IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10107-4

Supernovae shedding light on gamma-ray bursts(*) (**)

M. Della Valle
INAF-Arcetri Astrophysical Observatory - Largo E. Fermi 5, Firenze (Italy)

(ricevuto il 23 Maggio 2005; pubblicato online il 27 Ottobre 2005)

Summary. — We review the observational status of the Supernova (SN)/Gamma-Ray Burst (GRB) connection. We review the circumstantial evidences and the direct observations that support the existence of a deep connection between the death of massive stars and GRBs. The present data suggest that SNe associated with GRBs form a heterogeneous class of objects including both bright and faint Hypernovae and perhaps also "standard" Ib/c events. We provide an empirical estimate of the rate of Hypernovae, for a "MilkyWay-like" galaxy, of about $\sim 2.6 \times 10^{-4}$ yr^{-1} that may imply the ratio GRB/Hypernovae to be in the range $\sim 0.03 - 0.7$. In the same framework we find the ratio GRB/SNe-Ibc to be $\sim 0.008 \div 0.05$. We discuss the possible existence of a lag between the SN explosion and the associated gamma-ray event. In the few SN/GRB associations so far discovered the SN explosions and GRB events appear to go off simultaneously. Finally we present the conclusions and highlight the open problems that Swift hopefully will allow us to solve.

PACS `97.60` – Supernovae.
PACS `98.70` – γ-ray sources; γ-ray bursts.
PACS `01.30.Cc` – Conference proceedings.

1. – Introduction

Gamma Ray Bursts are sudden and powerful flashes of gamma-ray radiation that occur randomly in the sky at the rate of about one per day (as observed by the BATSE instrument). The distribution of the durations at MeV energies ranges from $T \simeq 10^{-3}$ s to about 10^3 s and is clearly bimodal [61, 26, 62], with "long" bursts characterized by $T > 2$ s. In the original discovery paper, [60] pointed out the lack of evidence for a connection between GRBs and Supernovae (SNe), as proposed by [19], but they concluded that "...the lack of correlation between gamma-ray bursts and reported supernovae does not conclusively argue against such an association...". This point remained a

---

(*) Paper presented at the "4th Workshop on Gamma-Ray Burst in the Afterglow Era", Rome, October 18-22, 2004.
(**) An extended version is available at astro-ph/0504517.

© Società Italiana di Fisica

TABLE I. – *SN 1998bw.*

$E_K(10^{52})$erg	^{56}Ni$(M_\odot)$	$M_{core}(M_\odot)$	$M_{MS}(M_\odot)$	$M_{left}(M_\odot)$	Ref.
2	0.7	12-15	40	~ 2.9	[56]
2	0.45	6-11	25-35	~ 2	[125]
0.7-5	0.4	14	40	~ 3	[88]

mystery for almost three decades and only at the end of the 1990s the discovery of GRB afterglows [20, 116, 37] at cosmological distances [85] and the discovery of SN 1998bw in the error-box of GRB 980425 [43] have started shedding light upon the nature of GRB progenitors.

2. – The SN/GRB connection: circumstantial evidences

Before 2003 the existence of a connection between SNe and long duration GRBs was supported by several lines of evidence, even if none of them was really conclusive.

1) SN 1998bw was the first SN discovered spatially and temporally coincident with a GRB (GRB 980425; [43]). Unexpectedly, SN 1998bw was discovered not at cosmological distances, but in the nearby galaxy ESO 184-G82 at $z = 0.0085$. This implied that GRB 980425 was underenegetic by 4 orders of magnitudes with respect to typical "cosmological GRBs". Moreover, the absence of a conspicuous GRB afterglow contrasted with the associated SN, which was extremely energetic, had expansion velocities a factor 3-4 higher than those of normal Ib/c SNe and was characterized by a peak luminosity of $\sim 10^{43}\,\mathrm{erg\,s^{-1}}$ (for a distance to SN 1998bw of $\sim$ 40 Mpc). This is about 10 times brighter than typical SNe Ib/Ic [17], therefore suggesting that a large amount of ^{56}Ni must have been synthesized in the SN explosion [56, 125, 89]. The theoretical modeling of the light curve and spectra suggests that SN 1998bw can be well reproduced by an extremely energetic explosion of an envelope-stripped star, with a C+O core of about $\sim 10M_\odot$, which originally was $\sim 40M_\odot$ on the main sequence (see table I). This picture is consistent with the radio properties of SN 1998bw, which can be explained as due to the interaction of a mildly relativistic ($\Gamma \sim 1.6$) shock with a dense circumstellar medium [64, 111, 123] due to a massive progenitors that has entirely lost its H envelope.

