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GRB-SN Association within the Binary-Driven Hypernova Model
Press Release

Long gamma-ray bursts (GRBs), in a few seconds, release luminosities (in gamma-rays) comparable to the luminosity of all stars in the observable Universe, which makes them detectable to the dawn of galaxy and stellar formation. One of the most striking observational properties of some of these sources is that they are accompanied by a supernova (SN) of type Ic, traditionally called GRB-SN association or connection. The GRB-SN association, probably the most constraining property of GRB theoretical models, is the subject of a new article by an ICRANet collaboration, accepted for publication in The Astrophysical Journal (`https://arxiv.org/abs/2303.16902`).

Supernovae Ic are considered part of the so-called core-collapse supernovae, thought to occur in the gravitational collapse of the iron core of an evolved star, forming a neutron star. The outer layers are expelled because the energy released from the core collapse exceeds their binding energy. On the other hand, long GRBs are mostly thought to be related to events forming stellar-mass black holes. Therefore, it appears difficult to render the two above theories compatible to produce a GRB-SN by a single object.

The new research deepens into this matter, highlighting observational and theoretical facts revealing the possible role of binaries in these sources. Indeed, it lists some facts that conspicuously evidence that most (if not all) GRB-SN should occur in binaries:

1. GRB-SN are related to massive star explosions.

2. Most massive stars belong to binaries.

3. GRBs are associated with supernovae Ic, which lack hydrogen (H) and helium (He).

4. Most supernova Ic models use the interaction with a binary companion to remove the H and He layers.

5. Stellar evolution predicts the direct formation of a BH only from zero-age main-sequence (ZAMS) stars above $25M_{\odot}$.

6. Observed pre-supernova stars are lighter than $18M_{\odot}$.

7. Theoretically, it is expected that the massive star's direct collapse to a black hole occurs without a supernova.

8. The explanation of GRB-SN emission at high energies (gigaelectronvolts) points to black hole masses consistent with a neutron star collapse origin rather than direct massive star collapse.

The article analyzed the supernova emission in the optical wavelengths of 24 GRB-SN associations. The SN optical emission is thought to be powered by the decay of nickel into cobalt in the material ejected. It was shown that the peak luminosity and time of occurrence of the SN are similar among the sources, spanning less than an order of magnitude difference. In contrast, the emission of the associated GRBs spans nearly seven orders of magnitude! One should add this result to the above list: it does not seem simple for a single object to explain a cataclysmic event with these two simultaneous properties.

From the modeling viewpoint, the publication focuses on the binary-driven hypernova (BdHN) scenario. In the BdHN model, the GRB-SN event occurs in binary conformed by a carbon-oxygen (CO) star and a neutron star companion. The core of the CO star collapses, generating a newborn neutron star and the supernovae. The latter triggers the GRB-observed episodes whose physical processes are scrutinized. The CO-NS fates explain the diversity of GRBs: BdHNe I are the most extreme with energies 10^{52}–10^{54} erg. Their orbital periods are about 5 minutes. In these sources, the material ejected in the supernova is easily accreted by the neutron star companion, so it reaches the point of gravitational collapse, forming a rotating black hole. In BdHNe II, the orbital period is 20–40 minutes and emit energies 10^{52}–10^{54} erg. The accretion is lower, so the neutron star remains stable. BdHN III have an orbital period of hours, and the accretion is negligible. They explain GRBs with energies lower than 10^{50} erg.

The new article features the BdHN frontier multimessenger physics and astrophysics: emission of neutrinos, gravitational waves, and electromagnetic radiation from the radio to the gamma rays occur in seven episodes, identified via time-resolved analysis of observational data, probing the physics of the early supernova, neutron-star accretion, black-hole formation, synchrotron radiation, black-hole gravitomagnetism, as well as quantum and classic electrodynamics processes that extract the black-hole energy predicted by the Christodoulou-Ruffini-Hawking black hole mass-energy formula. Specific examples of GRB-SN are analyzed in detail with their emission episodes: supernova-rise, newborn NS-rise, ultrarelativistic prompt emission, GeV emission, the black-hole echoes, soft and hard X-ray flares, X-optical-radio afterglow by synchrotron emission, and finally the optical supernova.

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