Gamma Ray Burst progenitors – a case for helium star mergers

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Received ..., Accepted ...

Abstract. Recently much work in Gamma-Ray Burst (GRB) studies was devoted to revealing the nature of outburst mechanism and to looking for GRB progenitors. Several types of progenitors were proposed for GRBs. Most promising objects are collapsars, compact object binaries, Helium star mergers and recently discussed supernovae. In this paper we consider four proposed binary star progenitors of GRBs: double neutron star (NS-NS), black hole neutron star (BH-NS), black hole white dwarf (BH-WD) mergers and Helium star mergers (He-BH). Helium star mergers are a possible outcome of common envelope evolution of a compact object entering the envelope of a giant with a helium core.

Using population synthesis we calculate number of the binary progenitors and show that BH-WD and Helium star mergers dominate population of the proposed binary progenitors. Comparison of distribution of different binary mergers around galaxies they are born in, with localization of GRB afterglows in their host galaxies shows that only Helium mergers may be responsible for GRBs with observed afterglows while it excludes NS-NS, BH-NS and BH-WD systems as GRB progenitors. Assuming that all GRBs come from Helium star mergers and comparing numbers of Helium star mergers with observed BATSE GRB rate let us derive upper limit on GRB collimation to be $\sim 4^\circ$.

Key words: stars: binaries; evolution — gamma rays: bursts — stars: neutron

1. Introduction

The last decade brought a great breakthrough in gamma-ray burst studies. Observations of GRB afterglows in X-ray, optical and radio wavelength domains (Costa et al., 1997; Groot et al., 1997) led to identification of GRB host galaxies (Groot et al., 1997) and measurements of their redshifts. This has solved the long standing problem of their origin. While we learned that GRBs come from cosmological distances there are still two major difficulties in understanding this phenomenon. First, we do not understand fully the physics of outburst. Although several models were proposed they all yet have to meet some severe constraints imposed by observations (i.e. releasing energies of $10^{51}$–$10^{54}$ ergs in timescales as short as $10^{-2}$ s in case of some GRBs). Second we don’t know what are the astrophysical objects leading to gamma-ray bursts, i.e. what are their progenitors?

Recently a black hole accretion disk model of GRB outburst has been favored (Meszaros, 1999; Brown et al., 2000; Fryer et al., 1999). Progenitors leading to this model include collapsars (Woosley, 1993; MacFadyen and Woosley, 1999) and binary stars: Helium star mergers (Fryer and Woosley, 1998), double neutron stars (Ruffert et al., 1997; Meszaros and Rees, 1997), black hole neutron star (Lee and Kluzniak, 1995; Kluzniak and Lee, 1998) and black hole white dwarf systems (Fryer et al., 1999). Also recently the supernovae gamma-ray bursts connection received much attention (Paczynski, 1999; Woosley, 2000; Chevalier, 2000), however there is still no clear evidence that these two phenomena are intrinsically correlated (Graziani et al., 1999).

The present paper is an extension of our previous studies (Belczynski and Bulik, 1999; Bulik et al., 1999; Belczynski et al., 2000) and we aim here at a discussion of viability of the proposed GRB binary progenitors.

One way of telling which group of proposed binaries might be responsible for GRBs is to predict their numbers and compare them to the observed number of GRBs. Population synthesis is a powerful tool for predicting numbers of binary populations although it suffers from many uncertainties as some parameters of single and binary evolution are poorly known. Moreover, population synthesis works well in predicting the relative numbers of events, while calculation of absolute numbers requires additional assumptions. Using population synthesis method we calculate production rates of Helium star mergers, double neutron stars, black hole neutron star and black hole white dwarf systems. We use BATSE detection limit of observed...
number of GRBs to compare with our predicted numbers of the binary progenitors.

Another way of discerning among the binary progenitors is to compare their merger site distributions around host galaxies with localization of GRBs within host galaxies. Again this may be accomplished by population synthesis method to simulate a given binary population and then placing it in galactic gravitational potentials one may trace each binary until its components merge due to gravitational wave energy losses. We perform such calculations for different galactic potentials and then compare the results to the observations of GRB afterglows and their positions within host galaxies. In this work we extend our previous studies to include two more proposed binary progenitors: black hole white dwarf binaries and Helium star mergers. Moreover, we improve our population synthesis code and for consistency we also present the updated results for two previously studied types of proposed progenitors: double neutron star and black hole neutron star systems.

