On the observation of supernovae in the late phases of Gamma-Ray Bursts

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Abstract

Gamma-Ray Bursts: the most luminous sources in the universe

The cosmic objects with the largest electromagnetic luminosity in the Universe are the Gamma-Ray Bursts (GRBs). In a finite time lasting less than 100s, the luminosity of such a single object equals the summed one of all the hundred billions of billions stars of the Universe.

The GRB families

There are two main GRB families: the long GRBs, lasting more than 2s, and the short GRBs, lasting less than 2s. For a few decades, all GRBs were considered to originate from the formation of a standard isolated black hole with an ultrarelativistic jetted emission. What has become clear in recent years is that all GRBs originate in binary systems composed by various combinations of evolved FeCO cores, white dwarfs, neutron stars and black holes. In more recent years it has become also clear that short GRBs represent the final outcome of the evolution of the binary systems which previously emitted a long GRB. Correspondingly, eight different subclasses of GRBs have been conceived [see table below and Ruffini, et al., ApJ, 832 (2016) 136].

	Sub-class	Number	*In-state*	*Out-state*	$E_{\rm p,i}$ (MeV)	$E_{\rm iso}$ (erg)	$E_{\rm iso,Gev}$ (erg)
I	S-GRFs	17	NS-NS	MNS	~ 0.2–2	$\sim 10^{49}$–10^{52}	–
II	S-GRBs	6	NS-NS	BH	~ 2–8	$\sim 10^{52}$–10^{53}	$\gtrsim 10^{52}$
III	XRFs	48	$\rm CO_{core}$-NS	νNS-NS	~ 0.004–0.2	$\sim 10^{48}$–10^{52}	–
IV	BdHNe	329	$\rm CO_{core}$-NS	νNS-BH	~ 0.2–2	$\sim 10^{52}$–10^{54}	$\gtrsim 10^{52}$
V	BH-SN	4	$\rm CO_{core}$-BH	νNS-BH	$\gtrsim 2$	$> 10^{54}$	$\gtrsim 10^{53}$
VI	U-GRBs	0	νNS-BH	BH	$\gtrsim 2$	$> 10^{52}$	–
VII	GRFs	1	NS-WD	MNS	~ 0.2–2	$\sim 10^{51}$–10^{52}	–
VIII	GR-K	1	WD-WD	MWD	~ 0.082	$\sim 10^{47}$	–

The single supernova evolution

The understanding of single supernovae still presents some outstanding problems, in the attempt to explain the supernova ejecta only in terms of fermions fulfilling beta equilibrium undergoing gravitational collapse. The emission of the supernova ejecta is still unsolved, and it is likely that the solution of this problem needs the introduction of additional electromagnetic effect. What is clear is that, in the early phases of the gravitational collapse of the neutron star, a very rich process of nuclear burning occurs, leading to the formation of a core made by Nichel and Cobalt. It is precisely this core that, undergoing nuclear decay, produces the optical supernova emission peaking after about 15 days.

The cosmic matrix

In all cases of long GRBs, the trigger originates in a supernova event occurring in a tight binary system composed of an evolved FeCO core and a companion neutron star. The further evolution of the system depends on the separation of the binary components, and, correspondingly, on the period of the binary system. As a function of this separation, the hypercritical accretion of the supernova ejecta onto the companion neutron star may lead to the formation of a more massive neutron star (in which case it is called a X-Ray Flash, XRF) or of a black hole (in which case it is called a Binary Driven Hypernova, BdHN): an authentic "cosmic matrix". The successive evolution of the system, all the way to the latest afterglow phases presents new phenomena whose detectability is strongly dependent on the viewing angle of the system (e.g. ultrarelativistic prompt emission, hard x-ray flares, soft x-ray flares, extended thermal emission, transition from the supernova to the hypernova phase, etc.). The most striking result is that the optical emission of the supernova, peaking after 15 days, appears to be quite universal, independent of the different properties of the previous GRB phases.

