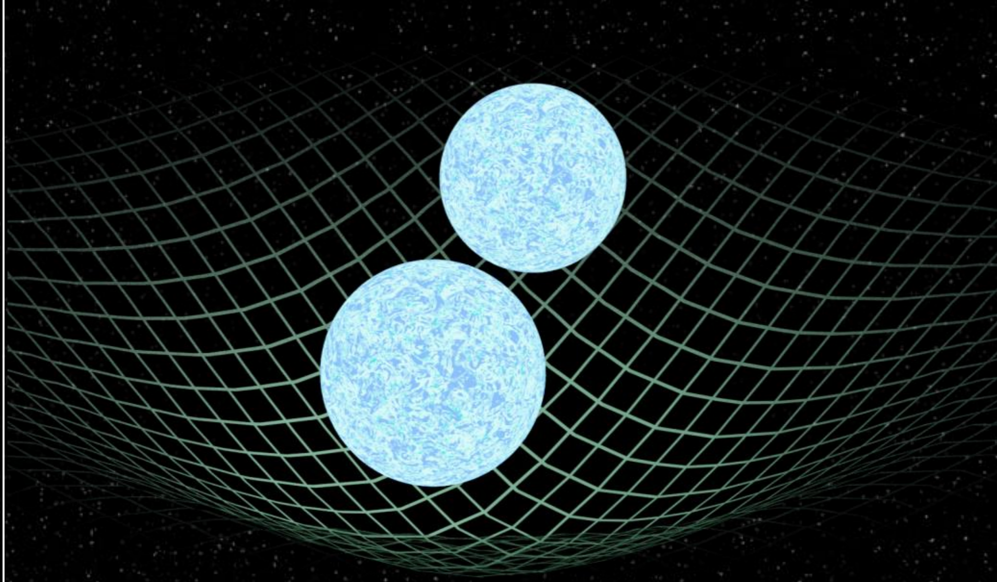
Orbital Evolution of Isolated Compact Binaries within their Host Galaxies

S. Mandhai[1], N. Tanvir[1], G. Lamb[1], J. Bray[2,3], C. Nixon[1]

[1] Department of Physics and Astronomy, University of Leicester, University Road, LE1 7RH
[2] Department of Physical Sciences, Robert Hooke Building, Kents Hill, Milton Keynes MK7 6AA
[3] Department of Physics, University of Auckland, Private Bag 92019, Auckland, New Zealand

Key Points:

- Compact binaries can consist of a combination of Neutron Stars and Black Holes. Upon merging, they can:
  - Distort space-time, resulting in Gravitational Waves.
  - Produce beams of highly energetic radiation known as, Short-duration Gamma-Ray Bursts.
- Identifying the parent galaxy of observed events is difficult.
- During their formation, these binaries can be ejected from their host galaxy due to the supernovae of the progenitor massive stars.
- Simulations can help understand the host galaxy properties and the observed offsets of short-duration gamma-ray bursts.
- Between >20% of binaries can escape their host galaxy.