Population synthesis method has already been applied to study compact object binaries in context of GRB progenitors. However most of authors have concentrated only on double neutron stars and black hole neutron star systems (Narayan et al., 1991; Phinney, 1991; Tutukov and Yungelson, 1993; Portegies Zwart and Spericuw, 1996; Bloom et al., 1999; Belczynski and Bulik, 1999; Bulik et al., 1999; Belczynski et al., 2000). Only one group (Fryer et al., 1999) presented calculations including all types of proposed binary progenitors and also collapsars. Our calculations besides the conclusions we obtain, may serve as a direct check and comparison for the results presented by Fryer et al. (1999).

In section 2 we present observational data on the distribution of GRBs around their host galaxies, in section 3 we describe the population synthesis code used in this paper and formation scenario for Helium star mergers, in section 4 we discuss the results, and we present our conclusions in section 5.

3. The model

We use the population synthesis code described in detail in Belczyński & Bulik (1999). The code was modified to allow for evolution of low mass and intermediate mass stars.

3.1. Modifications and description of population synthesis code

Initial conditions. All binary star initial parameters are drawn from the same distributions, but we have changed the limits of binary components masses. As of now, we use more accurate description of single stellar evolution (see below); now we let the primary (more massive component at beginning) to have mass in range 8.6–100 M⊙. The lower limit here has been set in order to make sure that the primary will explode in a supernova explosion (unless it is stripped of mass in early mass transfer/loss episode) and turn to a neutron star or a black hole. The range of secondary mass component is restricted now to 1.0–100 M⊙. The lower limit here ensures that the star has a chance to produce a remnant in the Hubble time. This way we study population of binaries which have the most chances to produce the proposed binary star GRB progenitors.

Single stellar evolution. To describe evolution of single star we use analytical formulae of Eggleton et al., (1989) and Tout et al., (1996) which are a new addition to our code. We follow a given star through different stages of its evolution: main sequence, Hertzsprung gap, red giant branch, core helium burning, and asymptotic giant branch. The star may become a naked Helium star due to wind mass loss and then we follow its evolution until it cools down to become a white dwarf or if it is massive enough to explode as a supernova and become a neutron star or a black hole.

We introduce one important change to the formulae of Tout et al., (1996). In our calculations we assume that the mass of a compact object formed in a supernova explosion is half of the helium core mass of exploding star. This describes only long GRBs as only for these bursts afterglows were so far observed.

Table 1. Localization of GRB afterglows in relation to the host galaxies

| GRB   | redshift | Offset ∆θ | R⊥ [kpc] |
|-------|----------|-----------|-----------|
| 970228| 0.695    | 0.30"     | 3.8       |
| 970508| 0.835    | 0.01"     | 0.15      |
| 971214| 3.42     | 0.06"     | 2.1       |
| 980703| 0.966    | 0.21"     | 3.5       |
| 980613| 1.096    | 0.88"     | 15        |
| 990123| 1.61     | 0.7"(?)   | 16(?) < 5 |
| 990510| 1.60     | < 0.08"   | < 2       |
| 990712| 0.434    | 0.24"     | 1.4       |

2. Observations – Distribution of GRBs

The discovery of gamma-ray burst afterglows by the Beppo SAX satellite lead to identification of GRB host galaxies, and to localization of the GRB events in relation to these galaxies. A list of GRBs with afterglows and their projected distances from the centers of host galaxies is shown in Table 1.

From Table 1 we see that GRBs take place not far from the centers of their host galaxies and in the case of GRB970508 the offset is only 0.01" off the center of the host galaxy. For a review of recent observations see (Bloom et al., 2000). Moreover, the host galaxies are typically small, irregular, with intense star formation processes (Fruchter, 2000). The data presented in Table 1 describes only long GRBs as only for these bursts afterglows were so far observed.
results in the mass range of compact objects stretching up to $\approx 20 M_\odot$, which can be compared to the maximum mass of compact objects of $\approx 3 M_\odot$ in the original prescription of Tout et al., (1996). We assume that compact objects below $3 M_\odot$ are neutron stars and over this limit black holes (for discussion see Belczyński et al., 2000).

