Mon. Not. R. Astron. Soc. **000**, 1–6 (2007) Printed 15 September 2008 (MN LATEX style file v2.2)

Probability for chance coincidence of a gamma-ray burst with a galaxy on the sky

Maria Angela Campisi[⋆] and Li-Xin Li
Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Strasse 1, D-85748 Garching bei München, Germany

Accepted 2008 September 11. Received 2008 September 11; in original form 2008 June 18

ABSTRACT
The nearby long GRB 060614 was not accompanied by a supernova, challenging the collapsar model for long-duration GRBs and the traditional classification scheme for GRBs. However, Cobb et al. have argued that the association of GRB 060614 and its host galaxy could be chance coincidence. In this work we calculate the probability for a GRB to be randomly coincident with a galaxy on the sky, using a galaxy luminosity function obtained from current galaxy surveys. We find that, with a magnitude limit that current telescopes can reach and an evolving galaxy luminosity function obtained from VVDS, the probability for chance coincidence of a GRB with a galaxy of redshift < 1.5 is about several percent. These results agree with previous estimates based on observed galaxies. For the case of GRB 060614, the probability for it to be coincident with a $z < 0.125$ galaxy by angular separation $< 0.5''$ is $\approx 0.02\%$, indicating that the association of GRB 060614 and its host galaxy is secure. If the telescope magnitude limit is significantly improved in future, the probability for GRB-galaxy association will be considerably large, making it very problematic to identify a GRB host based only on the superposition of a GRB and a galaxy on the sky.

Key words:
gamma-rays: bursts – galaxies: luminosity function, mass function.

1 INTRODUCTION

Observation of host galaxies of gamma-ray bursts (GRBs) is very important for understanding the nature of GRBs. Current observations reveal that long duration GRBs occur in star-forming galaxies, consistent with the general belief that long GRBs are produced by the death of massive stars (Conselice et al. 2005; Fruchter et al. 2006; Tanvir & Levan 2007; Wainwrigh et al. 2007, and references therein). The discovery of the connection between long GRBs and core-collapse Type Ibc supernovae (Galama et al. 1998; Li 2006; Woosley & Heger 2006, and references therein) supports the collapsar model of long GRBs (MacFadyen & Woosley 1999; MacFadyen, Woosley & Heger 2001).

In contrast, short-duration GRBs are found in both early- and late-type galaxies, similar to the situation of Type Ia supernovae. The rate of star formation in the host galaxies of short GRBs is often lower than that in the hosts of long GRBs (Berger 2006, and references therein). So far no supernovae have been found to be associated with short GRBs.

The difference in the observed host properties for short and long GRBs supports the idea that short and long GRBs have different progenitors. Long GRBs are believed to arise from the death of massive stars (the collapsar model)—most likely the Wolf-Rayet stars since all observed supernovae associated with GRBs are Type Ic, while short GRBs are more likely produced by the merger of compact stars—neutron star-neutron star merger and black hole-neutron star merger (Li & Paczyński 1998; O'Shaughnessy, Kalogera & Belczynski 2007).

However, the above scenario is challenged by the observation of GRB 060614. This is a long burst with a duration ~ 100 s, with a host galaxy at redshift $z = 0.125$ (Della Valle et al. 2006; Fynbo et al. 2006; Gehrels et al. 2006). For a long GRB that has such a low redshift it is expected that a supernova associated with it should be observed. However, despite extensive observation on its host, no supernova has been found down to limits fainter than any known Type Ic SN and hundreds of times fainter than the archetypal SN 1998bw that accompanied GRB 980425. This challenges the ordinary GRB classification scheme based on GRB durations and the general belief that long GRBs are produced by the core-collapse of massive stars (Zhang 2006; Watson et al. 2007).

In fact, except its duration, GRB 060614 is much like a short GRB in many aspects. Besides the fact that it has no associated supernova, GRB 060614 has a vanishing spectral lag that is typical of short GRBs (Mangano et al. 2007). Its lightcurve has a very hard and short-duration initial peak, followed by an extended soft emission. Zhang et al. (2007) have shown that if this burst had an eight time smaller total energy, it would have been detected by BATSE as a marginal short-duration GRB, and would have properties in the *Swift* BAT and XRT bands similar to GRB 050724.

GRB 060505 has a duration ~ 4 s and a host galaxy at

⋆ E-mail: campisi@mpa-garching.mpg.de

$z = 0.089$. No supernova has been detected at the location of this burst also (Fynbo et al. 2006; Ofek et al. 2006), so GRB 060505 has also been considered as a long GRB without a supernova. It has been argued that GRB 060505 is indeed a short burst (Ofek et al. 2006; Levesque & Kewley 2007, see, however, Thöne et al. 2008; McBreen et al. 2008). Models for "long GRBs without supernovae" have been proposed (King, Olsson & Davies 2007).

On the other hand, it has been suggested that GRB 060614 and its host galaxy was just a coincidence rather than a physical association (Cobb et al. 2006b). By counting the number of galaxies observed by SMARTS in a field centered on the burst, Cobb et al. (2006b) showed that the probability for a chance superposition of GRB 060614 and a galaxy along the line of sight is $\sim 1\%$. This probability is high enough to cause that several cases of chance superposition may have happened for *Swift* GRBs. This conclusion is enforced by a more detailed study by Cobb & Bailyn (2007).

The results of Cobb et al. have raised an important question in identifying GRB host galaxies based only on the superposition of a GRB and a galaxy on the sky (Levan et al. 2007). For a telescope with very high sensitivity, it would observe many galaxies on the sky, then the probability for a GRB to be aligned with a galaxy could be high. Then, unavoidably, some GRB hosts discovered in this approach might be superficial, i.e. they are not physically related to the GRBs. Cobb et al. obtained their results by using galaxy survey data. It is interesting to verify these results with an independent, more theoretical approach.