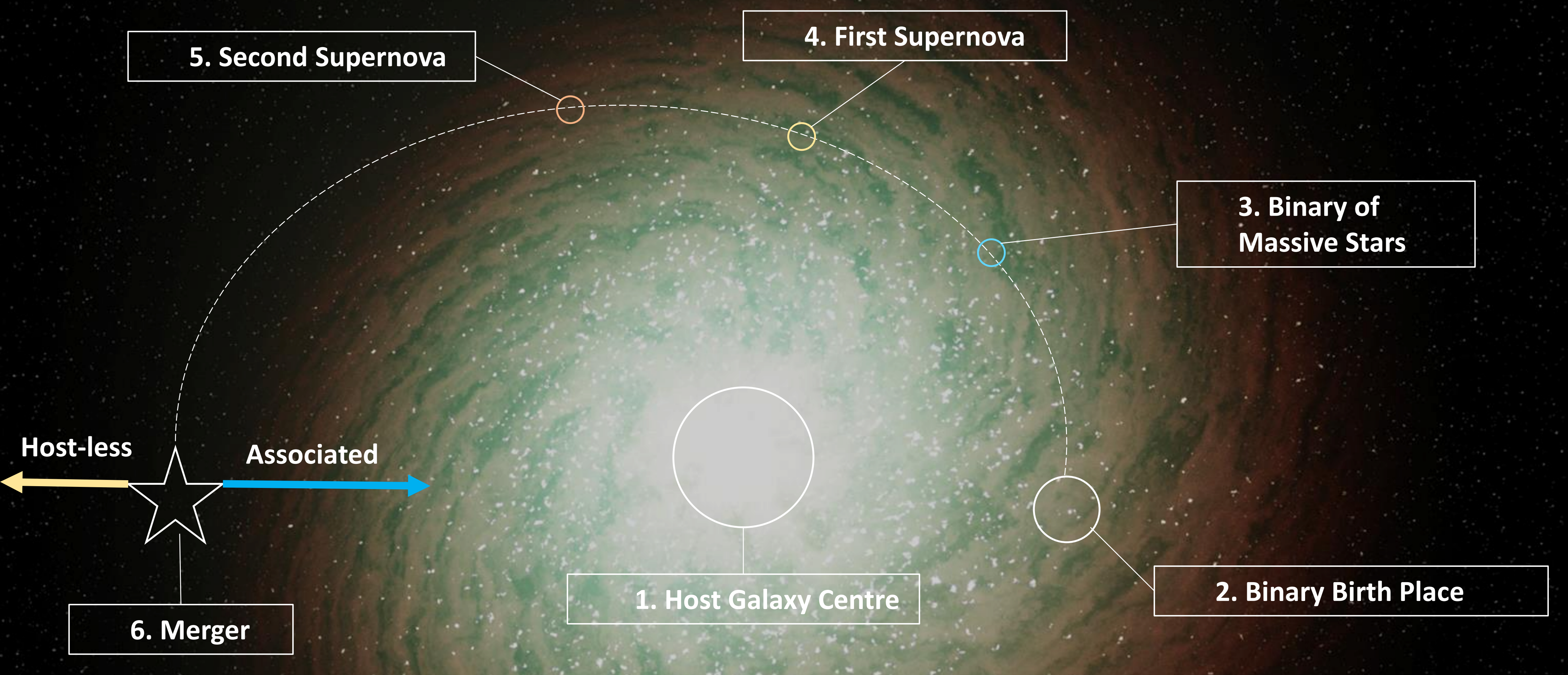


Why Are Compact Binaries Special?

- Dense remnants of two stars born with mass $> 8\ M_{sun}$, after they die.
- A binary system that can consist of a combination of Neutron Stars (NS), and Black-Holes (BH).
- Capable of distorting space-time and creating Gravitational Waves (GWs).
  - GWs provide unprecedented insight into the properties of NS and BH objects.
- Systems with at least one NS may produce electromagnetic counterparts such as Short-duration Gamma-Ray Bursts (SGRBs) and Kilonovae (KN) (results in the synthesis of heavy elements such as gold, and platinum) upon merging.
- The merger of two neutron stars with coincident GW (GW170817) and SGRB (GRB 170817A) detections marked the start of the multi-messenger era in astrophysics!

The Migration of Compact Binaries :

Figure 2.



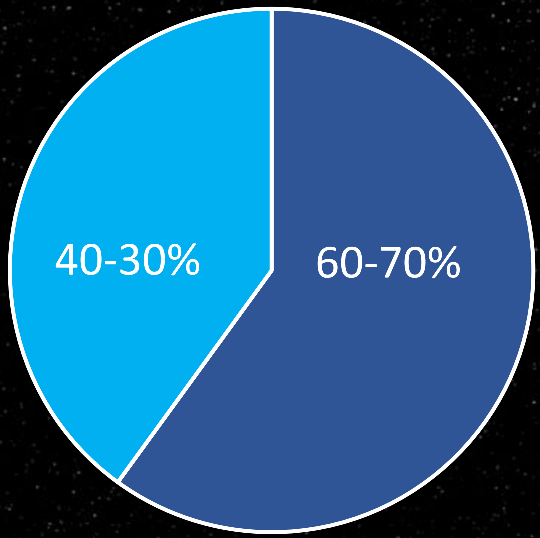
Key Stages:

