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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 ICRA-ICRANet collaboration, accepted for publication in The Astrophysical Journal [ApJ, 955 (2023) 93].*

SNe Ic are considered part of the so-called core-collapse SNe, thought to occur in the gravitational collapse of the iron core of an evolved star, forming a neutron star (NS). 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 (BHs). 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; most massive stars belong to binaries. Therefore, most (if not all) GRB-SN progenitors are binary systems.

2. GRBs are associated with SNe Ic, which lack hydrogen (H) and helium (He), and most SN Ic models use the interaction with a binary companion to remove the H and He layers.

3. Stellar evolution predicts the direct formation of a BH only from zero-age main-sequence (ZAMS) stars above $25M_\odot$ and without a SN, while observed pre-SN stars are lighter than $18M_\odot$.

The article analyzes the SN 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 ejected material. The peak luminosity and SN occurrence time are similar among the sources, spanning less than an order of magnitude difference. In contrast, the emission of the associated GRB 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 composed of a carbon-oxygen (CO) star and an NS companion. The core of the CO star collapses, generating a newborn NS and the supernova. The supernova 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 5–10 minutes. In these sources, the material ejected in the SN is easily accreted by the NS companion, so it reaches the point of gravitational collapse, forming a rotating BH. In BdHNe II, the orbital period is 20–40 minutes and emit energies $10^{52}$–$10^{54}$ erg. The accretion is lower, so the NS 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 X-rays, to the gamma-rays, to the GeV, to the TeV, to ultra-high-energy cosmic rays (UHECRs). These occur in seven episodes, identified via time-resolved analysis of observational data, probing new physical ultrarelativistic regimes previously unknown in our galaxy. Attention is given to the first episode, the early SN explosion originating from the $10M_\odot$ CO core collapse (SN-rise), and to the second episode, the accretion of the SN ejecta on the $\nu$NS ($\nu$NS-rise). The BH formation occurs by accretion of the SN ejecta on the companion NS, rather than the direct massive star collapse, and originates the associated MeV and GeV emission. The energetics are determined by the rotational energy extraction from a Kerr BH originating overcritical electromagnetic fields leading to an ultra-relativistic expanding $e^+e^-$ plasma that loads baryons from the ambient and manifests when it reaches transparency in the third episode, the UPE (ultrarelativistic prompt emission). The corresponding process in the under critical regimes occurring in a test electromagnetic field aligned with the BH rotation axis leads to the GeV emission, the fourth episode. The fifth Episode addressed the $\nu$NS emission with associated synchrotron emission in the X-rays, optical, and radio bands, followed by the sixth and seventh episodes given the Gamma-ray and X-ray flares. The optical radioactive decay of the SN ashes finally follows these seven episodes. Specific examples are given by the SPH simulations performed in collaboration with Los Alamos National Laboratory (see Fig. 1). The energetics of selected BdHNe types and the peak luminosity and time of the 24 SNe are compared and contrasted (see Fig. 2). The cases of two BdHNe I are analyzed in detail (GRB 180720B and GRB 190114C, see Fig. 3). For BdHNe II, the paper describes GRB190829A, and for BdHNe III, GRB171205A.

The unveiled details of the GRB episodes auspices a new era: to use the strongest high-energy sources on planet Earth, such as the European Hard X-ray Free Electron Laser (XFEL) operated by DESY at Hamburg and, for the TeV radiation, the accelerators of the European Organization for Nuclear Research (CERN) in Geneva, to perform the *diagnosis* of GRB physics.