Höflich *et al.* [55] presented an alternative picture based on the hypothesis that all SNe-Ic are the results of a spherical explosions. In this case the apparent luminosity of the SN may vary up to 2 mag, according to different combinations of the geometry of the explosion and line of sight of the observer. This result can explain the high luminosity at maximum of SN 1998bw, without calling for a dramatic overproduction of ^{56}Ni (~ 0.2 $M_\odot$ ^{56}Ni) and would allow SN 1998bw to have an explosion energy ($\sim 2\times10^{51}$ erg) similar to that of "normal" core-collapse supernovae. Maeda *et al.* [74], after analyzing the line profiles in late time spectra of SN 1998bw, also give some support to the idea that SN 1998bw was the product of an asymmetric explosion viewed from near the jet direction (yet characterized by high kinetic energy, of $\sim 10^{52}$ erg). The idea that Hypernovae and more generally SNe-Ib/c can be produced by asymmetric explosions is supported by polarimetry observations of core-collapse SNe (*e.g.*, [120, 68]), which seem to indicate that the degree of polarization increases along the SN-type sequence: II→ Ib→ Ic (*i.e.* with decreasing the envelope mass).

However, the association between two peculiar astrophysical objects such as GRB

980425 (very faint gamma-ray emission, unusual afterglow properties) and SN 1998bw (over luminous SN characterized by unusual spectroscopic features) was believed to be only suggestive, rather than representative, of the existence of a general SN/GRB connection.

2) The light curves of many afterglows show rebrightenings that have been interpreted as emerging supernovae outshining the afterglow several days or weeks after the GRB event ([7, 127], and references therein). However, since other explanations such as dust echoes [29] or thermal re-emission of the afterglow light [121] could not be ruled out, only spectroscopic observations during the rebrightening phase could remove the ambiguity. Indeed spectroscopic features of SNe are unique, being characterized by FWHM ~ 100 Å (see sect.**4**).

3) The detection of star–formation features in the host galaxies of GRBs [27, 39] has independently corroborated the existence of a link with the death of massive stars. For example, [16] have found that GRB hosts are galaxies with a fairly high (relative to the local Universe) star formation of the order of 10 $M_{\odot}$ yr$^{-1}/L^{\star}$ (see also [67]). Also the location of GRBs within their host galaxies seems consistent with the regions that contain massive stars [8].

4) Some GRB afterglows have shown absorption features at velocities of a few $\times 10^3$ km/s that has been interpreted as the result of the interaction with the stellar winds originating from the massive progenitors [15, 86].

3. – SN 2002lt/GRB 021211

One of the first opportunities to carry out spectroscopic observations during a GRB afterglow rebrightening arrived in late 2002. GRB 021211 was detected by the HETE–2 satellite [22], allowing the localization of its optical afterglow [36] and the measurement of the redshift $z = 1.006$ [118]. rebrightening is apparent in its light curve, starting ~ 15 days after the burst and reaching the maximum ($R \sim 24.5$) during the first week of January. For comparison, the host galaxy has a magnitude $R = 25.22 \pm 0.10$, as measured in late-time images. A spectrum of the afterglow + host was obtained with FORS 2, 27 days after the GRB, during the rebrightening phase. This spectrum is characterized by broad low-amplitude undulations blueward and redward of a broad absorption, the minimum of which is measured at ~ 3770 Å (in the rest frame of the GRB), whereas its blue wing extends up to ~ 3650 Å. The comparison with the spectra of SN 1994I, and to some extent also of SN 1991bg and SN 1984L (fig. 2 in [24]) supports the identification of the broad absorption with a blend of the Ca II H and K absorption lines. The blueshifts corresponding to the minimum of the absorption and to the edge of the blue wing imply velocities $v \sim 14\,400$ km/s and $v \sim 23\,000$ km/s, respectively. The exact epoch when the SN exploded depends crucially on its rising time to maximum light. SN 1999ex, SN 1998bw and SN 1994I (the best documented examples of type-Ic SNe) reached their B-band maximum ~ 18, 16 and 12 days after the explosion [52]. A model (based on the light curve of SN 1994I, corrected for cosmological effects and reddening) reproduces well the shape of the observed light curve. A null time delay between the GRB and the SN explosions is required by our photometric data, even if a delay of a few days would also be acceptable given the uncertainties in the measurements. It is interesting to note that SN 1994I, the spectrum of which provides the best match to the observations, is a typical type-Ic event rather than a bright *Hypernova* as the ones proposed for association with other long duration GRBs [43, 109, 54, 75].

4. – The "Smoking Gun": GRB 030329/SN 2003dh

The peculiarity of the SN 1998bw/GRB 980425 association and the objective difficulties to collect data for SN 2002lt (4 h at VLT to get one single spectrum) prevented us from generalizing the existence of a SN/GRB connection, although both cases were clearly suggestive. The breakthrough in the study of the GRB/SN association arrived with the bright GRB 030329. This burst, also discovered by the HETE–2 satellite, was found at a redshift $z = 0.1685$ [49], relatively nearby, therefore allowing detailed photometric and spectroscopic studies. SN features were detected in the spectra of the afterglow by several groups [109, 54, 58, 78] and the associated SN (SN 2003dh) looked strikingly similar to SN 1998bw. The gamma-ray and afterglow properties of this GRB were not unusual among GRBs, and therefore, the link between GRBs and SNe was eventually established to be general, so that, it applies to all "classical" and "long" cosmological GRBs.

