

Extreme Astrophysics

Final report

January 21, 2013

Long-duration gamma-ray bursts from compact binaries

Introduction and rationale

Long-duration gamma-ray bursts are the most energetic explosions in the Universe. They occur during the formation of a black hole from the collapsing core of a rapidly-rotating massive star. The outer parts of the core are ejected in the supernova explosion that forms the black hole and fall back to form a disc of material that orbits the newly-formed black hole. Accretion of this disc onto the black hole produces jets; if these jets point towards us we see the gamma-rays that form the gamma-ray burst.

Although the existence of gamma-ray bursts has been known since early space experiments in the 1960s, the real scientific breakthroughs in our understanding have come in the last 15 years. Some key theoretical problems remain, however, in understanding these events. The central problem is how to keep the stellar core spinning rapidly enough to the end of the massive star's life. We have shown that a natural way to keep the core spinning is for it to be in a *binary system* of two massive stars orbiting one another, and that this forms a natural explanation for some of the observed features of long-duration gamma-ray bursts.

Forming long gamma-ray bursts in a binary

In a binary star system, one star can raise tides within the other, similar to the tides that the Moon raises on the Earth's surface. These lock the star's rotation to the binary orbit, again, in the same way that the Moon's rotation is locked to its orbit round the Earth. This can keep the star rotating rapidly and thus permit the formation of a burst. By studying how rapidly the stellar core must rotate at the point of black hole formation we show that the companion must be a black hole that has formed earlier. By following the evolution of binary star systems we measured the number of suitable close binaries and show that it is likely comparable to the observed rate of long gamma-ray bursts.

Effects of a companion

To study the effect of the companion black hole we made numerical models of the trajectories of the gas as it falls back into the accretion disc (Figure 1). We conclude that there are two unavoidable consequences of a long gamma-ray burst having a binary companion. Firstly, the presence of the companion prevents material that falls back at later times from joining the accretion disc. This causes a break in the observed light from the gamma-ray burst. Secondly, after the break, the accretion peaks again. This would appear as a flare at late times. The properties of late-time light-curve breaks and flares that we predict are consistent with those observed in X-ray light curves of gamma-ray bursts. This shows that spin-up in a binary is the likely origin for a significant fraction of long-duration gamma-ray bursts.

Significance

Our work shows that spin-up by tides in a binary is the most likely origin for a substantial fraction of long-duration gamma-ray bursts. This is progress towards solving the ongoing problem of the powering of the central engine. A better understanding of the powering of long gamma-ray bursts is necessary to allow their potential as probes of the very distant early universe to be fully realised.

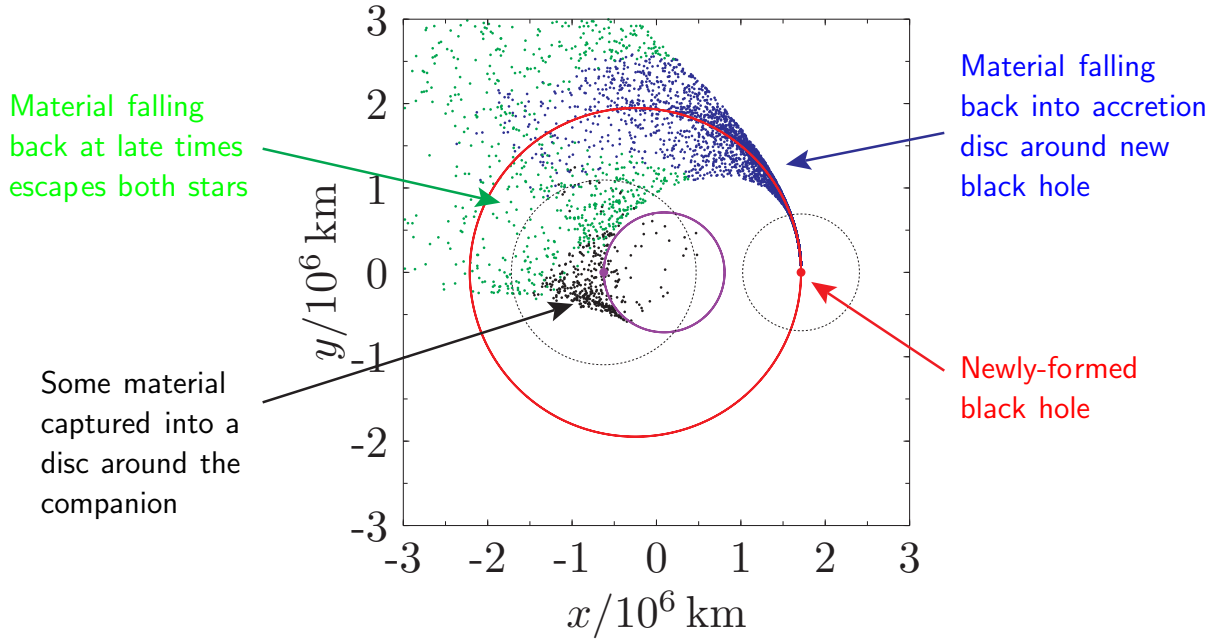


Figure 1: The positions in the orbital plane into which material falls back from a newly-forming black hole in a binary.

Other results

Short-duration gamma-ray bursts

We studied the offsets of shorter-duration gamma-ray bursts from their host galaxies. Short gamma-ray bursts occur during the merger of very close binaries containing two neutron stars. During the formation of these binaries they receive a kick, which can eject them from the disc of their host galaxies. We have modelled the formation of these binaries by following their evolution from newly-born stellar binaries. We show that, for the majority of bursts, their locations are consistent with the kicks that they would receive during formation. For the bursts with the largest offsets from their galaxies, however, we find that it is more likely that they formed in massive, old clusters of stars.

Planetary systems in young stellar clusters

Using the tools that we have developed to study stellar clusters and the different encounters between stars that can occur there we have investigated the effects that close encounters can have on planetary systems in young, dense stellar clusters. Similar to the encounters between stars that can form binaries that lead to short-duration gamma-ray bursts, stars hosting planets will undergo close encounters with other stars in their birth clusters. Recent research shows that most stars form in dense stellar clusters where the stars initially move rather slowly. We show that such clusters tend to collapse rapidly, and in the process of collapse the rate of encounters can be greatly increased. This has implications for the numbers of planetary systems like our Solar System, within which life could be able to survive.

Contact and further information

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