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Reference article:
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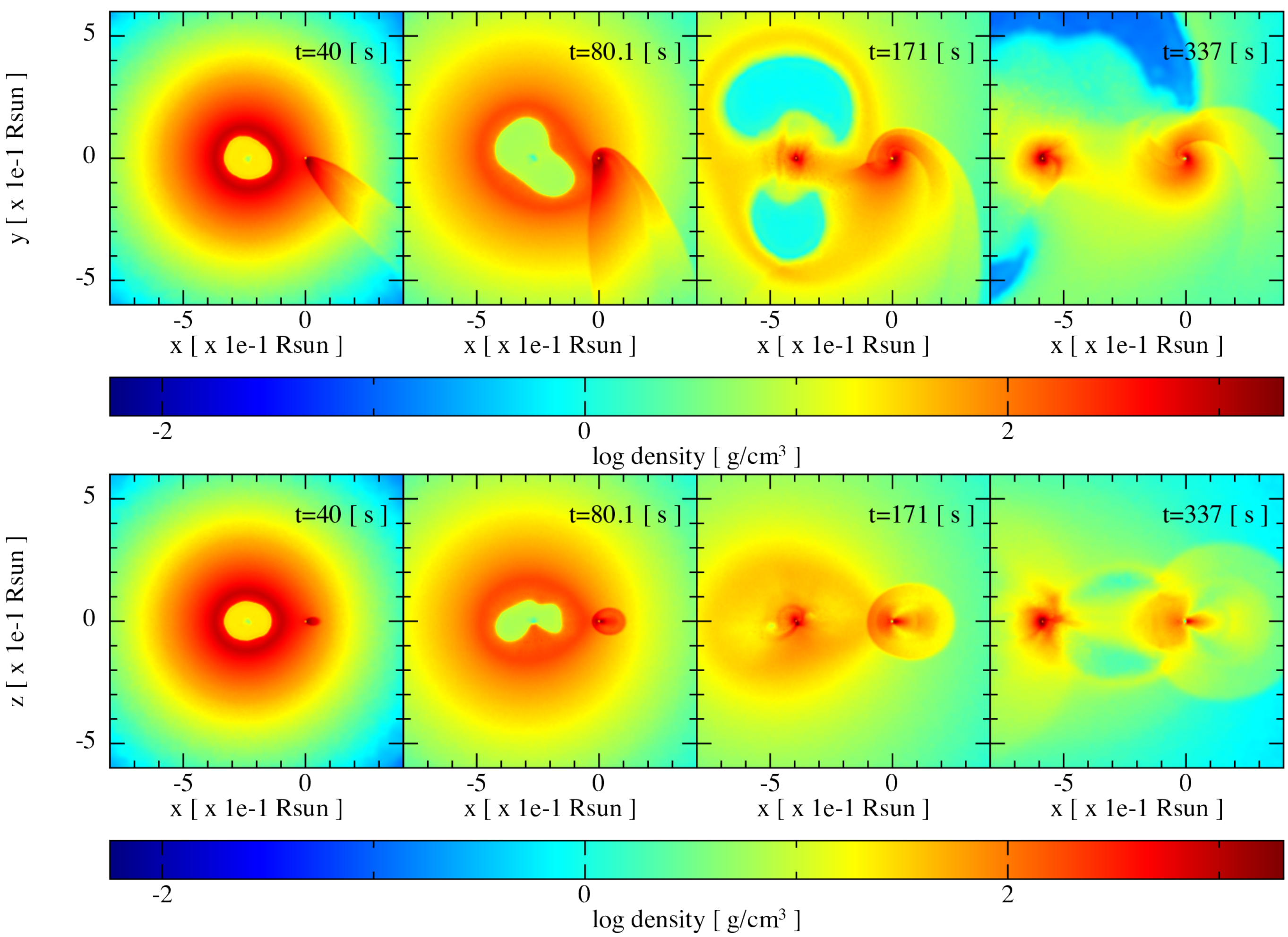


