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Selection effects in detecting gravitational waves from binary inspiral

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Abstract. We analyze the distribution of masses of compact object binaries to be seen in gravitational waves and the influence of observational selection effects on the observed population. We simulate the population of such binaries using the Star Track population synthesis code. We find that black hole - black hole binaries observed in gravitational waves will be dominated by the nearly equal mass objects, the black hole - neutron star binaries will mostly be the ones with the mass ratio $q < 0.5$. The neutron star - neutron star binaries observed in gravitational waves are very likely to include large number of non equal mass systems with small mass ratio, as low as even $q \approx 0.6 - 0.7$.

Key words. binaries: compact, stars: neutron, gravitational waves

1. Introduction

We use the StarTrack binary population synthesis code to analyze the distribution of mass ratios of compact object binaries. We consider three separate groups: the double neutron star binaries; the black hole neutron star binaries, and the double black hole binaries. We first consider the intrinsic distribution of mass ratios for these three groups, and then we calculate the detectability weighted distributions.

The StarTrack population synthesis code is a well tested program already used in a number of applications Belczynski et al. (2002). We start with binaries at the zero age main sequence, evolve a large number of them, and consider the properties of the resulting population of compact object binaries. For each binary we note the masses of individual objects. Assuming a value for the maximum mass of a neutron star the binaries can be classified in three groups: double neutron star binaries (NSNS), black hole neutron star binaries (BHNS), and double black hole binaries (BHBH).

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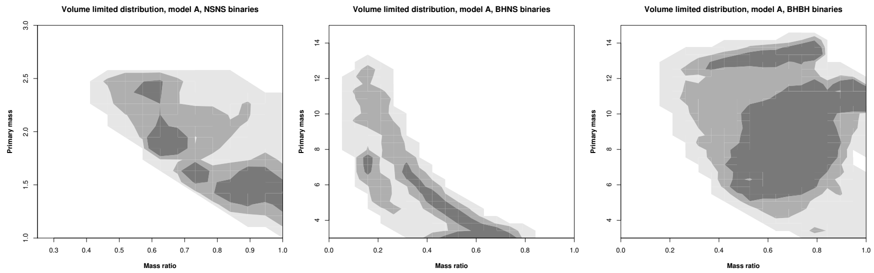

Fig. 1. The volume limited distributions (the one obtained in a simulation without taking into account observability) of masses and mass ratios of NSNS, NSBH and BHBH binaries from left to right. The darkest shading represents the region containing 68% of the systems, the medium gray shading represents the region containing 95% of the systems, and all the systems are enclosed within the light gray shading. respectively.