Depending on its initial mass any star will turn to become stellar remnant, i.e. a white dwarf, a neutron star or a black hole. During late stages of evolution (Hertzprung gap through asymptotic giant branch) stars are allowed to lose mass via stellar wind. We follow Tout et al., (1996) and include standard Reimers wind mass loss rate formula (Kudritzki and Reimers, 1978) and for very massive and large stars we include luminous blue variable strong winds (Humphreys and Davidson, 1994). It is important to note that Helium stars are not allowed to loose mass in our present code, and that leads to overestimations of the most massive compact object masses. Inclusions of Wolf-Rayet type winds for the naked Helium stars would decrease our maximum compact mass down to $\approx 12$–$15 M_\odot$. Such a change, however, would not change qualitatively conclusions of the present study.

**Binary evolution.** Binary evolution may change entirely the evolution of any of its components. For components of close binary systems, which will interact during the course of evolution, we calculate mass loss/gain during mass transfer/loss events. We include common envelope evolution, quasi-dynamic mass transfer and hyper accretion onto compact objects during common envelope phases as in our previous studies (Belczynski and Bulik, 1999). Components losing their Hydrogen-rich envelopes during giant stages become naked Helium stars, while those gaining mass (most often during they main sequence life) are rejuvenated. Rejuvenation and naked Helium star evolution is treated as described by Tout et al., (1996).

Any mass loss from the system (either through wind mass loss or during mass transfer/loss events) changes the binary orbit. Following evolution of binary and its components we also include tidal circularization (Portegies Zwart and Verbunt, 1996) and magnetic breaking (Tout et al., 1996). During supernova explosion we follow precisely the orbit evolution and we check if a system in which a super-nova explosion takes place survives the event. We calculate the mass of the newly formed compact object, the remaining mass is expelled from the system carrying off momentum, and a natal kick is added to the newly formed compact object (either a neutron star or a black hole) and then the new orbit is calculated. Systems which survive explosions receive additional center of mass velocity as an effect of the natal kick and mass loss from the outbursting component. Once the evolution of binary components is terminated and a system has survived mass transfer/loss events and supernova explosions we study populations of proposed binary GRB progenitors, that is NS-NS, BH-NS and BH-WD compact object binaries. These binaries evolve only due to gravitational wave energy loss which will cause the orbital separation decrease and finally lead to a merging event of two compact components and possibly to a gamma-ray burst. For supernova explosions and gravitational wave energy loss we use same treatment and formulae as in Belczyński et al. and Verbunt, (1996).

### 3.2. Helium star mergers

In this subsection we will describe more specifically an evolutionary path which may lead to formation of a Helium star merger, a new feature of our code.

The binary components may merge during mass transfer events, provided that the orbit is not too wide. As an example let us consider a binary, with an small enough orbital separation, so that the primary (the initially more massive component) during its expansion on the giant branch overfills its Roche lobe. Let us suppose that the mass ratio (secondary to primary) is small, so that the mass transfer will proceed on the dynamical timescale. The entire envelope of the giant primary will be lost, and it will become a naked Helium star. The secondary which is still on its main sequence will not have the time to accept any of the matter shed from the primary envelope, so it will survive the mass loss virtually unchanged. As a consequence of this mass loss event the binary orbit will shrink drastically. If there is enough orbital energy to expel the entire envelope of the primary then the system will survive (otherwise the helium core will merge with main sequence star, a case we are not interested in this study) and continue its evolution. If the Helium star is massive enough it will undergo a supernova Ib type explosion. Since the orbit is tight after the first mass transfer there is a good chance that the system will survive the supernova explosion. Thus the system now consists of a neutron star or a black hole and a main sequence star. As a consequence of mass loss from the system and randomly added kick to newly formed compact object the orbital separation increases and the orbit becomes eccentric. As the time goes on, the secondary, which is probably a more massive component now, will start its evolution up the giant branch. Once the secondary radius approaches the Roche lobe, tidal interaction circularizes the orbit and decreases the orbital separation. When the secondary overfills its Roche lobe the system goes through a similar phase as during the first mass transfer. If, as we have mentioned above, the secondary is the more massive component then the mass transfer proceeds again on dynamical time scale. In this mass transfer phase when the envelope of the secondary engulfs the system in a common envelope the compact object begins to spiral in toward the helium core of the giant. There is a chance now that the compact object will accrete some material from the envelope, as pointed by Bethe and Brown, (1998), and if it is a neutron star it may collapse to form a black hole. Since the orbit is already tight when the system enters the second mass transfer phase the orbital
energy available is not sufficient to expel the envelope of the secondary. The spiral in continues until the black hole enters Helium core of the giant. It disrupts tidally the Helium core, swallowing at the beginning a part of it, but the remaining helium material will form a hot, rapidly rotating disk around the black hole (Fryer and Woosley, 1998). This configuration, a Helium star merger, may lead to a gamma-ray burst in the black hole accretion disk GRB model (Fryer et al., 1999).