In this paper, we calculate the probability for a GRB to be coincident with a galaxy on the sky using galaxy luminosity functions and compare the results with that of Cobb et al. obtained with different ways. Then, we use our results to assess at what a level we can trust the GRB host galaxies that have been found so far. The UVOT on *Swift* can resolve a source to sub-pixels ($\sim 0.2''$). Hence, in our calculations we regard a GRB as a point source.

The approach that we adopt has the benefit of extending beyond the limit of current surveys and to broader types of problems. For example, with slight modification it can be applied to the calculation of the probability of Lyα forests in the spectra of quasars and GRBs which has important applications in probing the high-z Universe (Loeb 2002).

2 THE GALAXY LUMINOSITY FUNCTION

The galaxy luminosity function (LF) is a fundamental characteristics of the galaxy population and is essential for studying statistical properties of galaxies and their evolution. It gives the abundance of galaxies as a function of their luminosity, defined by the comoving number density of all galaxies with luminosity between L and $L + dL$ at redshift z. The LF of a population of galaxies is usually described by the Schechter function (Schechter 1976)

$$\Phi(L)dL = \Phi^* \left(\frac{L}{L^*}\right)^\alpha \exp\left(-\frac{L}{L^*}\right)\frac{dL}{L^*} \,, \tag{1}$$

where L^* is a characteristic luminosity, the constant α is the faint-end slope, and Φ^* is the normalization. These three parameters are determined by fitting the LF to the data from a galaxy survey.

The LF is often expressed in terms of magnitudes rather than luminosities, which is more convenient to use in UV and optical observations. The absolute magnitude M is related to the galaxy luminosity by $M - M^* = -2.5\log(L/L^*)$, where M^* is a characteristic magnitude corresponding to the characteristic luminosity L^*. Then, the Schechter LF becomes

$$\Phi(M)dM = (0.4\ln 10)\Phi^* \times 10^{0.4(\alpha+1)\left(M^*-M\right)} \exp\left[-10^{0.4(M^*-M)}\right] dM \,. \tag{2}$$

In a flat universe, the number of galaxies within a solid angle Ω with magnitude in the range $M_{\rm min}$–$M_{\rm max}$ and comoving distance $D_{\rm com}$ in the range D_1–D_2 is calculated by integral:

$$N = \Omega \int_{D_1}^{D_2} dD_{\rm com}\, D_{\rm com}^2 \int_{M_{\rm min}}^{M_{\rm max}} dM\, \Phi(M) \,. \tag{3}$$

The solid angle Ω is the solid angle covered by a survey, and $M_{\rm max} = M_{\rm max}(m, z)$ is the maximum absolute magnitude arising from the apparent magnitude limit m of the telescope. The comoving distance to a galaxy at redshift z is calculated by

$$D_{\rm com} = \frac{c}{H_0}\int_0^z \frac{dz}{\sqrt{\Omega_m\,(1+z)^3 + \Omega_\Lambda}} \,, \tag{4}$$

where c is the speed of light, H_0 is the Hubble constant, Ω_m is the fraction of mass contained in baryonic and dark matter in the Universe, and Ω_Λ is the fraction of mass contained in the cosmological constant or dark energy.

Throughout the paper we adopt a cosmology with $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$.

2.1 Morphology and Redshift Dependent LF

The LF is one of the fundamental observational properties of galaxies, and the amount of work dedicated by different groups of people to derive an accurate LF is substantial. The LF has been measured from many galaxy surveys with differing sample selections and redshift coverage, and different outcomes are compared by de Lapparent et al. (2003). The results in the literature have shown that there is no universal galaxy LF. Instead, the galaxy LF evolves with redshift and galaxy morphology.

It has been found that, in general, the faint-end LF of early-type galaxies is steeper than that of late-type galaxies, and the characteristic luminosity of early-type galaxies is smaller than that of late-type galaxies (Madgwick et al. 2002; Nakamura et al. 2003).

The LF of local galaxies is now well constrained by two large spectroscopic surveys: the Two-Degree Field Redshift Survey (2dFGRS; e.g. Norberg et al. 2002), and the Sloan Digital Sky Survey (SDSS; e.g. Blanton et al. 2003). The Canada-France Redshift Survey (CFRS), which includes galaxies up to $z \sim 1$, showed that the LF evolves with the cosmic redshift and the evolution depends on the galaxy populations.

For example, the CFRS survey shows unambiguously that the population evolves and that this evolution is strongly differential with color and, less strongly, with luminosity (Lilly et al. 1995). The LF of red galaxies changes little over $0.05 < z < 1$, while the LF of blue galaxies shows substantial evolution at redshifts $z > 0.5$.

At higher redshift, the evolution of LF in blue bands over the redshift range $0.5 < z < 5.0$, and in red bands over the redshift range $0.5 < z < 3.5$, has been derived from the FORS Deep Field survey (Gabasch et al. 2004, 2006). The LF measurements for different galaxy types have been derived up to $z = 1.5$ from the VVDS survey (Zucca et al. 2006).

In this paper, we consider the LF for each type of galaxies separately.

3 THE RADIUS-LUMINOSITY RELATION

To calculate the probability for a GRB to be coincident with a galaxy on the sky, we need to measure the projected radius of the galaxy on the sky. To do so, we associate with each galaxy a physical projected area, as a function of the redshift and of the luminosity of galaxies.

