Probability for a gamma-ray burst to be coincident with a galaxy on the sky

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Abstract. The nearby long GRB 060614 was not accompanied by a supernova, challenging the collapsar model for long GRBs and the traditional classification scheme for GRBs. However, Cobb et al. have argued that the association of GRB 060614 and its host galaxy might be a chance coincidence. In this work we calculate the probability for a GRB to be coincident with a galaxy on the sky using a galaxy luminosity function obtained from SDSS. We find that, up to redshift *sim*0.3 that can be reached for galaxies in SDSS, the probability is about one percent. Using an evolving galaxy luminosity function obtained from VVDS, we find that between $0.2 \leq z < 1.5$, the probability is about 2.3 percent. The probability will increase considerably if the telescope magnitude limit is improved significantly in future, making it very hard to identify a GRB host galaxy based only on the superposition of a GRB and a galaxy on the sky.

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INTRODUCTION

Observation of host galaxies of gamma-ray bursts (GRBs) is very important for understanding the nature of GRBs.

Long GRBs usually occur in starforming galaxies. Short GRBs occur in both active and inactive galaxies.

The difference in the observed host properties for short and long GRBs indicates that short and long GRBs have different progenitors. Long GRBs are believed to arise from the death of massive stars—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 [12].

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 $z = 0.125$ [4, 6, 7]. 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 GRB classification scheme based on GRB durations, and the general belief that long GRBs are produced by the death of massive stars [15, 14].

In fact, except its duration, GRB 060614 is much like a short GRB in almost every aspect. Besides the fact that it has no associated supernova, GRB 060614 has a vanishing

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spectral lags that are typical of short GRBs [10]. Its lightcurve has a very hard and short duration initial peak, followed by an extended soft emission. Zhang et al. [16] 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 $z = 0.089$. No supernova has been detected at the location of this burst also [4, 6, 7]. So, GRB 060505 has also been considered as a long GRB without a supernova. However, it has been argued that GRB 060505 is indeed a short burst [11, 9, see however, Thöne et al. 2007]. Models for "long GRBs without supernovae" have been proposed King et al. [8].

On the other hand, it has been suggested that GRB 060614 and its host galaxy was just a coincidence rather than a physical association [2]. By counting the number of galaxies observed by SMARTS in a field centered on the burst, Cobb et al. [2] 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 [1].

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. For a telescope with very a high sensitivity, it would observe many galaxies on the sky, then the probability for a GRB to be aligned with a galaxy would 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 important to verify the results in a more fundamental way.

In this paper, we calculate the probability for a GRB to be coincident with a galaxy on the sky by using galaxy luminosity functions, and compare the results with that of Cobb et al. Then, we use our results to assess at what a level we can trust the GRB host galaxies that have been found so far.

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 total solid angle spanned by galaxies ($\Omega_{\rm gal}$) to the total solid angle (Ω), covered by the survey:

$$P = \frac{\Omega_{\rm gal}}{\Omega} . \tag{1}$$

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:

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

where $\Phi(M)$ is the galaxy luminosity function (LF), which has been measured from many galaxy surveys with differing sample selections and redshift coverage. The results in literature have shown that there is not a universal galaxy LF. Instead, the galaxy LF evolves with redshift and galaxy morphology. LF measurements for different *galaxy types* have been done to a redshift up to $z = 1.5$ in the VVDS survey [17].

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 $S' = \pi R^2 \cos\theta$ ($0 < \theta < \pi/2$). Dahlen et al. [3] have shown that the galaxy size evolves strongly with redshift, 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 solid angle occupied by a galaxy is then

$$\omega_{\rm gal} = \frac{\langle S \rangle}{D_A^2} , \tag{3}$$

where D_A is the angular-diameter distance to the galaxy

Using the relations 2 and 3, the total solid angle occupied by galaxies is:

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

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

$$P = \int_0^{z_{\rm max}} dD_{com} \int_{M_{\rm min}}^{M_{\rm max}} dM \langle S \rangle (1+z)^2 \Phi(M) , \tag{5}$$

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

RESULTS AND 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-Right). The results are in agreement with that of Cobb et al. [2] and Cobb & Bailyn [1] which were obtained with different approaches.

The total probability is a few percent. Although this 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 200 GRBs have been detected by *Swift*. Our results imply that several cases of 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, including the case of GRB 060614.

Obviously, a secure identification of a GRB's host would be obtained by (I) the superposition of the GRB with a galaxy; and in addition, (II) the afterglow of the GRB and the host candidate give the same redshift.

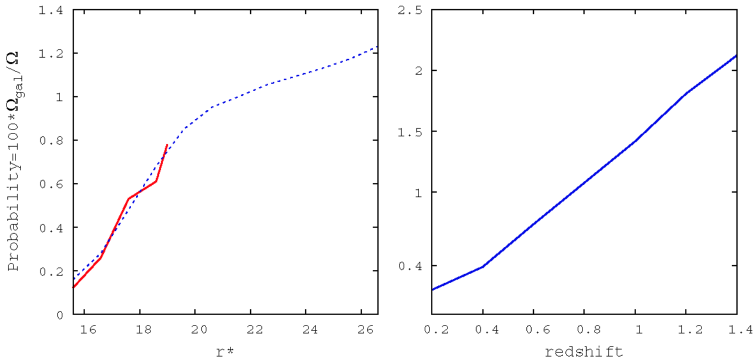

FIGURE 1. **Left:** Probability for a GRB to be coincident with a galaxy on the sky, obtained from the SDSS galaxies with $0.01 \leq z \leq 0.3$. The red-solid line is the ratio of the total solid angle occupied by the SDSS galaxies to the total solid angle covered by the survey. The blue-dashed line is the results from the equation 5. **Right:** Evolution of the probability for a GRB to be coincident with a galaxy on the sky, with $0.2 \leq z \leq 1.4$ and magnitude limit $m_b = 26$; the used LF's parameters were obtained from the VVDS survey.

We have also calculated the probability directly from the data of SDSS, following the approach of Cobb et al. The results are in agree with our analytical results (Fig. 1-Left).

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