Fig. 1. SPH simulation of a BdHN I

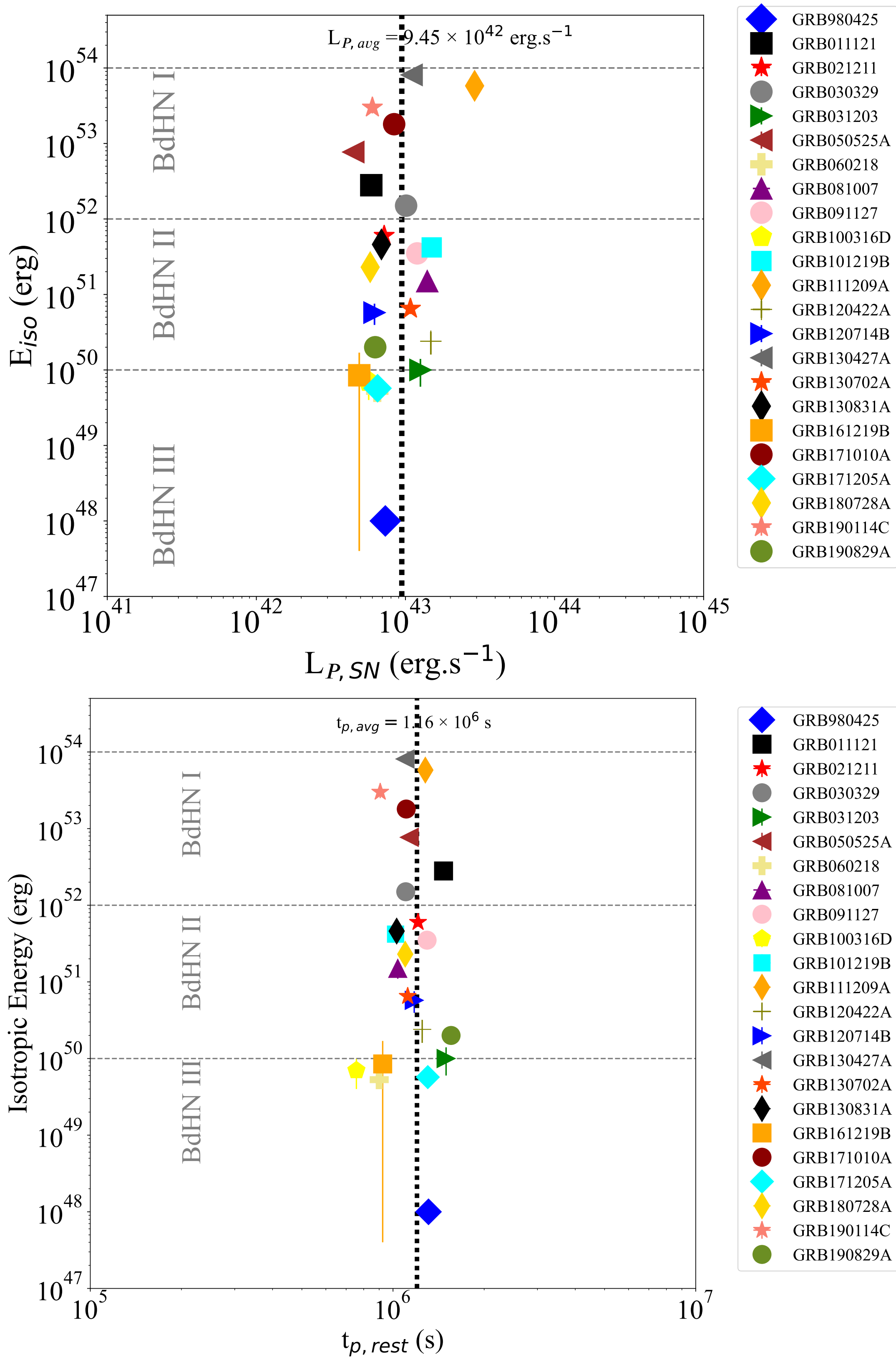


Fig. 2. Isotropic-equivalent energy of GRB versus the peak luminosity and time of the bolometric light curve of the associated SN.