For an elliptical galaxy, we assume that the area covered by the galaxy on the sky is $S = \pi R^2$, where R is an averaged radius. For a spiral or an irregular galaxy, which is not spherical, we assume that the galaxy has a random distribution in orientation. For a spiral or an irregular galaxy with an inclination angle θ, the area on the sky is $S' = \pi R^2 \cos\theta$ ($0 < \theta < \pi/2$).

Generally, the size of a galaxy is correlated with its luminosity. Hence, The value of R for a galaxy with a given luminosity can be derived from a statistical relation between the observed radius and luminosity, at a given redshift. The relation can be fitted by a power law

$$R = \left(\frac{L}{\zeta_i}\right)^{\varphi_i} , \tag{5}$$

where R is in kpc and L is in erg s^{-1}, ζ_i and φ_i are constants that depend on the galaxy morphological types and on the bandpass of the telescope.

Dahlen et al. (2007) have shown that the galaxy size evolves strongly with redshift. In particular they have claimed that there is a similar evolution in the size-luminosity relation in several wavelengths, over the range $0 < z < 6$. The evolution is consistent with the form $R_h \propto (1+z)^\beta$, where $\beta \sim -1$ and R_h is the half-light radius of the galaxy. The ratio R_{90}/R_{50} (radius containing 90% and 50% of the flux) is approximately constant for de Vaucouleurs and exponential profile galaxies (~ 3.3 and ~ 2.3, respectively), so we can assume that $R_{90} \propto (1+z)^\beta$.

The solid angle occupied by a galaxy is then

$$\omega_{\rm gal} = \frac{\langle S\rangle}{D_A^2} , \tag{6}$$

where D_A is the angular-diameter distance to the galaxy [related to the comoving distance by Etherington's reciprocity law $D_A = D_{\rm com}/(1+z)$; Etherington 1933], $\langle S\rangle$ is the projected area of the galaxy averaged over inclination.

For spherical or elliptical galaxies we have $\langle S\rangle = \pi R_0^2(1+z)^{2\beta}$, where R_0 is the radius of the galaxy. For disk spiral galaxies and irregular galaxies with a random distribution of inclination we have $\langle S\rangle = (1/2)\pi R_0^2(1+z)^{2\beta}$.

4 COMPUTATION OF THE PROBABILITY

The probability for a GRB to be aligned to a galaxy is always small. Hence, the probability is simply given by the ratio of the solid angle spanned by galaxies to the total solid angle

$$P = \frac{\Omega_{\rm gal}}{\Omega} , \tag{7}$$

where Ω is the solid angle of space covered by a survey, and $\Omega_{\rm gal}$ is the total solid angle occupied by galaxies. Using relations (3) and (6), the total solid angle occupied by galaxies is ($\Omega = 4\pi$)

$$\Omega_{\rm gal} = 4\pi \int_0^{z_{\rm max}} dD_{\rm com}\, D_{\rm com}^2 \int_{M_{\rm min}}^{M_{\rm max}} dM\, \frac{\langle S\rangle}{D_A^2}\, \Phi(M) , \tag{8}$$

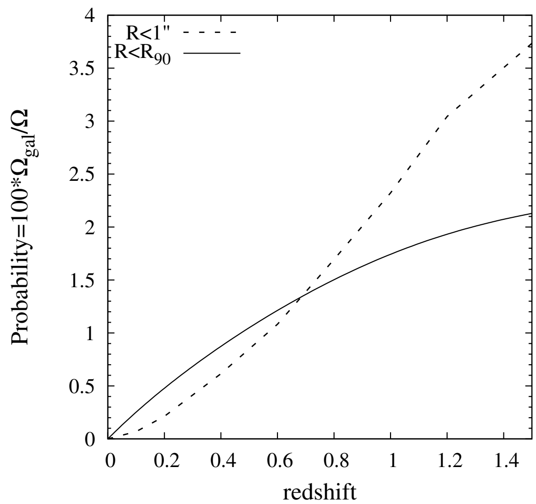

Figure 1. Probability for a GRB to be coincident with a galaxy on the sky, with $0 < z < 1.5$ and the B-band magnitude limit $m_b = 26.5$. The solid curve is calculated with equation (9), which assumes that a GRB is associated with a galaxy if the linear distance from the GRB to the galaxy center is less than R_{90}. The dashed curve is calculated with equation (11), which assumes that a GRB is associated with a galaxy if the angular distance from the GRB to the galaxy center is less than $1''$.

where $z_{\rm max}$ is the maximum redshift that can be reached by a survey. Then, by Etherington's reciprocity law, we have

$$P = \int_0^{z_{\rm max}} dD_{\rm com} \int_{M_{\rm min}}^{M_{\rm max}} dM\, \langle S\rangle (1+z)^2\, \Phi(M) , \tag{9}$$

we will adopt $\beta = -1$ to compute $\langle S\rangle$.

Since the LF decays exponentially toward the bright end, the exact value of $M_{\rm min}$ does not affect the final result. In our numerical calculation we take $M_{\rm min} = -30$. For a given luminosity distance $D_{\rm lum}$, the value of $M_{\rm max}$ is related to the magnitude limit of the telescope, m, by

$$M_{\rm max} = m - 5\log\frac{D_{\rm lum}}{10\ {\rm pc}} - K , \tag{10}$$

where K is the K-correction depending on the filter.

The parameters in the LF are derived from the SDSS and the VVDS catalogs (Nakamura et al.2003; Zucca et al. 2006) and the radius-luminosity relation from the SDSS catalogs (York et al.2000; Appendixes A & B). Then, the probability can be calculated by equation (9). The calculated results of P for the parameters in the B-band obtained from the VVDS survey (Zucca et al. 2006) are shown in Fig. 1 (solid line). In the calculations the K-corrections were provided by E. Zucca (see also Fukugita, Shimasaku, & Ichikawa 1995).