1. The host (or parent) galaxy plays a crucial role in the orbital dynamics of the binary. Binaries are more likely to form in galaxies rich in star formation. Binaries are less likely to escape more massive galaxies due to the stronger gravitational potential.
2. In our analysis, a binary is randomly placed within the galaxy based on the mass distribution of the stellar disk.
3. The main stars in the binary have evolved into giant stars, heavier than our Sun.
4. The dominant and more massive star in the system undergoes a supernova. The primary star is now a NS or BH.
5. The secondary star undergoes a supernova. The binary system now consists of two compact remnants.
6. The binary merges. If it merges far away from the galaxy, it may be considered host-less if followed up observationally.

Host Demographics of these Binaries :

In our study, we seeded a simulated population of binary systems within hydrodynamical galaxies from the EAGLE cosmological simulation to explore the migration of compact binaries. We then traced the orbits until the synthetic binaries coalesced. We find the demographic of the host galaxies at the point of merger, as shown in Figure 1.

Host Galaxy Morphology*



NSNS

BHNS

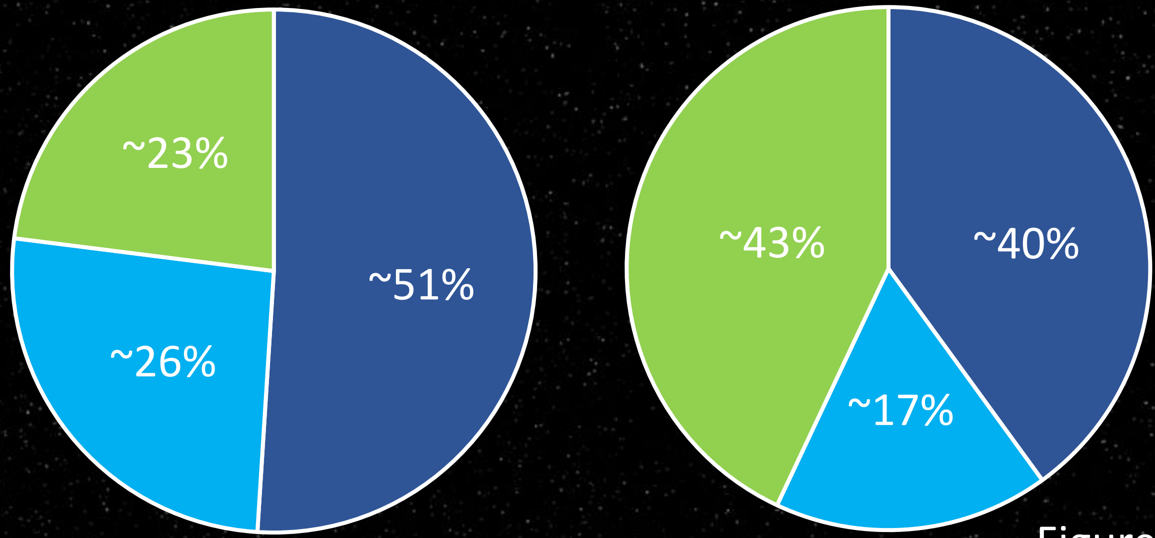


Figure 1.

The majority of binaries merge with host galaxies that are Late-Type such as spiral galaxies. The majority of the mergers occur in galaxies similar to the Milky Way.

With the inclusion of the orbital evolution, we gain an insight into the fraction of binaries that would be considered "host-less" observationally. The fraction of black-hole – neutron star (BHNS) systems that are found to be host-less is substantially greater than double neutron-star systems (NSNS).

