Binary-driven hypernova model gains observational support

May 19 2020

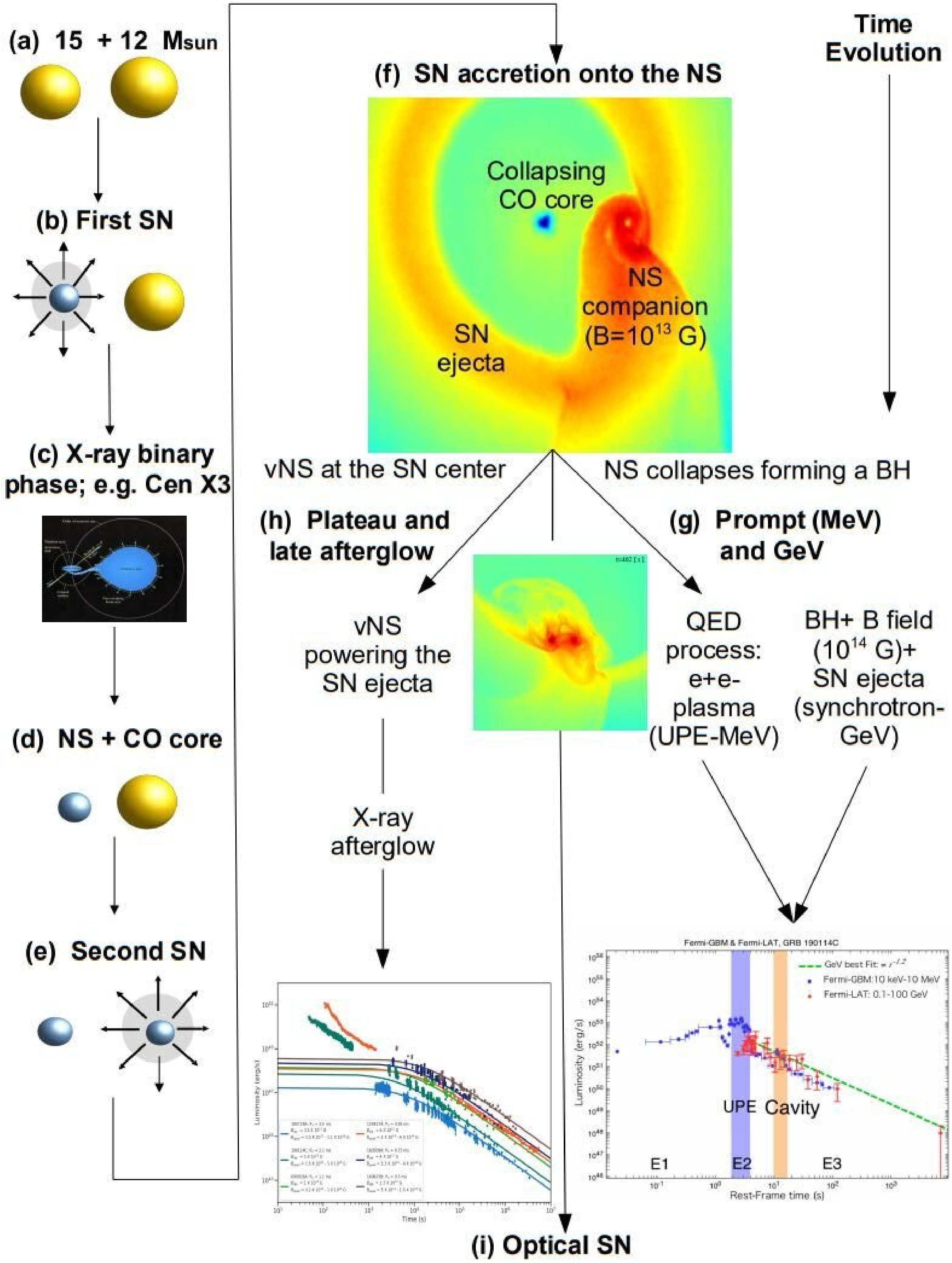
(a) 15 + 12 Msun
(b) First SN
(c) X-ray binary phase; e.g. Cen X3
(d) NS + CO core
(e) Second SN
(f) SN accretion onto the NS
Collapsing CO core
NS companion (B=10^13 G)
SN ejecta
Time Evolution
vNS at the SN center
NS collapses forming a BH
(h) Plateau and late afterglow
(g) Prompt (MeV) and GeV
vNS powering the SN ejecta
QED process: e+e- plasma (UPE-MeV)
BH+ B field (10^14 G)+ SN ejecta (synchrotron-GeV)
X-ray afterglow
Fermi-GBM & Fermi-LAT, GRB 190114C
GeV best Fit
Fermi-GBM:10 keV-10 MeV
Fermi-LAT: 0.1-100 GeV
Luminosity (erg/s)
UPE
Cavity
E1
E2
E3
Rest-Frame time (s)
(i) Optical SN