For a given galaxy survey, the projected area of resolved galaxies on the sky can be measured. Then equation (7) can be directly applied to calculate the probability for chance coincidence of a GRB with a galaxy on the sky. As an example, the fraction of the sky covered by galaxies in the Hubble Deep Fields (HDFs) is $\sim 5\%$ if the boundary of a galaxy is defined by twice the isophotal radius containing $\sim 90\%$ flux (Bernstein, Freedman, & Madore 2002).

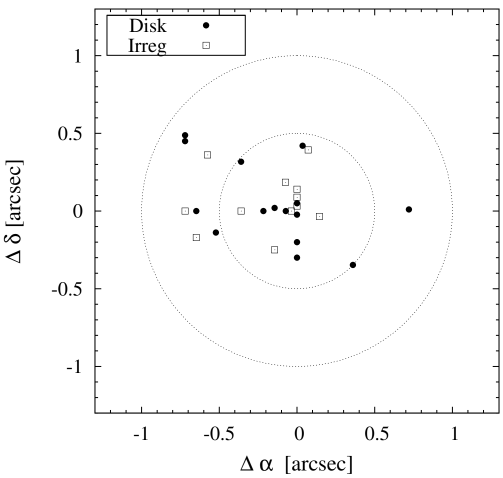

Figure 2. Displacement of GRB positions with respect to the center of their host galaxies for a sample of 27 long GRBs with well measured and resolved hosts (in the redshift range $0.089 \leqslant z \leqslant 3.42$).

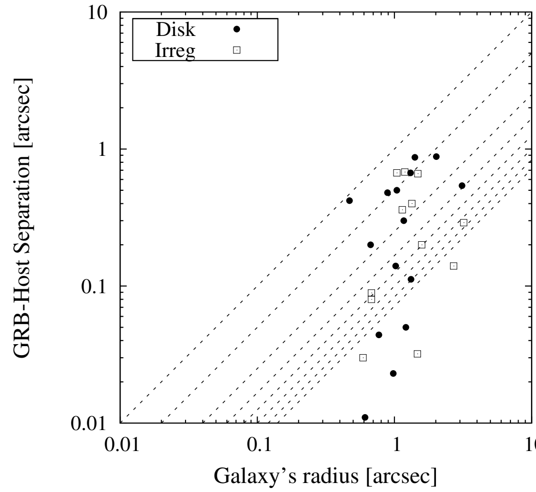

Figure 3. Radius of the host galaxies, computed with equation (5), versus the observed distance between GRBs for the same sample and their host galaxies. Dashed lines labels the relations of separation/galaxy radius $=$ $1/14, 1/12, 1/10, 1/8, 1/6, 1/4, 1/2, 1$ (blue-dashed line).

5 COMPARISON WITH OBSERVED HOST GALAXIES

For those GRBs with known hosts, we find out the distribution of the distance, projected on the sky, between the GRB's position and the center of the associated host galaxy. From this distribution, we can check if the observed distance is within the galaxy radius defined in the equation (5). From ~ 50 GRBs with both redshift and host associate, [1] we select 27 long GRBs , including only GRBs with sure host galaxy types and R-band magnitudes. Figure 2 shows the displacement between RA/DEC of the GRB's position and the host galaxy counterpart in the sample (see table C1 of the Appendix). Most GRBs with reliable host measurements have a separation smaller than $1''$ from the center of their counterpart. Our comparison is in agreement with previous works (Bloom et al. 2002; Fruchter et al. 2006).

In Fig. 3, we compare the galaxy radius defined by equation (5) and the observed distance between GRBs from the center of their host galaxies. Since all of the observed GRBs fall in the defined galaxy radius, equation (5) provides a reasonable estimate for galaxy radii and a scale measuring the association of GRBs and their hosts. The probability calculated with the galaxy radius that we have defined would lead to a reasonable estimate on the probability for a GRB to be coincident with a galaxy on the sky.

In practice people often identify association of a GRB with a galaxy by requiring that the projected distance from a GRB to the center of a galaxy on the sky is smaller than a critical angular distance, say $< 1''$. Then the probability for chance coincidence of a GRB and a galaxy on the sky is calculated by

$$P = \omega_{\rm c} \int_0^{z_{\rm max}} D_{\rm com}^2 dD_{\rm com} \int_{M_{\rm min}}^{M_{\rm max}} dM \, \Phi(M) \,, \qquad (11)$$

where $\omega_{\rm c} = \pi(1'')^2 = 7.384 \times 10^{-11}$ is the solid angle corresponding to a circle of radius $1''$. The probability calculated with this formula is shown in Fig. 1 with a dashed curve.

It appears that the probability calculated with an angular radius $1''$ is higher than that calculated with a linear radius R_{90}. This is caused by the fact that for a fixed angular radius the corresponding linear radius increases with distance while the luminous R_{90} decreases with redshift. Our results indicate that identifying the GRB-galaxy association with a linear distance scale is more reliable than with an angular scale from the galaxy center.

[1] http://www.grbhosts.org/

6 CONCLUSIONS

We have calculated the probability for a GRB to be coincident with a galaxy on the sky, using the luminosity function and the radius-luminosity relation derived from the SDSS and VVDS surveys.