***Averaged across redshift for BHNS/NSNS.**

**** Defined using galaxy shape diagnostic from Thob et al., 2019.**

***** Have observationally faint hosts (H>26) and/or merge at a large distance.**

Late-Type** Early-Type** Host-less***

Reasonable agreement with a similar study by Artale et al., 2019

Summary :

To understand the spatial and host characteristics of compact binaries in the era of multi-messenger, we:

1. **Seeded synthetic binaries into hydrodynamically simulated galaxies.**
2. **Evolved the orbits of the binaries, whilst also accounting for the velocity changes from the supernovae of the progenitor stars.**
3. **Constrained the demographics for the hosts of merging NSNS and BHNS systems.**
4. **Asked the question, "How many of these binaries could produce an electromagnetic counterpart such as an SGRB?" that would be detectable by *Swift*/BAT.**
5. **Deduced the population of expected SGRBs.**
6. **Plotted the on-sky projected distance (also known as the impact parameter) against redshift. See Figure 3.**
7. **Find consistency between our predicted results and the observed population of SGRBs with associated host galaxies.**

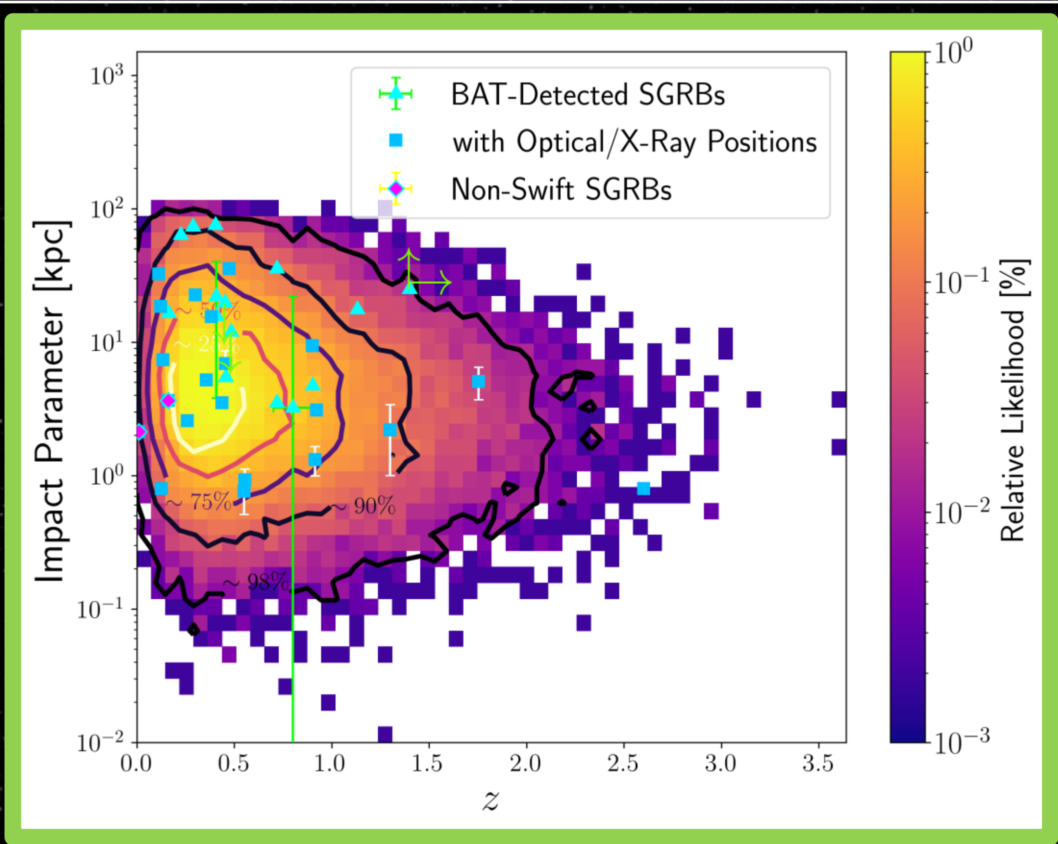


Figure 3. The distribution of impact parameter against redshift for a simulated population of hosted SGRB events arising from the mergers of compact binaries. The points correspond to observed SGRBs with associated host galaxies.

References:

A. Mandhai et al., 2021 (expected)
B. All the artwork used in this poster has been created by Soheb Mandhai, University of Leicester.

Acronyms:

NSNS – Neutron Star Binary
BHNS – Black Hole and Neutron Star Binary
BHBH – Black Hole Binary
GW – Gravitational Wave
SGRB – Short Duration Gamma-Ray Burst
KN – Kilonova(e)
EM – Electromagnetic
SN – Supernova(e)