxies in the error boxes of short GRBs detected before the launch of Swift conducted by Shaefer (2006), Nakar et al. (2006), and Ofek (2007) revealed no host galaxies. At the same time, none of the several host galaxies of short GRBs detected through Swift observations is a nearby one (Gehrels et al. 2005; Fox et al. 2005; Berger et al. 2005). Therefore, the more conservative estimates of the fraction of nearby bursts and the possible admixture of burst from SGRs in the samples of short GRBs, no more than a few, made by Popov and Stern (2006), Lazzatti et al. (2005), and in this paper seem realistic.

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