Since there is not a reliable luminosity function available to higher redshifts, the probability is calculated only up to a redshift $z \sim 1.5$ (Fig. 1). The results are in agreement with that of Cobb et al. (2006b) and Cobb & Bailyn (2007) which were obtained with different approaches. The total probability at $z = 1.5$ is a few percent.

We have also calculated the probability of chance coincidence with a criterion that a GRB is considered to be associated with a galaxy if the distance from the GRB to the galaxy center is smaller than $1''$ (Fig. 1, dashed line). This probability is larger than that calculated with R_{90} for $z > 0.7$ (Fig. 1, solid line), caused by the fact that for a fixed angular separation the corresponding linear separation increases with z and R_{90} decreases with z.

Although the chance probability is small, it warns us that identifying a GRB host based only on the superposition of a GRB with a galaxy on the sky is dangerous. So far about 350 GRBs have been detected by *Swift*, our results imply that several chance coincidence of a GRB with a galaxy might have already happened. As a result, some GRB hosts that have been found might be superficial. However, for the case of GRB 060614, calculation of the chance superposition of it and a $z < 0.125$ galaxy with separation $< 0.5''$ leads to a probability $P = 0.02\%$, consistent with the result of Gal-Yam et al. (2006). This small probability indicates that the association of GRB 060614 and its host is secure.

Obviously, a secure identification of a GRB's host would be obtained by (1) the superposition of the GRB with a galaxy; and

(2) the afterglow of the GRB and the host candidate give rise to the same measured redshift.

We have also calculated the probability directly from the data of SDSS, following the approach of Cobb et al. The results are presented in Appendixes A, which agree with our analytical results.

ACKNOWLEDGMENTS

We thank R. Narayan and R. Sunyaev for valuable comments and suggestions, E. Zucca for providing the K-corrections for the VVDS survey, and an anonymous referee for a very enlightening report.

REFERENCES

Berger E., 2006, in Holt S., Gehrels N., Nousek J., eds, Gamma-Ray Bursts in the Swift Era. Am. Inst. Phys., New York, p. 33
Bernstein R. A., Freedman W. L., Madore B. F., 2002, ApJ, 571, 56
Blanton M. R., et al., 2003, ApJ, 592, 819
Blanton M. R., et al., 2001, AJ, 121, 2358
Bloom J. S., Berger E., Kulkarni S. R., Djorgovski S. G., Frail D. A., 2003, AJ, 125, 999
Bloom J. S., Kulkarni S. R., Djorgovski S. G., 2002, AJ, 123, 1111
Bloom J. S. et al., 2002, ApJ, 572, L45
Bloom J. S., Djorgovski S. G., Kulkarni S. R., 2001, ApJ, 554, 678
Bloom J. S. et al., 1999, ApJ, 518, L1
Bloom J. S. et al., 1999, GCN 206
Bloom J. S., Djorgovski S. G., Kulkarni S. R., Frail D. A., 1998, ApJ, 507, L25
Butler N. et al., 2004, in Fenimore E. E., Galassi M., eds, Gamma-Ray Bursts: 30 Years of Discovery. Am. Inst. Phys., New York, p. 111
Cobb B. E., Bailyn C. D., 2008, ApJ, 677, 1157
Cobb B. E., Bailyn C. D., van Dokkum P. G., Natarajan P., 2006, ApJ, 651, L85
Conselice C. J. et al., 2005, ApJ, 633, 29
Christensen L., Hjorth J., Gorosabel J., 2004, A&A, 425, 913
Dahlen T., Mobasher B., Dickinson M., Ferguson H. C., Giavalisco M., Kretchmer C., Ravindranath S., 2007, ApJ, 654, 172
de Lapparent V., Galaz G., Bardelli S., Arnouts S., 2003, A&A, 404, 831
Della Valle M. et al., 2006, Nat, 444, 1050
Djorgovski S. G., Kulkarni S. R., Bloom J. S., Goodrich R., Frail D. A., Piro L., Palazzi E., 1998, ApJ, 508, L17
Etherington I. M. H., 1933, Phil. Mag., 15, 761
Frail D. A., Kulkarni S. R., Nicastro L., Feroci M., Taylor G. B., 1997, Nat, 389, 261
Fruchter A. S. et al., 2006, Nat, 441, 463
Fukugita M., Shimasaku K., Ichikawa T., 1995, PASP, 107, 945
Fynbo J. P. U. et al., 2006, Nat, 444, 1047
Fynbo J. U. et al., 2001, A&A, 373, 796
Gabasch A. et al., 2006, A&A, 448, 101
Gabasch A. et al., 2004, A&A, 421, 41
Galama T. J. et al., 2003, ApJ, 587, 135
Galama T. J. et al., 1998, Nat, 395, 670
Gal-Yam A. et al., 2006, Nat, 444, 1053
Gehrels N. et al., 2006, Nat, 444, 1044
Graziani C. et al., 2003, GCN 1956
Grav T. et al., 2001, GCN 1191
Gorosabel J., Jelínek M., de Ugarte Postigo A., Guziy S., Castro-Tirado A. J., 2005, Il Nuovo Cimento C, 28, 677
Gorosabel J. et al., 2003, A&A, 400, 127
Halpern J. P., Fesen R., 1998, GCN 134
Henden A., Vrba F., 2001, GCN 967
Hjorth J., et al., 2002, ApJ, 576, 113
Holland S. T. et al., 2002, AJ, 124, 639
Jensen B. L., Hjorth J., Pedersen H., Kristen H. E., Tomassi L., Pian E., Hurley K., 1999, GCN 454
Jakobsson P. et al., 2005, ApJ, 629, 45
Jakobsson P. et al., 2004, A&A, 427, 785
Jakobsson P. et al., 2003, A&A, 408, 941
King L., Corless V., 2007, MNRAS, 374, L37
Levan A. J. et al. 2007, MNRAS, 378, 1143
Levesque E. M., Kewley L. J., 2007, ApJ, 667, L121
Le Floc'h E. et al., 2002, ApJ, 581, L81
Li L.-X., 2006, MNRAS, 372, 1357
Li L.-X., Paczyński B., 1998, ApJ, 507, L59
Lilly S. J., Tresse L., Hammer F., Crampton D., Le Fevre O., 1995, ApJ, 455, 108
Loeb A., 2002, in Gilfanov M., Sunyaev R., Churazov E., eds, Lighthouses of the Universe: The Most Luminous Celestial Objects and Their Use for Cosmology. Springer-Verlag, Berlin, p. 137
MacFadyen A. I., Woosley S. E., Heger A., 2001, ApJ, 550, 410
MacFadyen A. I., Woosley S. E., 1999, ApJ, 524, 262
Madgwick D. S. et al., 2002, MNRAS, 333, 133
Mangano V. et al., 2007, A&A, 470, 105
Margon B., Deutsch E. W., Lamb D. Q., Castander F. J., Metzger M., 1997, IAUC 6618
Masetti N. et al., 2005, A&A, 438, 841
McBreen S. et al., 2008, ApJ, 677, L85
Mirabal N., Halpern J. P., O'Brien P. T., 2007, ApJ, 661, L127
Mirabal N., Halpern J. P., An D., Thorstensen J. R., Terndrup D. M., 2006, ApJ, 643, L99
Mirabal N., Halpern J. P., Wagner R. M., 2000, GCN 650
Nakamura O., Fukugita M., Yasuda N., Loveday J., Brinkmann J., Schneider D. P., Shimasaku K., SubbaRao M., 2003, AJ, 125, 1682
Norberg P. et al., 2002, MNRAS, 336, 907
Odewahn S. C. et al., 1998, ApJ, 509, L5
Ofek E. O. et al., 2007, ApJ, 662, 1129
O'Shaughnessy R., Kalogera V., Belczynski K., 2007, ApJ, 667, 1048
Paczynski B., 1998, ApJ, 494, L45
Palazzi E., Masetti N., Pian E., 1999, GCN 382
Parsons A. M. et al., 2006, GN 5252
Peterson B. A., Price P. A., 2003, GCN 1974
Petrosian V. 1976, ApJ, 209, L1
Price P. A. et al., 2002, ApJ, 571, L121
Price P. A. et al., 2001, ApJ, 549, L7
Price P. A., 2000, GCN 799
Rau A. et al., 2004, A&A, 427, 815
Sahu K. C. et al., 2000, ApJ, 540, 74
Schechter P., 1976, ApJ, 203, 297
Subrahmanyan R., Kulkarni S. R., Berger E., Frail D. A., 2001, GCN 1156
Tanvir N. R., Levan A. J., 2007, to appear in the proceedings of "070228: The next decade of GRB afterglows", Amsterdam, March 2007 (arXiv:0709.0861)