Fig. 1 Taken from 2020ApJ...893..148R. Schematic evolutionary path of a massive binary up to the emission of a BdHN. (a) Binary system composed of two main-sequence stars, say 15 and 12 solar masses, respectively. (b) At a given time, the more massive star undergoes the core-collapse SN and forms a NS (which might have a magnetic field B~1013 G). (c) The system enters the X-ray binary phase. (d) The core of the remaining evolved star, rich in carbon and oxygen, for short CO star, is left exposed since the hydrogen and helium envelope have been striped by binary interactions and possibly multiple common-envelope phases (not shown in this diagram). The system is, at this stage, a CO-NS binary, which is taken as the initial configuration of the BdHN model [2]. (e) The CO star explodes as SN when the binary period is of the order of few minutes, the SN ejecta of a few solar masses start to expand and a fast rotating, newborn NS, for short vNS, is left in the center. (f) The SN ejecta accrete onto the NS companion, forming a massive NS (BdHN II) or a BH (BdHN I; this example), depending on the initial NS mass and the binary separation. Conservation of magnetic flux and possibly additional MHD processes amplify the magnetic field from the NS value to B~1014 G around the newborn BH. At this stage the system is a vNS-BH binary surrounded by ionized matter of the expanding ejecta. (g) The accretion, the formation and the activities of the BH contribute to the GRB prompt gamma-ray emission and GeV emission. Credit: ICRANet

The change of paradigm in gamma-ray burst (GRBs) physics and astrophysics introduced by the binary driven hypernova (BdHN) model, proposed and applied by the ICRA-ICRANet-INAF members in collaboration with the University of Ferrara and the University of Côte d'Azur, has gained further observational support from the X-ray emission in long GRBs. These novel results are presented in the new article, published on April 20, 2020, in the *Astrophysical Journal*, co-authored by J. A. Rueda, Remo Ruffini, Mile Karlica, Rahim Moradi, and Yu Wang.

The GRB emission is composed by episodes: from the hard X-ray trigger and the gamma-ray prompt emission, to the high-energy emission in GeV, recently observed also in TeV energies in GRB 190114C, to the X-ray afterglow. The traditional model of GRBs attempts to explain the entire GRB emissions from a single-component progenitor, i.e., from the emission of a relativistic jet originating from a rotating black hole (BH). Differently, the BdHN scenario proposes GRBs originate from a cataclysmic event in the last evolutionary stage of a binary system composed of a carbon-oxygen (CO) star and a neutron star (NS) companion in close orbit. The gravitational collapse of the iron core of the CO star produces a supernova (SN) explosion ejecting the outermost layers of the star, and at the same time, a newborn NS (νNS) at its center. The SN ejecta trigger a hypercritical accretion process onto the NS companion and onto the νNS. Depending on the size of the orbit, the NS may reach, in the case of short orbital periods of the order of minutes, the critical mass for gravitational collapse, hence forming a newborn BH. These systems where a BH is formed are called BdHN of type I. For longer periods, the NS gets more massive but it does not form a BH. These systems are BdHNe II. Three-dimensional simulations of all this process showing the feasibility of its occurrence, from the SN explosion to the formation of the BH, has been recently made possible by the collaboration between ICRANet and the group of Los Alamos National Laboratory (LANL) guided by Prof. C. L. Fryer (see Figure 1).

The role of the BH for the formation of the high-energy GeV emission has been recently presented in the *Astrophysical Journal*. There, the "inner engine" composed of a Kerr BH, with a magnetic field aligned with the BH rotation axis immersed in a low-density ionized plasma, gives origin, by synchrotron radiation, to the beamed emission in the MeV, GeV, and TeV, currently observed only in some BdHN I, by the Fermi-LAT and MAGIC instruments. In the new publication, the ICRA-ICRANet team addresses the interaction of the νNS with the SN due to hypercritical accretion and pulsar-like emission. They show that the fingerprint of the νNS appears in the X-ray afterglow of long GRBs observed by the XRT detector on board the Niels Gehrels Swift observatory. Therefore, the vNS and the BH have well distinct and different roles in the long GRB observed emission.

