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Distribution of compact object mergers around galaxies

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Abstract. Compact object mergers are one of the favoured models of gamma ray bursts (GRB). Using a binary population synthesis code we calculate properties of the population of compact object binaries; e.g. lifetimes and velocities. We then propagate them in galactic potentials and find their distribution in relation to the host.

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

1. Introduction

The discovery of GRB afterglows by BeppoSAX (Costa et al. 1997) introduced the standard astronomical methods to the GRB field. It led to subsequent identification of host galaxies (Groot et al. 1997), and to measurement of the distance through redshift. At the time of writing we know two redshifts of afterglows, and a few of host galaxies. In three cases it was possible to locate the afterglow within the host galaxy. GRB 970228 lies $\approx 0.4''$ from the center of its host galaxy (Fruchter et al. 1997), GRB 970508 and GRB 971214 lie within $0.01''$ and $0.05''$ (Kulkarni et al. 1998) of the centroid of the host galaxies respectively.

There are two major physical models for cosmological GRBs: the compact object merger model, and the collapsar model. Both models predict a relation bewtween GRB sites and their galaxies. However, this relation is less strict in the case of the compact object merger model. In this paper we present a calculation of compact object population properties and the consequent distribution of their mergers in relation to the host galaxies. We present our model in Sect. 2, and show the results and compare them with observations in Sect. 3.

2. The model

We use the population synthesis code (Belczyński & Bulik 1999), which concentrates on the population of massive star binaries; i.e., those that may eventually lead to formation of compact objects and compact object binaries. There are many parameters that describe the evolution of binaries; however, we concentrate here on one of them - the width of the kick velocity distribution $\sigma_{\rm v}$ (we assume that the kick velocity distribution is a three dimensional maxwellian). In this paper we do not distinguish between black neutron star and double neutron star systems. A more detailed discussion is presented in Bulik et al. (1999).

Since little is known about the host galaxies of gamma-ray bursts, in particular their types and masses, we will present two extreme cases: (i) propagation in the potential of large spiral galaxy like the Milky Way, and (ii) propagation in empty space corresponding to e.g. globular cluster origin. The potential of a spiral galaxy can be described as the sum of three components: bulge, disk, and halo. A convenient way to describe the Galactic potential has been proposed by Miyamoto & Nagai (1975), while a series of more detailed models were constructed by Kuijken & Gilmore (1989). We assume that the distribution of binaries in our model galaxy follows the mass distribution in the young disk (Paczyński 1990). Our calculation follows the approach used by Bulik et al. (1998)

Each binary moves initially with the local rotational velocity in the galactic disk. After a supernova explosion we add an appropriate velocity, provided that the system survives the explosion. We calculate the orbit of each system until it merges, provided that the merger time is smaller than the Hubble time (20 Gyrs here).

3. Results

The distribution of kick velocities a neutron star receives at birth is not very well known. Dewey & Cordes (1987) describe it as a weighted sum of 80% with the width of $175\,{\rm km\ s}^{-1}$, and 20% with the width $700\,{\rm km\ s}^{-1}$. We use the population synthesis code with four values of the kick velocity distribution width: with no kick velocites $\sigma_{\rm v} = 0\,{\rm km\ s}^{-1}$, and with $\sigma_{\rm v} = 200,\ 400,\ 800\,{\rm km\ s}^{-1}$. The results are presented in Fig. 1. In the case of propagation in the empty space the mean distance travelled from the place of birth decreases with increasing the kick velocity distribution width $\sigma_{\rm v}$. This is due to the fact that with high kick velocities only tightly bound systems survive and their expected lifetimes are short. On the other hand the typical velocities of the binaries increase; however the dominant effect is that of the decrease of the lifetimes. While the mean of the distribution becomes smaller, the