Galaxy type	ζ_i	φ_i
E/S0	1.12e+42	0.561
Sbc/Scd	2.33e+40	0.335
Irr	1.40e+40	0.305

Table A1. Best-fit parameters in the radius-luminosity relation (5) in the r-band for SDSS galaxies, with R in kpc and L in erg s^{-1}.

Taylor G. B., Frail D. A., Beasley A. J., Kulkarni S. R., 1998, GCN 152
Thöne C. C. et al., 2008, ApJ, 676, 1151
Vreeswijk P. M. et al., 2004, A&A, 419, 927
Wainwright C., Berger E., Penprase B. E., 2007, ApJ, 657, 367
Watson D., Fynbo J. P. U., Thöne C. C., Sollerman J., 2007, Phil. Trans. R. Soc. A, 365, 1269
Woosley S. E., Bloom J. S., 2006, ARA&A, 44, 507
Woosley S. E., Heger A., 2006, ApJ, 637, 914
Yamaoka H., Ayani K., Itagaki K., 2004, GCN 2781
York D. G. et al., 2000, AJ, 120, 1579
Zhang B., Zhang B.-B., Liang E.-W., Gehrels N., Burrows D. N., Mészáros P., 2007, ApJ, 655, L25
Zhang B., 2006, Nat, 444, 1010
Zucca E. et al., 2006, A&A, 455, 879

APPENDIX A: THE SDSS CATALOG

SDSS catalog (York et al. 2000)[2] contains the largest redshift sample of galaxies with both photometric and spectroscopic observations. It is a homogeneous data set that is suitable for statistical studies of galaxies. The SDSS sample for LF measurements (Nakamura et al. 2003) contains ~ 1500 bright galaxies, in the redshift range $0.01 < z < 0.12$ with $13.2 \leqslant r^* \leqslant 15.9$. The galaxies are classified into four groups by the $g - r$ color: $0 \leqslant T \leqslant 1.0$ (corresponding to Hubble type E-S0), $1.5 \leqslant T \leqslant 3$ (S0/a-Sb), $3.5 \leqslant T \leqslant 5.0$ (Sbc-Sd), and $5.5 \leqslant T \leqslant 6$ (Im) (Fukugita et al. 1995). The LF was calculated with three methods: ML (maximum likelihood), SWML (stepwise maximum likelihood), and the $V_{\max}$ method.