4. Results and discussion

4.1. Relative production rates

In Figure 1 we show the relative numbers of four different GRB progenitor types that merge within the Hubble time (15 Gyrs) as a function of the width of the distribution from which we draw kick velocity a compact object receives in a supernova explosion.

Two things are clearly seen; first the number of WD-BH binaries and Helium mergers (He-BH) is about the same and is more then an order of magnitude greater then the number of NS-NS and BH-NS binaries. It means that if GRBs originate from binary mergers then they mainly come from WD-BH binaries and/or Helium mergers.

Second, the relative number of a given progenitor type falls off approximately exponentially with the kick velocity. This is quite clear, the larger kick compact object receives the larger chance that the system will be disrupted in supernova explosion. And this is a reason for smaller production rates with increasing kick velocity. Assumptions about the kick velocity distribution plays an important role on results of compact object binaries population synthesis. We draw the kick velocities from a three dimensional Gaussian distribution of a given width which we treat as a parameter in our studies. There is a line of evidence coming form pulsars galactic velocity observations that the distribution of kicks is bimodal and consists of a weighted sum of two distributions: about 80% are intermediate kicks of about 200 km s\(^{-1}\) and the other 20% are high velocity kicks of about 700 km s\(^{-1}\) (Cordes and Chernoff, 1997). However if real distribution is in fact bimodal, then the high velocity component won’t have significance for properties of the population of compact object binaries, as these will tend to be disrupted by high velocity kicks. High velocity component will imprint its presence in the kick distribution through high peculiar velocities of single pulsars and will decrease number of compact object binaries. The lesson from this is that if one studies properties of compact object binaries, and not their numbers, then only the lower component of the kick velocity distribution is relevant.

Relative production rates may be calibrated to obtain the real rates in our Galaxy (eg. see eq. 14 in Belczyński and Bulik, 1999). For example, for the width of kick velocity of \(v_{kick} = 200\) km s\(^{-1}\) we obtain: 1 merging event per Milky Way like galaxy per \(10^6\) yrs for BH-NS systems, 3 events for NS-NS binaries and 60 for WD-BH and Helium mergers. These numbers are obtained under assumption that binary fraction is 50%, that there are 0.02 supernovae per year in the Galaxy, and that the star forming process has been constant throughout the history in the Milky Way.

4.2. History of binary merging events

The results of the population synthesis code can be combined with our knowledge of the star formation rate history to yield the rate of various types of GRB progenitors as a function of redshift. Star formation history at high redshift is not well known, however it is generally agreed that the star formation rate rises steeply up to \(z \approx 1\). At higher redshifts the analysis of the Hubble Deep Field (Madau et al., 1996) provided lower limits on the rate, yet these limits decrease with increasing redshift. On the other hand Rowan-Robinson (1999) argues that the star formation does not fall down and remains roughly at the same level above \(z = 1\). We consider two cases: a star formation function falling down steeply above \(z \approx 1\) (the thin line in Figure 2), and a case of strong star formation continuing up to \(z = 10\) (the thick line in Figure 2).

