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Investigating the Gamma-Ray Burst – Supernova Connection

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Abstract. We have undertaken a literature search for associations of gamma-ray bursts (GRBs) with supernovae (SNe), and we have constructed a much larger table of cases than has been published until now. The table contains a suite of physical properties for the GRBs (and the SNe when available), which will allow us and others to infer valuable knowledge about the GRBs and their physical mechanisms. From this basic table, we have undertaken a very preliminary examination, looking at the intrinsic GRB properties at hand, i.e. duration, isotropic energy output, peak spectrum energy, fluence, spectral index, redshift etc., and we present initial results. Future analyses will be performed to try to determine whether GRBs with no associated SNe constitute a subclass or category of bursts with particular characterizing properties.

1. Introduction

With the consensus that "long" gamma-ray bursts (of duration more than ~ 2 seconds) are due to hypernovae (very big stars exploding as described by the collapsar model), the search for correlations between GRBs and SNe has become a lively topic in this very active field. Very few SNe have been found for GRBs, however, whether by direct detections or by catalog searches, which may or may not be surprising: perhaps this is due to the large distances at which GRBs occur, or perhaps to special properties for some GRBs, making them more or less amenable to an SN association. This has led researchers to ask what characteristics make some GRBs manifest themselves as supernovae and others not. To investigate this, lists of GRBs with/without SNe (when searches were performed) needed to be constructed.

Bosnjak et al. [1] constructed one such list using only the BATSE catalogs of GRBs and based on the following approach: a) spectra were searched for a late re-brightening ("bump") in the optical afterglow of the GRB, which could be the signature of an underlying SN; b) SNe catalogs were searched for coincidence (spatial and temporal) with detected GRBs (although positions are often tainted by large uncertainties – more than 8 degrees in many cases). That list contained 36 GRBs, all but three with suggested SN associations. However, contrary to the consensus in the community, about half of the SNe listed in the table are of type Ia, making them highly doubtful.

Hjorth [2] produced another such list, updated and expanded from [3] and [4]; it too contained 36 GRB, 12 of them with SN associations. Most recently, Cano et al. [5] published a new list, similar to [2] but with more physical parameters (e.g. V-magnitude, bolometric luminosity), but often available for only a few GRBs.

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2. Research, New Data, and Results

To produce a new list, we used the following approaches:

- Search publication databases (NASA/ADS, Astro-ph ArXiv, Google Scholar) to collect information on GRBs, related SNe, and their physical properties;
- Search for corresponding objects (SNe for GRBs or vice-versa) by close dates and celestial locations within databases of astronomical objects (e.g. the Swift GRBs database, the Central Bureau for Astronomical Telegrams, the Gamma-ray Coordinates or Coordination Network, the Open Supernova Catalog for SNe).

Our table of new GRB-SN cases contains 95 GRBs, about 25 of them new and not previously reported, most of them with SN associations. 'No SN found' is a rather difficult criterion to implement for the simple reason that it is often impossible to know whether a GRB's afterglow was observed for long enough (tens of days) for any SN "bump" to be seen or not. The double list gives physical parameters for the GRBs (duration, redshift, isotropic gamma-ray energy, spectral index, fluence, etc.). We must stress that this data is preliminary; most but not all the association cases are robust; checks are still being made, as well as searches for physical parameter values in order to ascertain and complete the data as strongly and fully as possible. Likewise, finding GRBs where SNe were really looked for and were not found is not straightforward.

A quick analysis of all the GRBs with/without SNe reveals the following:

- The GRBs for which an SN has been ascertained are closer than those without: average redshift of 0.34 (± 0.33), compared to 0.57 (± 0.52). The (statistically not significant) difference is not surprising: it is easier to detect supernovae for closer GRBs, considering the low fluxes.
- GRB duration sets are very similar for GRBs with/without SNe, both in the observer's frame: 40.1 ± 47.8 vs. 47.6 ± 46.6 s (leaving out 3 bursts longer than 1,000 s and half a dozen bursts with T90 < 1 s, as short GRBs are not supposed to result from explosions and hence should not be associated with SNe), and in the rest frame: 29.9 ± 32.6 vs. 29.8 ± 33.9 s.
- No difference was found in the peak V-magnitude, in the photon index, or the spectral index.