To derive the radius-luminosity relation, we take from the SDSS catalog the Petrosian radius R_{90} in the r^* band (which contains 90% of the Petrosian flux), the value of the apparent brightness r^*, and the galaxy redshift. Note that, SDSS has adopted a modified form of the Petrosian system (Petrosian 1976) to define the radius of a source (see Blanton et al. 2001 for details). For the exponential profile, R_{90} corresponds to the true 90$\%$ light radius, while for the de Vaucouleurs profile $R_{90} = 0.43 R_{90\rm true}$.

Then we convert the apparent magnitude r^* to an absolute magnitude M and luminosity L, adopting the K-correction supplied by Fukugita et al. (1995) for each galaxy type.

The derived sky-projected radius and luminosity in the r^*-band for about 240000 galaxies with $r^* < 19.6$ in a sky region of 2500 $\deg^2$ are shown in Fig. A1 for different galaxy types (elliptical, spiral, and irregular). Power-law fits to the R-L relation (eq. 5; divided by $\sqrt{2}$ for spiral and irregular galaxies for the average random projection effect) are summarized in Table A1.

We selected a subsample of galaxies with $15.6 < r^* < 19.6$ (to be consistent with the magnitude limit adopted in eq. 9), and computed the ratio of the sky area covered by them to the total area of the sky. The results are shown in Fig. A2. They agree well with that calculated with equation (9) with $z < 0.3$ (the redshift covered by the SDSS galaxies).

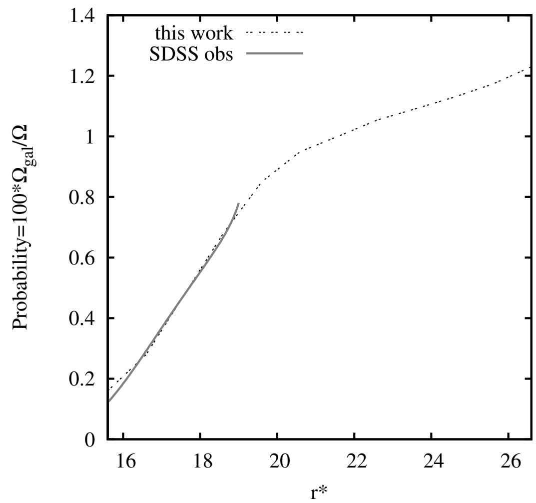

Figure A2. Probability for a GRB to be coincident with a galaxy on the sky, obtained from the SDSS galaxies with $0 < z < 0.3$. The solid line is the ratio of the total solid angle occupied by the SDSS galaxies to the total solid angle covered by the survey. The dashed line is calculated with equation(9).

Galaxy type	ζ_i	φ_i
E/S0	3.32e+41	0.413
Sbc/Scd	3.36e+40	0.322
Irr	8.46e+40	0.361

Table B1. Best-fit parameters in the radius-luminosity relation (5) in the B-band for VVDS galaxies, with R in kpc and L in erg s^{-1}.

APPENDIX B: THE VVDS LF

The VIMOS VLT Deep Survey (VVDS) is a deep spectroscopic survey, containing galaxies up to redshift $z \sim 1.5$. The first epoch VVDS deep sample covers a sky area of about 2200 arcmin^2, containing about 7700 galaxies with $17.5 \leqslant I_{AB} \leqslant 24$. Using this sample, Zucca et al. (2006) derived an evolving and morphology-dependent LF. The galaxies were divided into four types: E/S0, early spiral, late spiral, and irregular. The parameters in the derived luminosity functions are listed in table 3 of Zucca et al. (2006). The best-fit parameters for the radius-luminosity relation are listed in Table B1.

APPENDIX C: THE LONG GRB SAMPLE

In Table C1 we provide details on the long GRBs used in the Figs. 2 and 3. The sample contains 27 GRB hosts from the *GHostS* archive (http://www.grbhosts.org).

[2] http://www.sdss.org/

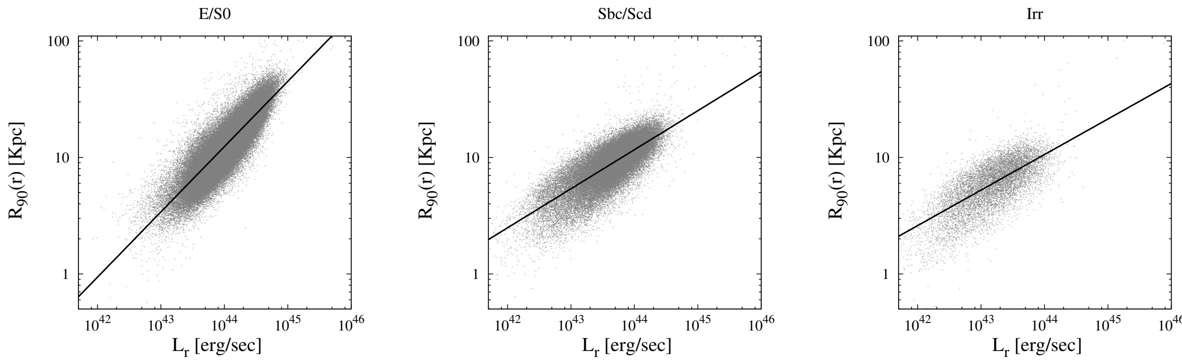

Figure A1. The sky-projected R_{90} versus the luminosity in the r^*-band for the SDSS galaxies with $15.6 < r^* < 19.6$ and $0 < z < 0.3$. Each panel corresponds to a galaxy type (elliptical/S0, spiral/Sbc-Scd, and Irregular galaxies). The solid line is the best-fit with equation (5) (divided by $\sqrt{2}$ for spiral and irregular galaxies for the average random projection effect). The values of the fitted parameters are listed in Table A1.

Table C1. Sample of 27 long GRBs with known redshift and host.