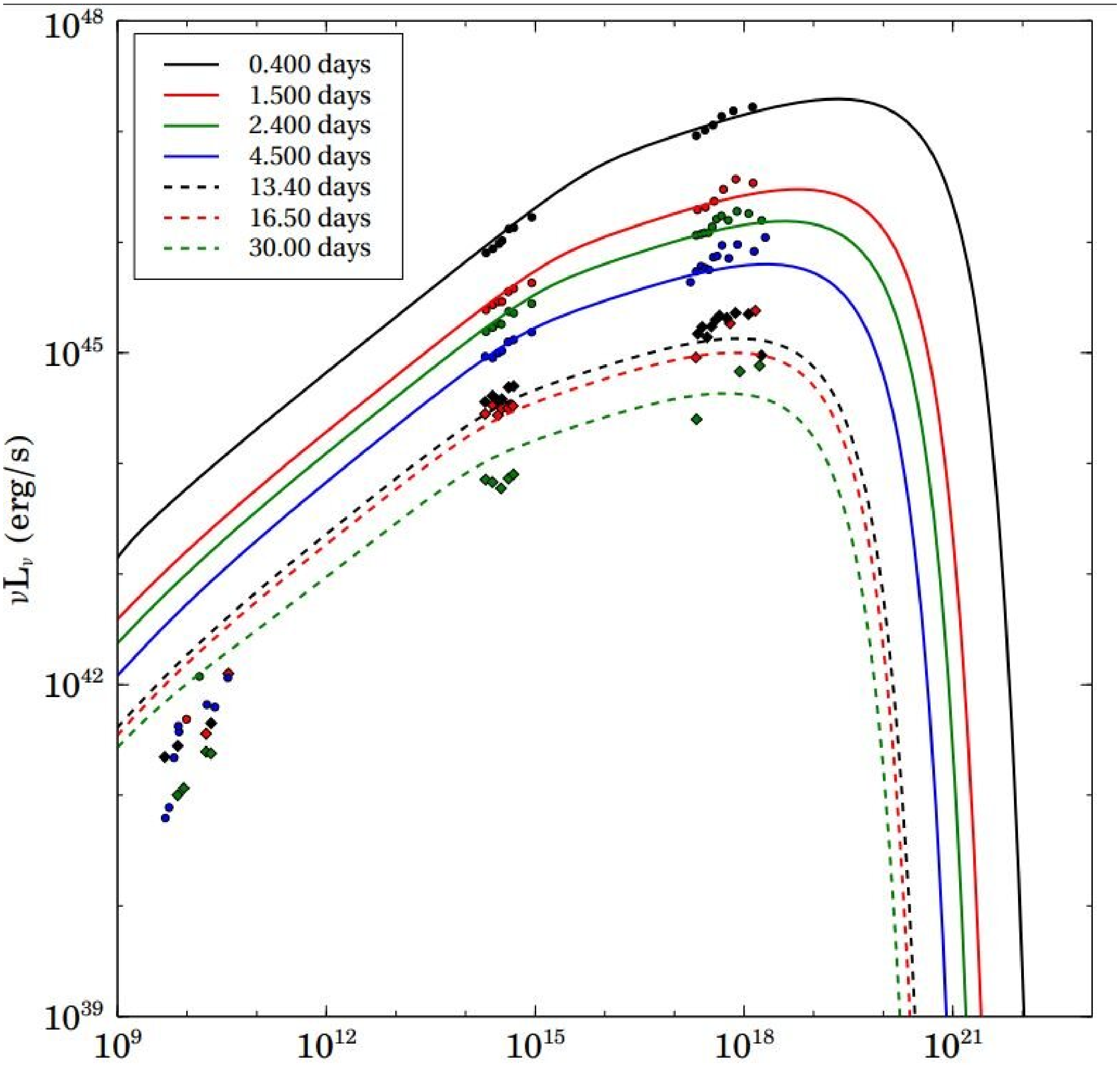

Fig. 2 :Model evolution of synchrotron spectral luminosity at various times compared with measurements in various spectral bands for GRB 160625B.