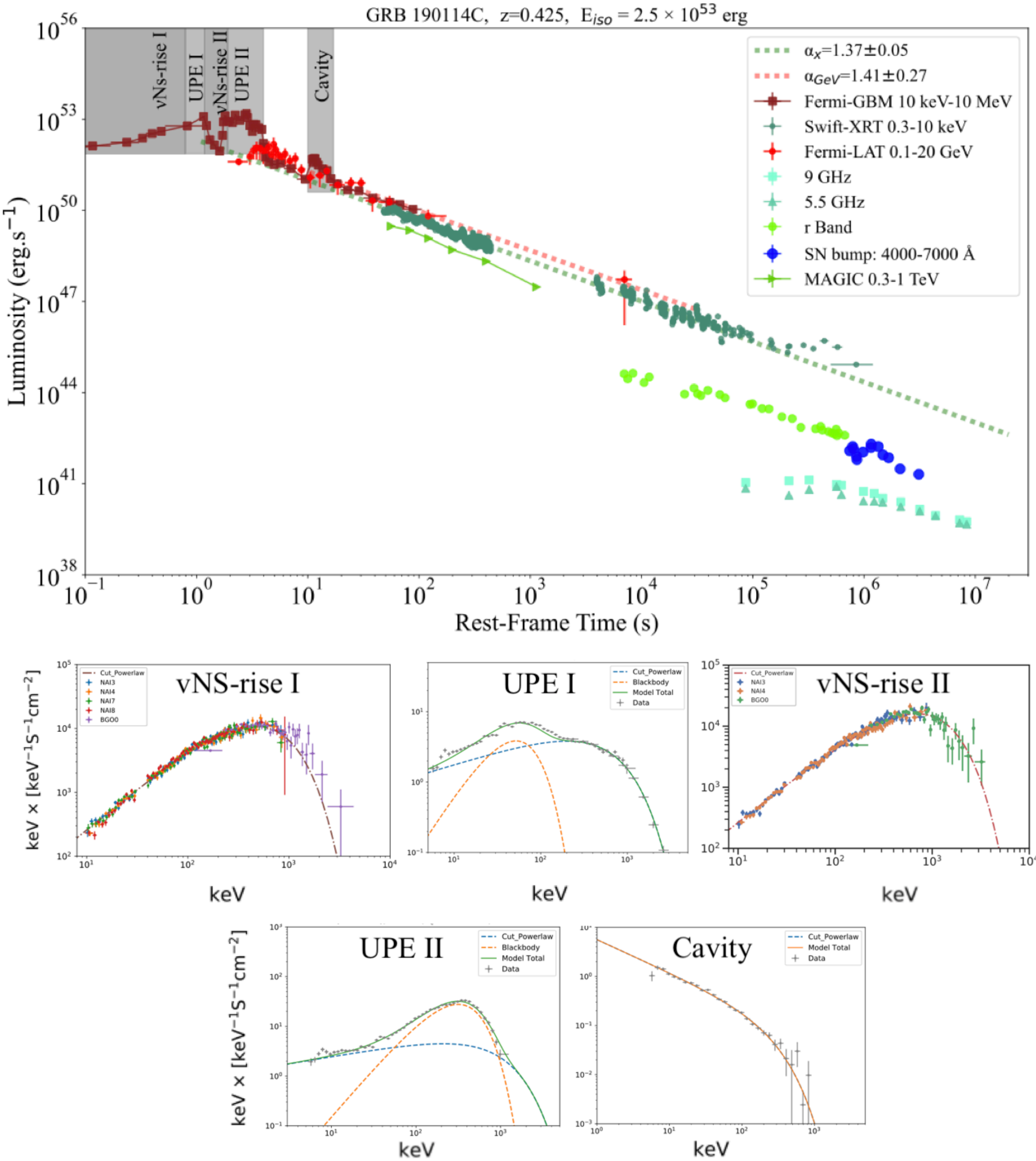


Fig. 3. The case of GRB 190114C.