GRB name (1)	z (2)	d_L [Mpc] (3)	M_R (4)	R_{90} [arcsec] (5)	D [arcsec] (6)	α_H (J2000.0) (7)	δ_H (J2000.0) (8)	α_{GRB} (J2000.0) (9)	δ_{GRB} (J2000.0) (10)	Ref. (11)
Disk galaxies										
030323	3.372	29251	27.28	1.02	0.14	166.5391	-21.7704	166.5391	-21.77033	[1]
020819	0.41	2245	19.48	3.11	0.54	351.8310	+6.2655	351.831145	+6.26554	[2]
011211	2.141	16888	25.97	1.04	0.49	168.8250	-21.9489	168.8249	-21.94894	[3]
011121	0.362	1939	23.23	2.02	0.88	173.6240	-76.0282	173.6235	-76.0282	[4]
010921	0.451	2513	22.58	1.17	0.29	344.0000	+40.9312	344.000	+40.93128	[5]
010222	1.48	10735	25.61	0.77	0.044	223.0520	+43.0184	223.05202	+43.0184	[6]
000418	1.118	7594	24.15	0.98	0.023	186.3300	+20.1031	186.3300	+20.10311	[7]
000210	0.846	5386	24.22	0.89	0.48	29.8149	-40.6592	29.815	-40.6591	[8]
991208	0.706	4315	24.6	0.67	0.19	248.4730	+46.4558	248.4730	+46.455834	[9]
990712	0.434	2401	22.45	1.21	0.049	337.9710	-73.4079	337.97096	-73.40786	[10]
990705	0.842	5355	22.78	1.41	0.87	77.47670	-72.1317	77.4770	-72.1315	[11]
990123	1.6	11817	24.41	1.31	0.67	231.3760	+44.7664	231.3762	+44.7664	[12]
980703	0.966	6341	22.9	1.32	0.11	359.7780	+8.58530	359.77780	+8.585300	[13]
970508	0.835	5300	25.2	0.61	0.011	103.4560	+79.2721	103.45604	+79.27208	[14]
970228	0.695	4233	25.88	0.47	0.43	75.4444	+11.7816	75.4442	+11.78159	[15]
Irregular galaxies										
060614	0.125	587	22.52	1.14	0.36	320.8839	-53.0267	320.884	-53.0267	[16]
060218	0.0331	148	20.16	3.21	0.29	50.4153	+16.8671	50.41534	16.86717	[17]
050826	0.296	1535	21.67	1.34	0.40	87.7566	-2.6433	87.75658	-2.64327	[18]
041006	0.712	4360	25.15	0.59	0.03	13.7093	+1.2349	13.70931	+1.23490	[19]
030528	0.782	4890	22.0	1.48	0.66	256.0010	-22.6194	256.0012	-22.6194	[20]
030429	2.66	21986	26.3	1.04	0.67	183.2810	-20.9138	183.28118	-20.91381	[21]
030328	1.52	11110	24.06	1.19	0.68	182.7015	-9.3476	182.70166	-9.34750	[22]
020405	0.691	4204	21.59.	1.58	0.19	209.5130	-31.3728	209.5130208	-31.37275	[23]
000926	2.036	15882	24.18	1.47	0.032	256.0400	+51.7862	256.0400	+51.78611	[24]
000911	1.06	7094	25.27	0.68	0.079	34.6432	+7.7410	34.64316	+7.74102	[25]
980613	1.097	7418	25.33	0.68	0.089	154.4910	+71.4571	154.4910	+71.457083	[26]
971214	3.42	29750	26.35	2.72	0.14	179.1100	+65.2001	179.1100	+65.20013	[27]

Note. — Col. (1) GRB name. Col. (2-3) Redshift and luminosity distance in Mpc. Col. (4) Observed host magnitude in the R-band AB system (Fruchter et al. 2006, and references therein). Col. (5) Radius in arcsec used in this work. Col. (6) Distance in arcsec between GRB and host. Col. (7-8) Positions of the host. Col.(9-10) Positions of the GRB. Col. (11) References: [1] Graziani et al. (2003); Vreeswijk et al. (2004); [2] Jakobsson (2005); [3] Grav et al. (2001); Holland et al. (2002); [4] Subrahmanyan et al. (2001); Bloom et al. (2002); [5] Price et al. (2002); [6] Henden et al. (2001); Galama et al. (2003); [7] Mirabal et al. (2000); Bloom et al. (2003); [8] Gorosabel et al. (2003); [9] Jensen (1999); Christensen et al. (2004) ; [10] Sahu et al. (2000); Christensen et al. (2004); [11] Palazzi et al. (1999); Le Floc'h et al. (2002); [12] Bloom et al. (1999); [13] Taylor et al. (1998); Djorgovski et al. (1998); Christensen et al. (2004); [14] Frail et al. (1997); Bloom et al. (1998); Christensen et al. (2004); [15] Margon et al. (1997); Bloom et al. (2001); [16] Parsons et al. (2006); Gal-Yam et al. (2006); Gehrels et al. (2006); [17] Mirabal et al. (2006); [18] Mirabal et al. (2007); [19] Yamaoka et al. (2004); Wainwrigh et al. (2007); [20] Butler et al. (2004); Rau et al. (2004); [21] Jakobsson (2004); [22] Peterson & Price (2003); Gorosabel et al. (2005); [23] Wainwrigh et al. (2007); [24] Price et al. (2001); Fynbo et al. (2001); [25] Price (2000); Masetti et al. (2005); [26] Hjorth (2002); Halpern & Fesen (1998); [27] Odewahn et al. (1998).