An Insight Into The Galactic Hosts and Environments of Merging Compact Binary Objects

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Abstract

Using the cosmological simulation, EAGLE, and a population of synthetic binaries from the BPASS stellar evolution code, we evolve and observe the host properties of binary neutron stars (NSNS), a black-hole and a neutron star (BHNS), and a binary black hole (BHBH). We present the preliminary results of our study for binary neutron stars. We find binaries merging at z < 0.4 tend to have long delay times and have a larger likelihood of having heavy, star forming hosts. These binaries typically merge $< 10\,\mathrm{kpc}$, on-sky projected distance, from the centre of their galaxy.

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1. Objective

Some compact binaries, such as double neutron stars, may produce an observable short-duration gamma-ray burst and/or kilonova, upon merging. The observation of GRB 170817A (Abbott et al., 2017b) and AT2017gfo (Tanvir et al., 2017), respectively, with the gravitational wave detection of GW170817 (Abbott et al., 2017a) provided compelling evidence supporting this association.

Non-dynamically formed binaries will receive a natal-kick as a result of the supernova progenitors of the neutron star components. The aim of the study conducted in Mandhai et al., (in-prep) is to understand the properties of the galactic hosts and environments of these binaries, as well as the relative host-binary projected on-sky separation (or impact parameter).

2. Cosmological and Population Simulations

We have seeded a population of simulated BPASS (Binary Population and Spectral Synthesis) binaries (Bray & Eldridge, 2016) into the EAGLE (Evolution and Assembly of GaLaxies and their Environments) cosmological simulation (Schaye et al., 2015). We then traced the evolution of both galaxies and the binaries up to the point of coalescence. From Figure 1, we observe a concentration of merging neutron star binaries arising from heavy, star forming rich galaxies. We find that these binaries tend to have long delay-times before merging. Galaxies with a low stellar mass and poor star formation have a low probability of hosting these binaries. Low mass galaxies tend to be intrinsically faint, and have relatively weaker gravitational potentials which enable formed binaries to migrate away to considerable distances from the centre of the galaxy, with less resistance (e.g. see black triangles in Figure 1). Also, see similar works by Mapelli et al. (2019) and Adhikari et al. (2020).

3. Offset of Merging Binaries from their Hosts

We evolve the orbits of each binary across the cosmic time until the systems merge. Figure 2 shows an example orbital that a binary may have if a $100\,\mathrm{km\,s^{-1}}$ kick is applied for each supernova. The impact parameter from the centre of the galaxy to the merged remnant is then calculated assuming a random galaxy orientation. The resulting distribution is shown in Figure 3. We find the most probable impact parameter of our merging binary population is $\sim 10\,\mathrm{kpc}$ from the centre of the host. Cumulatively, we find that considerable fraction of binaries merge at greater distances with some reaching $> 10^3\,\mathrm{kpc}$. Short-duration gamma-ray bursts resulting from mergers at these distances would likely be classified as "host-less" if observed, (Mandhai et al., 2018). However, bursts from host galaxies that are intrinsically faint/distant (at high redshift) may also contribute to the numerous classified host-less burst, (e.g. Tunnicliffe et al., 2014; Fong et al., 2013).

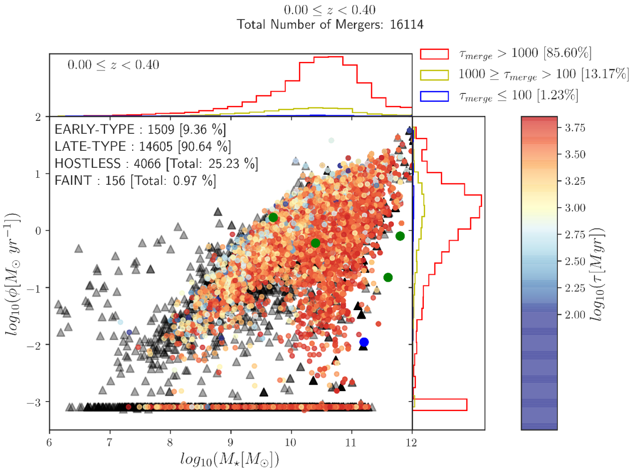

Fig. 1. A sample distribution of the host star formation rate vs the stellar mass for binary neutron stars (NSNS) at $z < 0.40$. The coloured gradient represents the length of the delay time (Myr). The histogram shows the relative population of NSNS binaries with a total lifespan, τ, in the ranges: $\tau < 100$ (Blue), $100 \leq \tau < 1000$ (Yellow), $\tau \geq 1000$ (Red). The green points indicate the known properties of short-duration gamma-ray burst hosts, (Berger, 2014). The blue point indicates the relative location of NGC 4993, the host of GW170817. Black triangles are used for galaxies that are either faint (H > 26) or have binaries that have been kicked to a significant distance from the centre, and hence may appear "host-less".

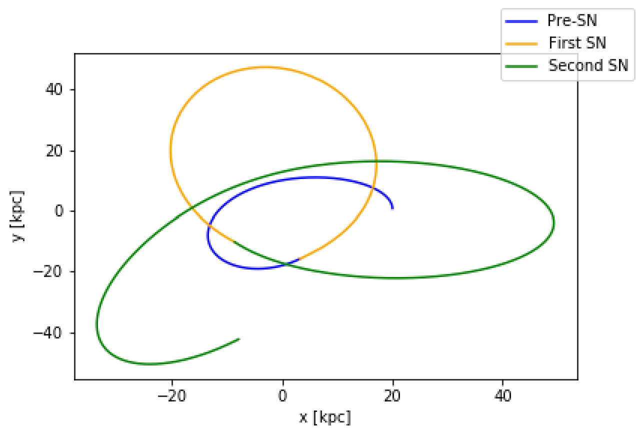

Fig. 2. The orbital path of a binary in the x-y plane of the host galaxy. The noted colours refer to the stages before and after the first and second supernovae. For this example, an isotropic kick with a velocity of $100\,\mathrm{km\,s^{-1}}$ is applied for each supernova. Note: the duration of each phase prior to the second supernova has been exaggerated for demonstration purposes.

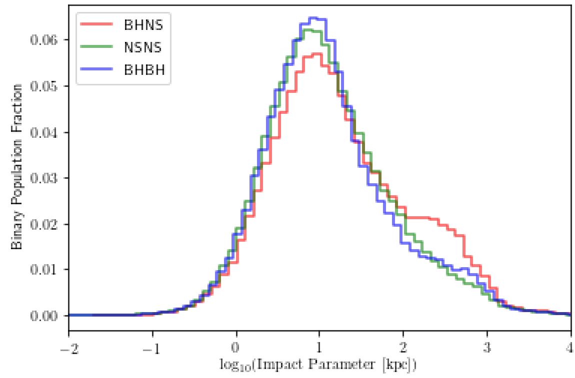

Fig. 3. The projected off-sky distance of binaries from their host galaxy, for binary neutron stars (NSNS - Green), black-hole and a neutron star (BHNS - Red), and binary black-holes (BHBH-Blue). The size of each bin corresponds to $10^{0.1}$ kpc.

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