There are more analyses to be performed on the GRBs with/without SNe: a) Bosnjak et al. [1] reported that most of the SN-associated bursts that they analyzed have single-peak spectra; the 29 new ones we have dug up should be checked for this characteristic; b) how do the two groups differ in fitting (or not) the GRB correlations (e.g. Amati, Yonetoku, etc.)? c) taking into account the distances/redshifts, how do these groups differ in terms of luminosity/magnitude in the optical and the gamma domains? These are questions that we plan to explore in the near future.

3. Conclusions

In our (preliminary) investigation of the GRB-SN connection, we have collected some 30 new GRBs, most of them with a supernova counterpart. This is a substantial increase in the number of previously listed/published GRBs with/without associated SNe [1, 2, 5]. We have performed only preliminary checks on these objects to ascertain the SN association, and we shall strengthen those claims (positive or negative) in the near future.

We have performed very basic and quick comparisons between the two groups and did not find any surprising or significant differences (in durations and spectral indices). GRBs with SNe were found to be closer, which is normal observational bias. More substantial analyses, for instance of the spectra (single peak or not) and of the physical parameters that should correlate à la Amati, Yonetoku, and other proposed relations, will be performed in the near future.

If GRBs with SNe turn out to have different properties than those without SNe, the implications would be very significant. At minimum, it would give observers an indicator of which GRBs one should target when instrumentally searching for SNe. More importantly, it might imply a somewhat different physical process at work in the explosion and perhaps even a different class of objects that undergo such bursts and supernova explosions. For instance, Bosnjak et al. [1] do not rule out Type Ia supernovae in the associations they make with GRBs even though the general consensus is that (long) GRBs should be associated with Type Ic, or at least Type Ibc, supernovae.

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Table 1a – Sample of GRBs with SNe associations

GRB	SN	Identification	z	T_{90} (sec)	$T_{90\text{-rest-frame}}$ (sec)	M_{Vpeak}	E_{giso} (erg)	Spectral Index (Gamma)	Photon Index	Fluence (erg/cm^2)
920613	1992ae		0.075	129 ± 8.4	120 ± 7.8					1.86×10^{-6}
951107	1995bc		0.048	43.52	41.53			1.62		1.45×10^{-6}
970514	1997cy		0.063	1.3	1.2		4×10^{48}			4.1×10^{-5}
980425	1998bw		0.0085	18	17.8	−19.15	8.57×10^{48}	2.56 ± 0.7		$(3.04 \pm 0.21) \times 10^{-6}$
991002	1999eb	S&T M [6]		1.9	1.9			1.12		6.2×10^{-5}
011121	2001ke	LCB [7]	0.362	47	34.5	−19.05	7.80×10^{52}			
030329	2003dh	LCB [7]	0.1685	22.76	19.48	−19.2	1.50×10^{52}			
050525A	2005nc	LCB [8]	0.606	8.84	5.5	−18.8	2.50×10^{52}	2.09	1	153.0×10^{-7}
060218	2006aj	LCB [9]	0.0334	2100	2000	−18.7	5.30×10^{49}	3.52	2.26	15.70×10^{-7}
080319B			0.938	124.9	64.4	−18.5	1.14×10^{54}	1.81	1.04	810×10^{-7}
081007	2008hw	LCB [10]	0.53	9.01	5.89	−19.2	1.60×10^{51}	2.1	2.51	7.1×10^{-7}
090618		LCB [11]	0.54	113.34	73.6	−18.4	2.57×10^{53}	1.83	1.42	1050×10^{-7}
091127	2009nz	LCB [12]	0.49	7.42	4.98	−19.0	1.10×10^{53}	1.8	2.05	90×10^{-7}
100316D	2010bh	SN Obs [2]	0.0591	1300	1200	−18.25	5.90×10^{49}	2.49	2.29	3.0×10^{-7}
101219B	2010ma	Spectro [13]	0.552	51	32.86	−19.37	4.20×10^{51}	1.86	1.56	21×10^{-7}
130427A	2013cq	LCB [14]	0.3399 ± 0.0002	162.8	121.52	-12.1	9.6×10^{53}	1.79	1.21	4.2×10^{-3}
130831A	2013fu	LCB [11]	0.4791	32.5 ± 2.5	22.0 ± 1.7	-14.4	$(4.6 \pm 0.2) \times 10^{51}$	1.79	1.93	$(6.5 \pm 0.2) \times 10^{-6}$
150818A		Spectro [15]	0.282	123.3	96.18	> -19.36		1.98	1.96	42×10^{-7}

