Explosions in Interacting Binaries: from Supernovae to Gamma-Ray Bursts

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Binary Evolution in the Field

The most massive binaries contain two stars massive enough to undergo supernova explosions. Most of these binaries are tight enough for their component stars to interact during their evolution, transferring mass from one star to another. A typical evolutionary scenario where three episodes of mass transfer lead to a double neutron star binary is shown on the right.

Interacting binaries yield important clues about the nature of supernovae. We have studied the high-mass X-ray binary Cygnus X-1 to determine the origin of the very high spin of its black hole (Axelsson et al. 2011). We show that the black hole cannot have been spun up by tidal interactions in the progenitor, or by subsequent accretion from its companion. We suggest that an asymmetric supernova explosion contributed the spin.

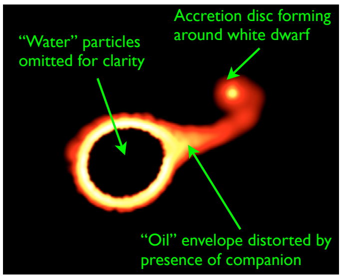
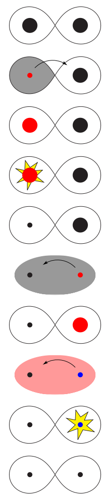


Figure: Oil-on-water in action. Mass is being transferred from a low-mass main-sequence star to a white dwarf in an eccentric orbit. A slice through the centre of the binary is shown shortly after pericentre. Mass is seen to flow from the star on to the white dwarf. The distortion of the main-sequence star's atmosphere by the gravity of the white dwarf and formation of an accretion disc can be clearly seen. The body of the main-sequence star is omitted for clarity.

Lower-mass binaries form a white dwarf and a neutron star. Via a chain of mass-transfer events the white dwarf can form first; the subsequent supernova leads to an eccentric binary (Church et al. 2006). Such WD-NS binaries are still eccentric when they come into contact after gravitational wave driven inspiral. We have developed the novel "oil-on-water" SPH method to study mass transfer in eccentric binaries (Church et al. 2009). Lund PhD student Alexey Bobrick is working with us to apply oil-on-water to WD-NS binaries.



In the field → Young massive binaries → Interacting binaries → Long gamma-ray bursts / Ultra-compact binaries

In stellar clusters → Lower-mass binaries → Interactions with neutron stars → Ultra-compact binaries → Short gamma-ray bursts

Short Gamma-Ray Bursts: a Tale of two Origins

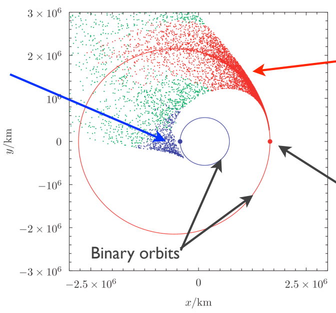
Ultimately, many massive binaries evolve into ultra-compact binaries containing a neutron star orbiting another neutron star or a black hole. Such binaries emit gravitational waves, spiral together and merge; during the merger process an accretion disc forms that can power a short gamma-ray burst. The preceding supernova explosions "kick" the compact binary which can lead to the burst occurring well outside the binary's host galaxy.

Long Gamma-Ray Bursts

Long gamma-ray bursts occur during the supernova explosions of rapidly-rotating massive stars. Because the star is rotating some material has too much angular momentum to fall radially back in to the newly-formed black hole. Instead a disc forms; accretion of the disc powers a jet and hence a gamma-ray burst.

We are studying how a companion in a close binary can impart the angular momentum necessary to drive late-time activity in long gamma-ray bursts. In all supernova explosions some of the material is ejected to large distances but then falls back radially on to the newly-formed black hole. In a close binary this material will be deflected by a companion and instead fall back into a disc.

Figure: Disc formation around a newly-formed black hole and its companion in a massive binary. The dots show positions of particles as they fall back into the plane; without the companion they would all fall back directly on to the black hole.



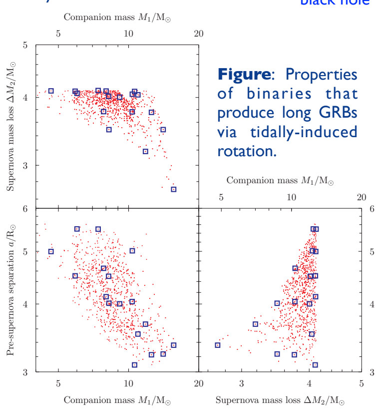


Figure: Properties of binaries that produce long GRBs via tidally-induced rotation.

To investigate this process further we have used our rapid binary evolution code to identify a sample of binaries in which a GRB is expected from binary spin-up of the black hole progenitor, according the the criteria of Levan, Davies and King (2006). We are now studying the effects of this process on the light curves of the gamma-ray bursts that will occur in these binaries.

Field Binaries: Origin 1

We have modelled short gamma-ray burst offsets by synthesising a large population of binaries and following their galactic orbits until the burst occurred. We used the short bursts' observed hosts to create a predicted probability distribution for each burst's offset. We find that most burst offsets are consistent with their predicted distributions. However, some bursts (e.g. GRB 060502B) are too far away from their host galaxies. We suggest that such large-offset bursts have an origin in extra-galactic globular clusters.

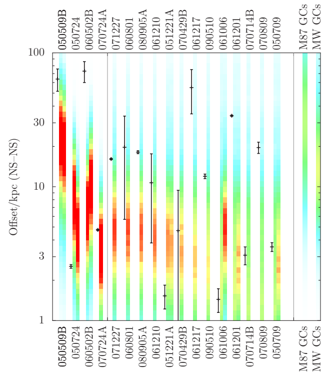


Figure: predicted offset (host-burst distance) distributions. The highest probability regions are shown in red, then in order yellow, green, cyan and white. The burst ID is shown at the bottom. Results are ordered by host galaxy mass, with elliptical hosts to the left. Black error bars show offsets as observed by *Swift*.

Globular Clusters: Origin 2

Short gamma-ray bursts are expected to occur in globular clusters from dynamically-formed double neutron star binaries. Neutron stars sink to the cores of the clusters where they exchange into binaries. We show that short burst formation rates in globular clusters are comparable those in field binaries and that the offset distributions fit the larger-offset bursts (Church et al. 2011).

References

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