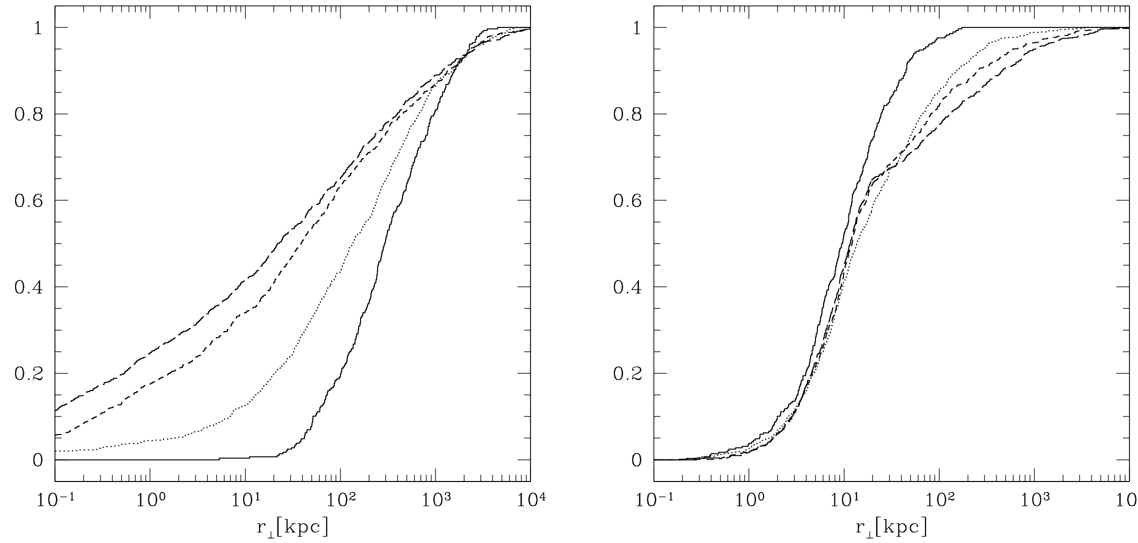

Fig. 1. Cumulative distribution of projected distances on the sky: the left panel shows the distribution of distances travelled by a compact object binary in the case of propagation in an empty space, while the right panel shows the distribution of the distances between the center of the massive host galaxy and the merger site. The solid line corresponds to the case $\sigma_v = 0\,\mathrm{km\,s^{-1}}$, the dotted line $\sigma_v = 200\,\mathrm{km\,s^{-1}}$, the short-dashed line $\sigma_v = 400\,\mathrm{km\,s^{-1}}$, and the long dashed line $\sigma_v = 800\,\mathrm{km\,s^{-1}}$

width of the distribution increases, so that the distribution always reaches a few Mpc. Depending on the kick velocity, between 80% and 40% of the mergers take place further than 100 kpc (projected) distance from the place of birth, and between 25% and 15% travel beyond a Mpc.

In the case of propagation in the potential of a large galaxy, the mean distance from the center of the galaxy does not change with the kick velocity, and is about 10 kpc; i.e. the size of the galaxy in our simulations. This is because the slow systems are bound in the galactic potential and their distribution traces that of the matter in the galaxy, regardless of their lifetime. The width of the distribution increases with increasing σ_v, as was the case above. The tail here is due to the systems that are unbound, and is nearly identical to the case of propagation in empty space. Between 5% and 30% of the systems travel further than 100 kpc, and up to 7% of the mergers reach the distance of 1 Mpc.

While the statistics of GRB afterglows that are detected and localized within the host galaxies is small, we note that in eight cases host galaxies have been identified, with two cases under discussion: 980425 may be a very unusal burst and 971227 was not searched for exhaustively (Hogg & Fruchter 1998). This indicates that bursts afterglows are correlated with faint ($R \sim 25$) galaxies. From our simulations we find that a significant fraction of the neutron star mergers should be ejected far from the hosts, and then the probability of chance association with a galaxy would be $10 - 15\%$. Thus continuing assciations of GRB afterglows with galaxies will disfavour the compact object merger model. On the other hand GRBs that take place outside host galaxies may not produce afterglows, thus preventing good localizations. In the compact object merger model the fraction of such bursts would be about $10 - 20\%$. GRBs detected by BeppoSAX are only those with durations longer than 6 s, so perhaps the compact object mergers are connected with short bursts, while the long bursts are produced by a different physical mechanism (e.g., collapsars), that links them to galaxies. In conclusion, studies of the afterglows and their relations to the host galaxies can yield another important constraint on the models of GRBs.

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