The case of GRB 180720B: a BdHN (see GCN 23019)

The following steps are in principle observable:

1) Supernova explosion and formation of the new neutron star
   [see e.g. Rueda & Ruffini, ApJL, 758 (2012) L7]
2) Hypercritical accretion on the binary neutron star companion
   [see e.g. Fryer, Rueda, Ruffini, ApJL, 793 (2014) L36]
3) The reaching of the companion neutron star critical mass
   [see e.g. Becerra, et al., ApJ, 833 (2016) 107]
4) The formation of the black hole
   [see e.g. Becerra, et al., ApJ, 833 (2016) 107]
5) The formation of the optically thick e+e- plasma
   [see e.g. Ruffini, et al., A&A, 359 (2000) 855]
6) The ultrarelativistic prompt emission
   [see e.g. Ruffini, et al., ApJL, 581 (2002), L19]
7) The transition from the supernova to the hypernova phase
   [see e.g. Ruffini, et al, arXiv:1712.05001]
8) The x-ray flares
   [see e.g. Ruffini, et al., ApJ, 852 (2018) 53]
9) The afterglow
   [see e.g. Ruffini, et al., A&A, 565 (2014) L10]
10) The optical emission of the supernova
   [see e.g. Ruffini, et al., ApJ, 798 (2015) 10]
11) The search for the black hole in the supernova remnant.

The case of GRB 180728A: a XRF (see GCN 23066)

The following steps are in principle observable:

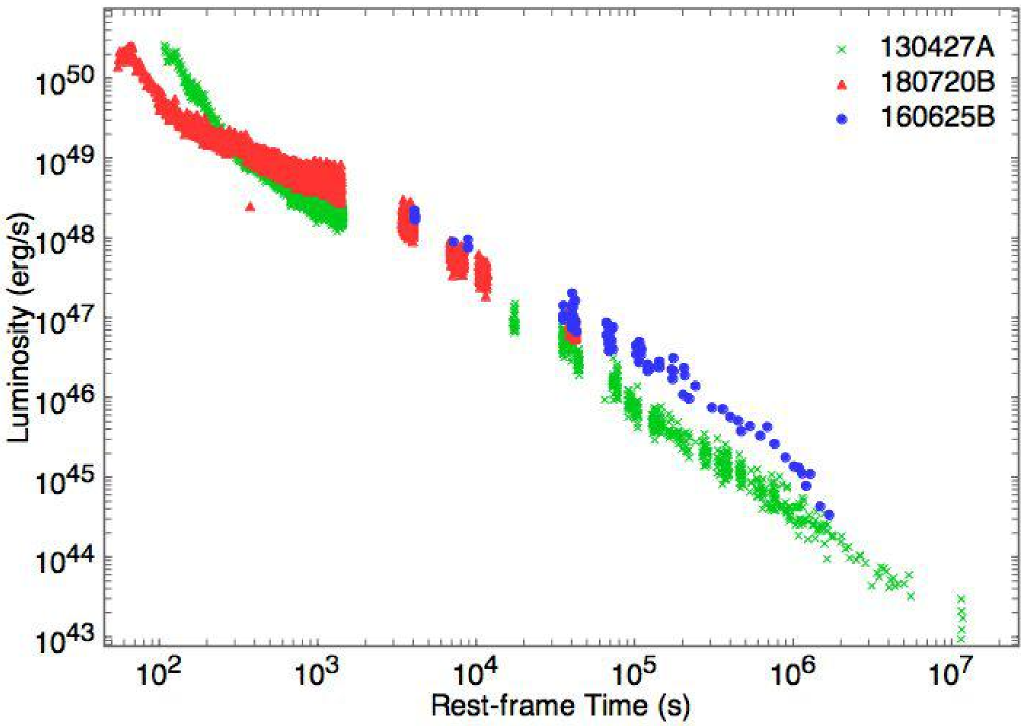
1) Supernova explosion and formation of the new neutron star
   [see e.g. Rueda & Ruffini, ApJL, 758 (2012) L7]
2) Hypercritical accretion on the binary neutron star companion
   [see e.g. Fryer, Rueda, Ruffini, ApJL, 793 (2014) L36]
3) The formation of the massive neutron star
   [see e.g. Becerra, et al., ApJ, 833 (2016) 107]
4) The formation of the optically thick e+e- plasma
   [see e.g. Ruffini, et al., A&A, 359 (2000) 855]
5) The ultrarelativistic prompt emission
   [see e.g. Ruffini, et al., ApJL, 581 (2002), L19]
6) The transition from the supernova to the hypernova phase
   [see e.g. Ruffini, et al, arXiv:1712.05001]
7) The afterglow
   [see e.g. Ruffini, et al., A&A, 565 (2014) L10]
8) The pulsar like processes of the binary neutron star system inside the supernova remnant.