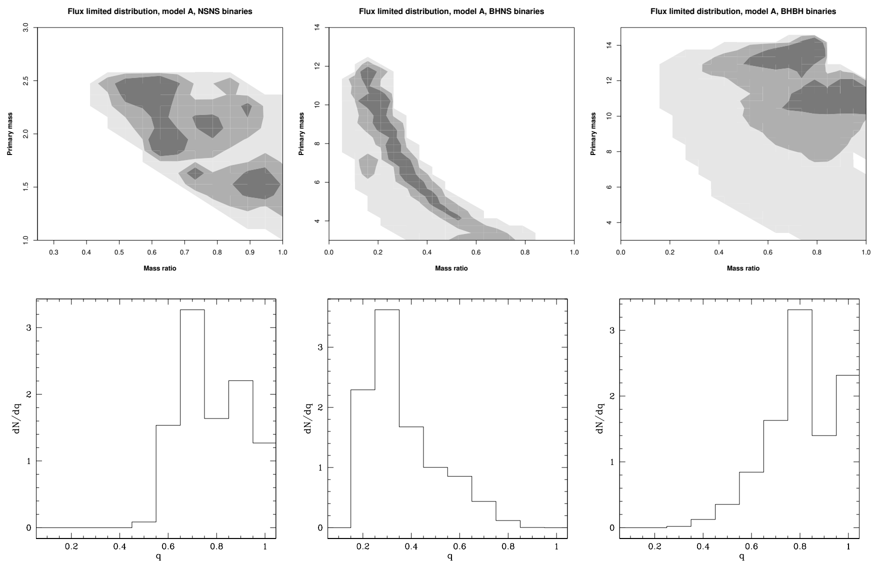

Fig. 2. The top panels - the distribution of masses and mass ratios in the observed in GW samples for NSNS, NSBH and BHBH binaries from left to right. The bottom panels show the corresponding expected distributions of the mass ratios of binaries observed in the gravitational waves.

2. Results and conclusions

In this paper we present the results obtained with what we call the standard model of stellar population synthesis. This model (denoted model A in Belczynski et al. (2002)) is our "best bet" and contains all values of the stellar evolution parameters that are generally agreed to be in best agreement with observations. We also verify the results by considering more than 20 different models Bulik et al. (2004). We assume that the maximum mass of a neutron star is 2.5 $M_{\odot}$.

We present the densities of the compact object binaries in the space spanned by the mass of the primary (more massive object in the binary) and mass ratio for two cases: the intrinsic (volume limited) distribution (Fig 1.), and the observed (flux limited) one (Fig. 2). The intrinsic distribution is the one obtained in a simulation without taking into account observability. In other words the intrinsic distribution can be understood as the volume limited one, and it corresponds e.g. to the properties of the population in a given galaxy.

In order to calculate an flux limited distribution we assume that a gravitational wave detector signal to noise is given by Bonazzola & Marck (1994):

$$\frac{S}{N} \propto \mathcal{M}^{5/6}$$

where $\mathcal{M} = (m_1 m_2)^{0.6}(m_1 + m_2)^{-0.2}$ is the chirp mass, and m_1 and m_2 are the masses of the components of the binary. We also assume that the Universe is Euclidean with a constant star formation rate history. Each binary is counted with a weight proportional to the volume it is observable in

$$V \propto M^{5/2}$$

Higher chirp mass binaries are more likely to be observed since they are observable in a much larger volume. This observability weighted distribution analogous to the flux limited distribution in astronomy, where brighter objects are seen in larger numbers because they are visible in larger volume of space. This corresponds to a distribution of actually observed objects with a given telescope or detector. In the plots the outer contours encircle region containing 95% and the inner contours encircle 68% of the binaries. The resulting distributions for BHBH, BHNS and NSNS are shown in Figs. 1 and 2.

The properties of the distributions of masses and mass ratios of binaries vary with the type of the binary. In the case BHBH binaries the intrinsic distribution of masses encompasses evenly the entire region allowed for them. However, the observability weighted distribution is dominated by the equal mass binaries with both BH at the high mass end. We therefore find that the most interesting cases to consider are the BHBH binaries consisting of two BHs with masses near the maximum mass allowed by the model: $q > 0.7$. Such systems will dominate the observed sample of all stellar mass compact object mergers since the number of the observed BHBH binary mergers is typically a factor of ten larger than all other mergers combined Lipunov et al. (1997); Bulik & Belczyński (2003).

In the case of the BHNS binaries the intrinsic distribution of masses stretches along an elongated region peaking at low mass of the primary and high mass ratio. In the observability weighted distribution the binaries with a intermediate to high mass BH with a maximum mass NS are preferred: $q \approx 0.3 - 0.5$.

Finally, in the case of double neutron star binaries the intrinsic distribution of masses has a peak for binaries with equal mass close to the minimum mass of neutron stars, and several picks in a tail extending to lower mass ratios. This tail becomes dominant in the observability weighted distribution. Therefore most interesting NSNS merger calculations are: two equal mass stars of $\approx 1.4 M_\odot$, and binaries containing a massive neutron star with respectively smaller companion: $q \approx 0.6$ — 0.7. This second case has so far been overlooked.

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