The Supernova-Collapsar Scenario for the Gamma-Ray Bursts

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We propose that a gamma-ray burst can result from the merger of a neutron star with a massive main-sequence star following a supernova explosion. The scenario for how this can happen is outlined in Leonard, Hills & Dewey 1994, ApJ, 423, L19-L22. The initially more massive star in a massive binary system evolves and ultimately undergoes core collapse to produce a neutron star and a supernova. Since the outer layers of the originally more massive star have been transferred to the secondary, then the supernova may be hydrogen deficient. The newly-formed neutron star receives a random kick during the explosion. In a small fraction of the cases, the kick has the appropriate direction and amplitude to remove most of the orbital angular momentum from the post-supernova binary system, and the result is an orbit with a pericenter distance smaller than the radius of the secondary. Consequently, the neutron star rather quickly becomes embedded inside the secondary, and sinks to its center, giving the envelope of the merged object a lot of rotational angular momentum in the process. Leonard, Hills & Dewey estimate the rate of this process in the Galaxy to be 0.06 per square kpc per Myr for secondaries more massive than 15 solar masses. The fate of the merged object has been the source of much speculation, and we shall assume that a collapsar-like scenario results. That is, the neutron star experiences runaway accretion due to neutrino losses, collapses into a black hole, which continues to accrete, and produces a pair of jets that bore their way out of the merged object. Observers who lie in the direction of either jet will see a gamma-ray burst. Roughly 0.01 of supernovae in massive binary systems result in neutron stars quickly becoming embedded in the secondaries, and of those which produce black holes, only 0.01 would be observable as gamma-ray bursts, if the jets are beamed into 0.01 of the sky. This scenario naturally explains iron lines in gamma-ray burst spectra, due to the processed material from the supernova explosion that surrounds the collapsar.

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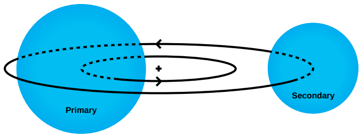

Consider a massive close main-sequence binary system and its subsequent evolution. Let us call the component stars the primary and the secondary. The primary is initially more massive than the secondary.

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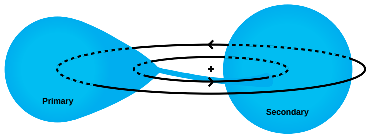

The primary evolves more rapidly than the secondary, expands to fill its Roche lobe, and transfers matter to the secondary. The primary is now less massive than the secondary.

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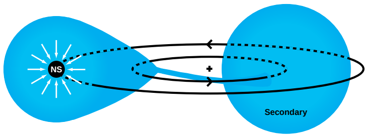

The core of the primary burns its nuclear fuel until the core can no longer support itself against gravity. Then the core collapses into a neutron star (NS).

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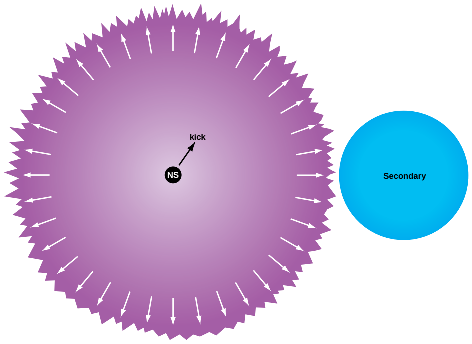

The primary undergoes a supernova explosion, and the neutron star receives a random asymmetric kick. The supernova may be observed to be hydrogen poor, due to the loss of the envelope of the primary (mainly to the secondary).

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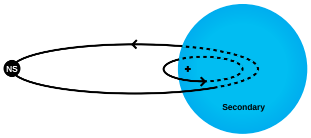

In a small fraction of cases (~1%) the asymmetric kick removes most of the orbital angular momentum from the binary system, and the post-explosion orbit has a periastron distance smaller than the radius of the secondary.

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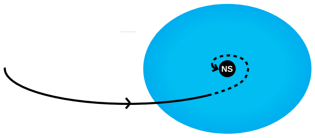

The neutron star quickly becomes embedded inside the secondary, and spirals towards the center of the secondary, giving the secondary a lot of rotational angular momentum in the process. The neutron star also accretes matter from an accretion disk that forms around it.

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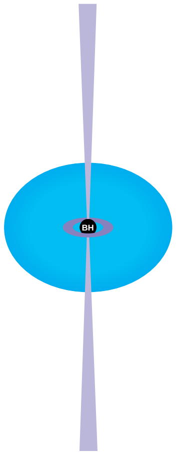

The neutron star continues to accrete, and collapses into a black hole (BH). A pair of jets are thrown off from the poles of the black hole. These jets bore their way through the envelope of the secondary.

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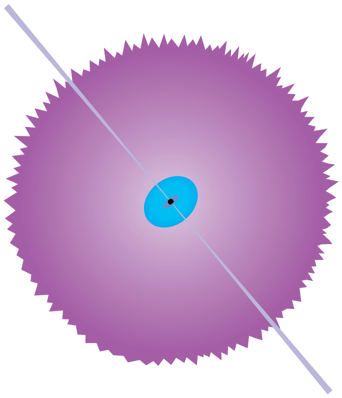

The jets also bore through the supernova remnant into interstellar space. If a jet is directed towards the observer, then a gamma-ray burst can be observed (in addition to the supernova).