For a given type \(i\) of the GRB progenitor we can calculate the number of events up to the redshift \(z\):

\[
N_i(z) = \frac{4\pi}{3} \int_0^z r_z^2 \frac{dr_z}{dz} \frac{R_i(z)}{1 + z} dz ,
\]
where \( r_z \) is angular distance \( r_z = cH_0\int_0^z (\Omega_m(1+z^3)+\Omega_\Lambda)^{1/2} \), \( R_i(z) \) is the rate of a given type of event at the redshift of \( z \):

\[
R_i(z) = \int_{t_i(z)}^{t'} R_{sfr}(z) \ast f_i \ast (t')p(t-t')dt',
\]

where \( t \) is the conformal time, \( dt = dz(1+z)^{-1}(1+\Omega_m)(1+z)^2 - z(z+2\Omega_\Lambda)^{-1/2} \), \( p(t) \) is the probability distribution of a merger of a given type as a function of time since formation of the system. We calculate the distribution \( p(t) \) for each type of a merger using the population synthesis method.

In Figure 3 we show the cumulative rates of different merging events as a function of redshift. We have combined our relative numbers (shown on Figure 1) for different progenitors with the star formation rate function (Madau et al., 1996) and (Rowan-Robinson, 1999), and after taking into account the evolutionary time delay of a given merging event we integrated our relative production rates to find the merger rates as a function of redshift. In this example calculation we used two cosmological models with and without the cosmological constant: \( \Omega_m = 0.3 \), \( \Omega_\Lambda = 0.0 \), and \( \Omega_m = 0.3 \), \( \Omega_\Lambda = 0.7 \). In both cases the Hubble constant is \( H_0 = 65 \text{ km s}^{-1}\text{Mpc}^{-1} \). We used the kicks drawn from the distribution which is a weighted sum of two Gaussians: 80 percent with the width of 200 km s\(^{-1}\) and 20 percent with the width 800 km s\(^{-1}\).

The curves in Figure 3 can be compared with the BATSE gamma-ray burst detection rate corrected for BATSE sky exposure, which is \( \approx 800 \) events per year. Comparison of the cumulative distributions for different progenitor types with the BATSE rate shows that if any of the progenitor types included in our calculations were to reproduce the BATSE rate, then we should not see GRBs from redshifts greater than \( z = 0.3! \) Of course this is not the case (e.g. see Table 1), as GRBs with higher redshifts were observed, and the median observed GRB redshift is \( z \approx 1 \). However, we have not yet introduced the collimation factor into our results. The predicted cumulative rates presented in Figure 3 will decrease if we account for collimation and thus restricted visibility of gamma-ray bursts. To lower down our calculated rates to the BATSE rate, for average GRB redshift of about unity, we would need the collimation of about \( 4^\circ \) for BH-WD and Helium mergers and about \( 12^\circ \) for BH-NS and NS-NS mergers. And, as the population is dominated by BH-WD and Helium mergers then overall requirement for collimation is to be \( \approx 4^\circ \). This is only an upper limit as we would expect such a collimation factor if all GRBs were originating only from binary progenitors.

The thin lines in Figure 3 flatten out for high redshifts (\( z \geq 5 \)). In other words we do not expect binary mergers at high redshifts. This is a combined effect of two factors. First, the star formation rate function (SFR) we have used (Madau et al., 1996; Totani, 1997) falls down steeply for high redshifts. This means that at high redshifts we do not expect many stars, and thus their mergers. However the SFR we have used is highly uncertain for high redshifts and our result here may be quantitatively questionable. However, the thick lines in Figure 3, corresponding to the predictions of the SFR of Rowan-Robinson (1999) do climb up with redshift. In this case the number of GRBs up to the redshift of 10 is nearly double that up to the redshift of 2. Thus, future detection (or non detection) of GRBs from such high redshifts will serve as a probe of the SFR at large redshifts.

Non zero lifetimes of binary progenitors are the second thing that makes our curves to flatten out with redshift. Binary GRB progenitors need a specific time to evolve to a compact object binary or to a Helium merger (\( t_{\text{eval}} \)) and the compact object binaries need time to merge due to gravitational wave energy losses (\( t_{\text{merger}} \)). These times are non negligible and are specific for each group of proposed binary GRBs progenitors. For our sample of binaries we found characteristic lifetimes which are the sum of the evolutionary times and merging times \( t_{\text{life}} + t_{\text{merger}} \). They are, for NS-NS: \( \sim 10^7-10^{12} \) yrs, for BH-NS: \( \sim 10^7-10^{10} \) yrs, for He-BH: \( \sim 10^5-10^9 \) yrs, for BH-WD: \( \sim 10^7-10^{12} \) yrs. We see that these times are non negligible, and even if star formation process has begun at some point, for a given \( z \), we need to wait at least \( 10^6-10^7 \) yrs to start producing GRBs of binary origin.