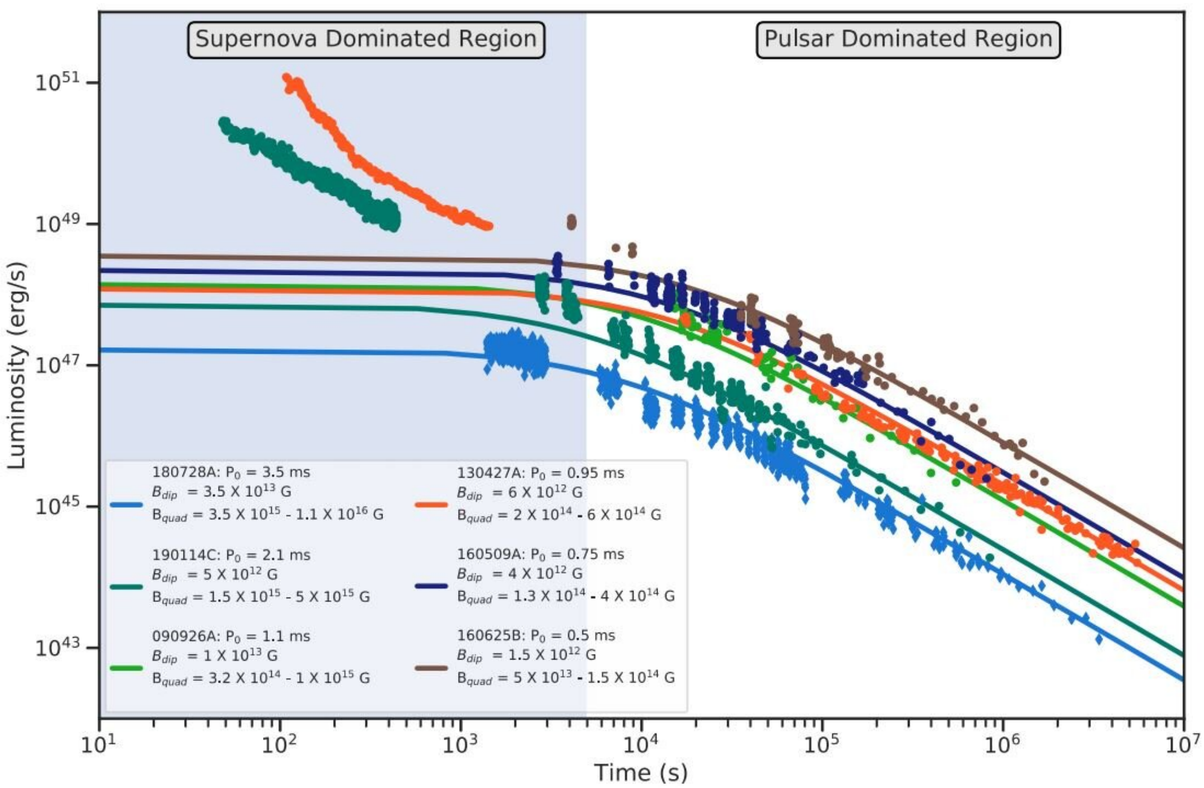

Fig. 3 The brown, deep blue, orange, green and bright blue points correspond to the bolometric (about 5 times brighter than the soft X-ray observed by Swift-XRT data) light-curves of GRB 160625B, 160509A, 130427A, 190114C and 180728A, respectively. The solid lines are theoretical light-curves obtained from the rotational energy loss of the vNS powering the late afterglow (t>5000 s, white background), while in the earlier times (30010^4 s, it has been shown that the power-law decaying luminosity is powered by the vNS rotational energy loss by the torque acted upon it by its dipole+quadrupole magnetic. From this, it has been inferred that the vNS possesses a magnetic field of strength ~ 10^12 to 10^13 G, and a rotation period of the order of a millisecond (see Figure 3). It is shown that the inferred millisecond rotation period of the vNS agrees with the conservation of angular momentum in the gravitational collapse of the iron core of the CO star which the vNS came from.

The inferred structure of the magnetic field of the "inner engine" agrees with a scenario in which, along the rotational axis of the BH, it is rooted in the magnetosphere left by the NS that collapsed into a BH.

On the equatorial plane, the field is magnified by magnetic flux conservation.

More information: J. A. Rueda et al. Magnetic Fields and Afterglows of BdHNe: Inferences from GRB 130427A, GRB 160509A, GRB 160625B, GRB 180728A, and GRB 190114C, *The Astrophysical Journal* (2020). DOI: 10.3847/1538-4357/ab80b9

Provided by ICRANet