TITLE: GCN CIRCULAR
NUMBER: 23019
SUBJECT: GRB 180720B: Testing the universality of the newly born neutron star in BdHNe
DATE: 18/07/22 22:30:27 GMT
FROM: Remo Ruffini at ICRA <ruffini@icra.it>

R. Ruffini, Y. Aimuratov, C. L. Bianco, Y. C. Chen, D. M. Fuksman, M. Karlica, R. Moradi, D. Primorac, J.A. Rueda, N. Sahakyan, Y. Wang, on behalf of the ICRANet team, report:

GRB 180720B (Siegel et al., GCN 22973) is a long GRB with isotropic energy ~6.0e53 erg (Frederiks et al., GCN 23011). It belongs to the long GRB subclass of Binary Driven Hypernovae (BdHNe) (Ruffini et al., 2016, ApJ, 832, 136), with energies larger than 1e52 erg and GeV radiation, which allows the determination of the black hole mass (Ruffini et al., arXiv:1803.05476). It includes GRB 130427A associated to SN 2013cq (Ruffini et al., GCN 14526, Xu et al., GCN 14646), as well as GRB 160625B (Troja et al., 2017). The comparison of X-ray light-curves is attached [1], plotted in the rest frame of the sources. These sources are polar views from the normal to the plane of the binary progenitor (Ruffini et al., arXiv:1803.05476). In GRB 180720B, which has redshift z = 0.654 (GCN 22996), being a BdHN, a supernova is expected to peak, using the averaged observed value (Cano et al., 2016), at 21.8 +/ 4.3 day after the trigger (11 August 2018, uncertainty from August 7th to August 15th): the prolonged observations of the afterglow in all bands, especially the optical band, is recommended to further probe the nature of the supernova and of the newly born neutron star, strikingly constant in all BdHNe (see also Becerra et al., arXiv:1803.04356).

[1] Link: http://www.icranet.org/documents/20180721.jpg



Caption of figure: Three BdHNe with polar views from the normal to the plane of the binary progenitor, pointing to the similarities. GRB 130427A with redshift z=0.34 is associated to the companion supernova SN 2013cq. GRB 160625B has redshift z=1.406, which is too far for the optical observation of the associated supernova (Woosley & Bloom, 2006). GRB 180720B with redshift z=0.654 is expected to have the observation of an associated supernova.

TITLE: GCN CIRCULAR
NUMBER: 23066
SUBJECT: GRB 180728A: A long GRB of the X-ray flash (XRF) subclass, expecting supernova appearance
DATE: 18/07/31 10:29:39 GMT
FROM: Remo Rufinni at ICRA <ruffini@icra.it>

R. Ruffini, Y. Aimuratov, C. L. Bianco, Y. C. Chen, D. M. Fuksman, M. Karlica, R. Moradi, D. Primorac, J.A. Rueda, N. Sahakyan, Y. Wang, on behalf of the ICRANet team, report:

GRB 180728A has T90=6.4s (P. Veres et al., GCN 23053), peak energy 142 (-15.+20) keV, and isotropic energy (2.33 +/- 0.10)x10^51 erg (D. Frederiks, et al., GCN 23061). It presents the typical characteristic of a subclass of long GRBs called X-ray flashes (XRFs, see Ruffini et al., ApJ 832 (2016) 136), originating from a tight binary of a FeCO Core undergoing a supernova explosion in presence of a companion neutron star (NS) which undergoes hypercritical accretion. The outcome (see Fig. [1]) is a new binary composed by a more massive NS (MNS) and a newly born NS (vNS). Using the averaged observed value (Cano et al., 2016), and considering the redshift z=0.117 (A. Rossi et al., GCN 23055), a bright optical signal will peak at 14.7 +/- 2.9 days after the trigger (12 August 2018, uncertainty from August 9th to August 15th) at the location of RA 253.56472 and DEC -54.04451, with an uncertainty 0.43 arc sec (S. J. LaPorte et al., GCN 23064). The follow-up observations, especially the optical bands for the SN, as well as attention to binary NS pulsar behaviors in the X-ray afterglow emission, are recommended.

[1] Link: http://www.icranet.org/documents/180728A_f1.png

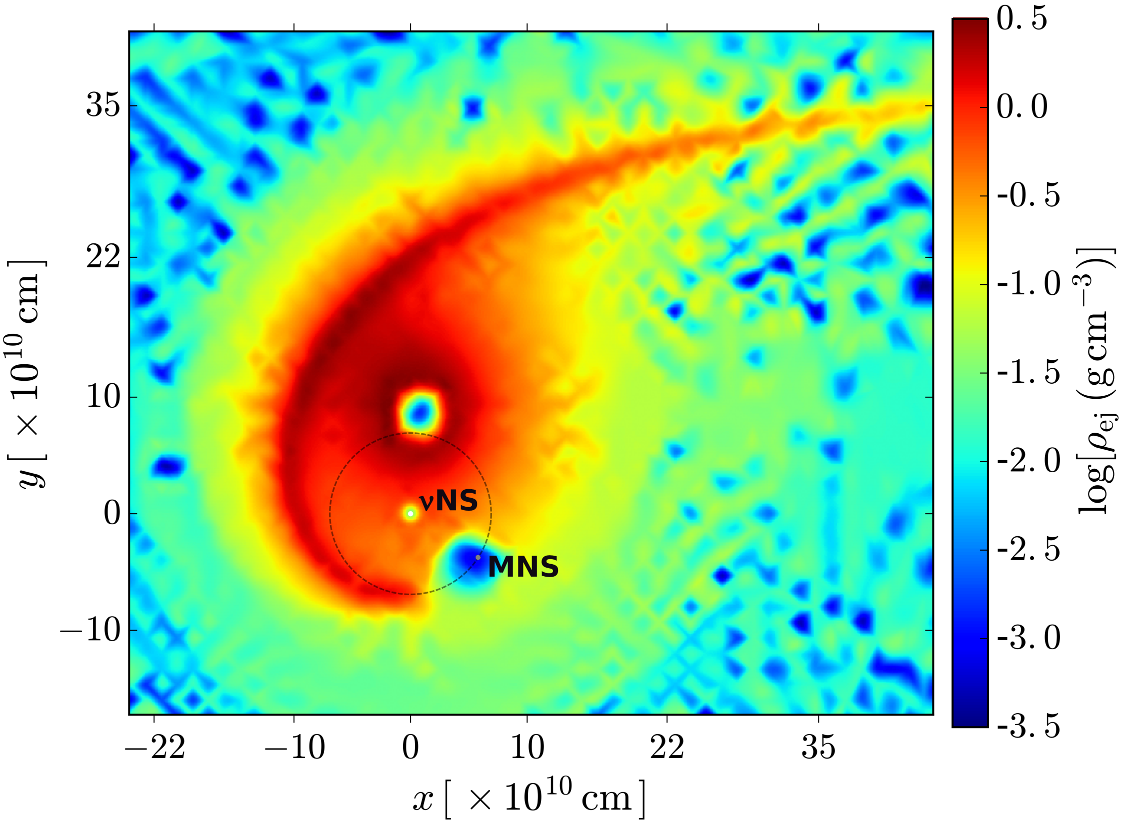


Figure Caption: Snapshot of the binary system formed by the MNS and by the vNS together with the SN ejecta density. See for details Fig. 7 of Ruffini et al., ApJ 832 (2016) 136.