An additional point to emphasize here is that the evolutionary times (\( t_{\text{eval}} \)), besides merging times, may play important role for some types of binary GRB progenitors. They are less important for NS-NS and BH-NS systems which are end products of high mass stars (very fast evo-
Fig. 3. Cumulative event rates of different types of GRB progenitors. The left panel corresponds to the cosmological model described by $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$, while the right panel to $\Omega_m = 0.3$ and $\Omega_\Lambda = 0$. The solid line describes the NS-NS rate, the dash dotted line describes the BH-NS rate, the short dashed line corresponds to the BH-WD rate and the long dashed line shows the He-BH rate. The thin lines corresponds to the assumed star formation rate of Madau et al., (1996), while the thick lines represents the results obtained using the rate of Rowan-Robinson (1999). Note that BH-WD, and He-BH events strongly dominate the population.

olution) and for which merging times ($t_{\text{merger}}$) are comparable with their total lifetimes $t_{\text{life}}$. However evolutionary times are important for BH-WD systems, as it may take a long evolutionary time to form a white dwarf, usually comparable with the merging time of final compact black hole white dwarf binary. It is even more clearly seen in the case of Helium mergers for which evolutionary times equal total lifetimes, as these systems merge during common envelope evolution of still unevolved (not a compact object) binary.

The above example calculation shows that the WD-BH and He-BH events are far more numerous than the NS-NS or BH-NS events. The absolute numbers presented above depend on a number of assumptions leading from the binary population synthesis to the observed rate. The second rather robust result is that if the star formation rate remains high even at high redshifts, the number of GRBs from such high $z$ must be significant - see the difference between thin and thick lines in Figure zdist.

4.3. Distribution of binary mergers around host galaxies

In Figure 4 we present the distribution of center of mass velocities gained by systems in the supernova explosions versus binary lifetimes (the time binary takes to evolve from ZAMS to final merger of two components). Data is presented on four panels for four types of the binary GRB progenitors. On each panel we plot three lines to show the distribution of mergers in respect to host galaxy of the size and mass comparable to Milky Way. Together these lines define the region in the parameter space with systems that can escape from a massive galaxy (Bloom et al., 1999).

The horizontal dashed line corresponds to the Hubble time (15 Gyr); we are not interested in the system above this line as they do not have a chance to merge within Hubble time.

The vertical solid line corresponds to $v = 200 \text{ km s}^{-1}$, which is approximately the escape velocity from an intermediate mass galaxy. Systems to the right of this line (with velocities higher then the escape velocity) will merge outside their host galaxy.

The inclined solid line corresponds to a constant value of $v \times t_{\text{merge}} = 30 \text{ kpc}$, which is about the radius of a high mass galaxy. Systems above this line have gained high enough velocity and have enough time to escape from their host galaxy to merge outside of it.

We note that a significant fraction of NS-NS and BH-WD merging events takes place outside of the host galaxies, and thus their distributions are inconsistent with the GRB observations. This conclusion is even stronger because it was drawn for the case of massive large host galaxy. As noted in Sec. 2, GRBs’ host galaxies are small, and in this case even more NS-NS and BH-WD mergers would take place outside their hosts then it is inferred
Fig. 5. Cumulative distribution BH-NS events around low mass host galaxies. The solid line corresponds to the case of no natal kicks $\sigma_v = 0 \text{km s}^{-1}$, the dotted line shows the case of $\sigma_v = 100 \text{km s}^{-1}$, and the dashed line represents the case of $\sigma_v = 200 \text{km s}^{-1}$. More than 50% of BH-NS merger events take place outside the 15 kpc radius from the host.

Form Figure 4. One may argue that binary mergers taking place outside galaxies in a thin intergalactic medium would not produce afterglows, and thus would not contribute to observed distribution of GRBs in relation to their host galaxies. However, according to Costa 2000), all GRBs observed by Beppo SAX are accompanied by afterglows.