Identification: S&T M = Spatial & Temporal Match; LCB = Light Curve Bump; SN Obs = SN Observed; Spectro = Spectroscopy.

Table 1b – GRBs with no SNe found

GRB	z	T_{90}	T_{90} in rest frame	M_{Vpeak}	Spectral Index (Gamma)	Photon Index	Fluence (erg/cm^2)
000630		20					$(15.1\pm1.1)\times10^{-6}$
050824	0.828	22.6	12.36	20.02	1.94709	2.76	2.66×10^{-7}
060505	0.089	4	3.67				
060614	0.125	108.7	96.62	19.54	1.89544	2.02	2.04×10^{-5}
070419A	0.971	115.6	58.65	20.0	2.18444	2.35	5.58×10^{-7}
090902B	1.822	21	7.44				
100418A	0.624	7	4.31	19.90	2.26662	2.16	3.4×10^{-7}
111005A	0.01326	26	25.66			2.03	6.2×10^{-7}
111228A	0.716	101.2	58.97	17.73	2.03824	2.27	85×10^{-7}

References

[1] Bosnjak Z et al. 2006 Gamma-ray bursts associated with supernovae: a systematic analysis of BATSE GRB candidates *A & A* **447**, 121-132

[2] Hjorth J 2013, Table of GRB–SN connections http://www.dark-cosmology.dk/GRBSN/GRB-SN_Table.html

[3] Hjorth J and Bloom J S 2012 The Gamma-Ray Burst - Supernova Connection *Gamma-Ray Bursts*, Cambridge Astrophysics Series 51, eds. Kouveliotou C Wijers R A M J and Woosley S Cambridge: Cambridge University Press 169-190

[4] Hjorth J 2013 The supernova–gamma-ray burst–jet connection *Phil Trans R Soc A* **371**: 20120275

[5] Cano Z et al. 2016 The Observer's Guide to the Gamma-Ray Burst-Supernova Connection. Eighth Huntsville Gamma-Ray Burst Symposium held 24-28 October 2016 LPI Contribution No. 1962 id.4116

[6] IAU Circular 7269 http://www.cbat.eps.harvard.edu/iauc/07200/07269.html

[7] Zeh A *et al.* 2004 A Systematic Analysis of Supernova Light in Gamma-Ray Burst Afterglows *Astrophys J* **609**, 952–961

[8] Della Valle M. *et al.* Hypernova Signatures in the Late Rebrightening of GRB 050525A. *Astrophys. J.* **642**, L103–L106

[9] Campana S et al. (2006) The association of GRB 060218 with a supernova and the evolution of the shock wave *Nature* 442, 31 August 2006 pp. 1008-1010

[10] Jin Z-P et al. (2013) GRB 081007 and GRB 090424: The Surrounding Medium, Outflows, and Supernovae *Astrophys. J.* **774**, 114

[11] Cano Z et al. (2011) A tale of two GRB-SNe at a common redshift of $z = 0.54$ *Mon. Not. R. Astron. Soc.* **413,** 669–685

[12] Cobb B E et al. (2010) Discovery of SN 2009nz Associated with GRB 091127 *Astrophys. J. Lett.*, **718**, L150–L155

[13] Sparre M et al. (2011) Spectroscopic Evidence for SN 2010ma Associated with GRB 101219B *Astrophys. J. Lett.*, **735**, L24-L28

[14] Ruffini R et al. (2015) GRB 130427A and SN 2013cq: A Multi-wavelength Analysis of an Induced Gravitational Collapse Event *Astrophys. J.*, **798**, 10-20

[15] GCN 18213 https://gcn.gsfc.nasa.gov/gcn3/18213.gcn3