Thus, we are left with two binary progenitors: BH-NS systems and Helium star mergers. As seen from Figure 5, we predict that all of them would produce gamma-ray bursts inside their host galaxies provided that hosts are large and massive. But as noted before this is probably not the case, and we have calculated their distribution in case when their hosts were small, low mass galaxies. We approximate trajectories of our systems in a potential of a small galaxy by propagation in empty space. We place them in one point and let them move with velocities gained during supernova explosions. We follow their trajectories until they finish their life in a merging event. We present the expected cumulative distributions of the projected distance from the center of the host galaxy for BH-NS merging events in Figure 5 and for Helium star mergers in Figure 6.

In Figure 5, we see that more than 50% of BH-NS systems merge outside the 15 kpc projected radius. This is in clear disagreement with the GRB distribution observations, which show that all so far observed GRBs take place within 15 kpc radius off their host galaxy center.

This excludes BH-NS systems as potential GRB progenitors given that GRB host galaxies are small (Fruchter 2000).

Thus the only possibility left for the binary origin of GRBs are Helium star mergers. From Figure 6 we see that almost 95% of these merging events take place within the 15 kpc radius from the host, just as expected if they were gamma-ray burst progenitors! This result is independent of the host galaxy size and mass, as we have shown that these mergers will merge within 15 kpc radius even in the case of no pull from their host – in the case of propagation in empty space.

Now, if we assume that all GRBs are coming from binary stars we must remark that all long GRBs result from Helium star mergers and we estimate collimation factor of these burst to be $\sim 4^\circ$. All the other merging events, coming form NS-NS, BH-NS and BH-WD systems may be responsible for short GRBs, for which afterglows and thus their distributions in respect to host galaxies have not yet been observed.

5. Conclusions

We have calculated the properties of the possible binary GRB progenitors: BH-NS, NS-NS, BH-WD, and He mergers. The GRB binary progenitor production rates fall off exponentially with width of natal kick velocity distribution. We calculate the expected redshift distributions and
Fig. 4. The distribution of different type of compact object binary mergers in the space spanned by the binary center of mass velocity and the binary lifetime (from ZAMS to final merger). The horizontal dashed line corresponds to the Hubble time (15 Gyr). In the region for $t_{\text{merge}} < 15$ Gyr we present two solid lines: the vertical corresponding to $v = 200 \text{ km s}^{-1}$ – approximately the escape velocity from a galaxy, and the line corresponding to a constant value of $v \times t_{\text{merge}} = 30 \text{ kpc}$. Together these lines define the region in the parameter space with systems that can escape from the host large galaxy.

numbers for each type of the progenitor, and find that BH-WD and He-BH type events dominate over the NS-NS or BH-NS mergers. Moreover, in calculating the redshift distribution of binary progenitors of GRBs one can not neglect the evolutionary times $t_{\text{evol}}$. In our example calculation we find that assuming that all GRBs result from binary mergers, then the population is dominated by BH-WD and He-BH star mergers, and the collimation must be of order $\sim 3 \times 10^{-3}$ ($\sim 4^\circ$). The existence or nonexistence of GRBs at high redshifts depends on the star formation history. In particular the recent measurement of $z = 4.50$ in case of GRB000131 (Andersen et al., 2000) suggests that the star formation rate has been high up to high $z$. 
We find that only the He-BH (Helium star merger) model of GRBs is consistent with Beppo SAX observations of long bursts and their localization in host galaxies. As noted in several previous papers a larger fraction of NS-NS binaries merge outside even massive host galaxies. The distribution of BH-NS mergers is tighter around the massive galaxies, however we find that they do escape from the potentials of small galaxies. Our population synthesis code results indicate that a significant fraction of the BH-WD binaries should obtain large enough velocities so that they can escape from the potential well even of a massive galaxy. This differs from the results of Fryer et al., (1999), who find that the BH-WD binaries should lie within the host galaxies. Moreover our code results in a much larger fraction of BH-WD binaries than the fraction Fryer et al., (1999) obtain. Finally we remark that NS-NS, BH-NS and BH-WD mergers can be responsible for short bursts which are not observed by Beppo SAX. This could be resolved by HETE-II, if short burst afterglows are discovered, and if their host galaxies are identified.

Acknowledgements. We would like to thank Chris Fryer for helpful discussions and comments during the 5th Huntsville GRB Symposium. This work has been supported by the KBN grants 2P03D02219 (KB), 2P03D00418 (TB), and 2P03D02117 (BR) and also made use of the NASA Astrophysics Data System.

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