The modeling of the early spectra of SN 2003dh [82] has shown that SN 2003dh had a high explosion kinetic energy, $\sim 4 \times 10^{52}$ erg (if spherical symmetry is assumed). However, the light curve derived from fitting the spectra suggests that SN 2003dh was not as bright as SN 1998bw, ejecting only $\sim 0.35\ M_\odot$ of ^{56}Ni. The progenitor was a massive envelope-stripped star of $\sim 35 - 40 M_\odot$ on the main sequence [82]. The spectral analysis of the nebular-phase emission lines carried out by [63] suggests that the explosion of the progenitor of the GRB 030329 was aspherical, and that the axis is well aligned with both the GRB relativistic jet and our line of sight.

5. – GRB 031203/SN 2003lw: the older brother of GRB 980425/SN 1998bw

GRB 031203 was a 30 s burst detected by the INTEGRAL burst alert system [84] on 2003 Dec 3. At $z = 0.1055$ [98], it was the second closest burst after GRB 980425. The burst energy was extremely low, of the order of 10^{49} erg, well below the "standard" reservoir $\sim 10^{51}$ erg of normal GRBs [38, 91]. Only GRB 980425 and XRF 020903 were less energetic. In this case, a very faint NIR afterglow could be discovered, orders of magnitude dimmer than usual GRB afterglows [75]. A few days after the GRB, a rebrightening was apparent in all optical bands [5, 112, 18, 42]. The rebrightening amounted to $\sim 30\%$ of the total flux (which is dominated by the host galaxy), and was coincident with the center of the host galaxy to within $0.1''$ (~ 200 pc). Even after correcting for cosmological time dilation, the light curve of SN 2003lw is broader than that of SN 1998bw, and the latter requires an additional stretching factor of ≈ 1.1 to match the R and I data points. The R-band maximum was reached in ~ 18 (comoving) days after the GRB. After assuming a light curve shape similar to SN 1998bw, which had a rise time of 16 days in the V band, data suggest an explosion time nearly simultaneous with the GRB. A precise determination of the absolute magnitude of the SN is made difficult by the uncertain extinction. Based on the ratios of the Balmer lines of the host galaxy, the average combined Galactic and host extinction is $E_{B-V} \approx 1.1$. Given the good spatial coincidence of the SN with the center of the host, such value is a good estimate for the SN extinction. With the assumed reddening, SN 2003lw appears to be brighter than SN 1998bw by 0.5 mag in the V, R, and I bands. The absolute magnitudes of SN 2003lw are hence $M_V = -19.75 \pm 0.15$, $M_R = -19.9 \pm 0.08$, and $M_I = -19.80 \pm 0.12$. The spectra of SN 2003lw are remarkably similar to those of SN 1998bw obtained at comparable epochs (see [75] for details). Both SNe show very broad absorption features, indicating high expansion velocities. This makes SN 2003lw another example of Hypernova. A preliminary analysis of early spectra of 2003lw (Mazzali *et al.* 2005, in preparation) indicates that

Table II. – *Hypernovae.*

SN	cz (km/s)	Ref.	SN	cz (km/s)	Ref.
1997dq	958	[83]	2003bg	1320	[32]
1997ef	3539	[30]	2003dh	46000	[109, 54]
1998bw	2550	[43]	2003jd	5635	[33, 79]
1999as	36000	[53]	2003lw	30000	[75]
2002ap	632	[81, 35]	2004bu	5549	[34]
2002bl	4757	[31]			

this Hypernova produced a large amount of Ni, possibly in the range $0.6 - 0.9 M_{\odot}$. The progenitor mass could be as large as 40–50 $M_{\odot}$ on the main sequence.

6. – Rates of SNe Ib/c, Hypernovae and GRBs

The measurement of the SN rate is based on the control-time methodology [128] that implies the systematic monitoring of galaxies of known distances and the use of appropriate templates for the light curves of each SN type (see [13] for bias and uncertainties connected with this procedure). Unfortunately all Hypernovae reported in table II have been not discovered during time "controlled" surveys, and therefore any attempt to derive an absolute value of the rate of Hypernovae should be taken with great caution. One possibility is to compute the frequency of occurrence of all SNe-Ib/c and Hypernovae in a limited distance sample of objects. From the Asiago catalog (`http://web.pd.astro.it/supern`) we have extracted 91 SNe-Ib/c, 8 of which are Hypernovae, with $cz < 6000$ km/s. This velocity threshold is suitable to make the distance distribution of "normal" Ib/c and Hypernovae statistically indistinguishable (KS probability = 0.42). After assuming that the host galaxies of both "normal" SNe Ib/c and Hypernovae have been efficiently (or inefficiently) monitored by the same extent, one can infer that the fraction of Hypernovae is about $7/91 \simeq 8\%$ (after excluding SN 1998bw because it was searched in the error-box of GRB 980425) of the total number of SNe Ib/c. Since Hypernovae can be brighter than normal SNe-Ib/c, their discovery may be favored, therefore 8% should be regarded as an upper limit for their frequency of occurrence. For a "Milky-Way–like" galaxy (*i.e.* $L_B = 2.3 \times 10^{10} L_{B_{\odot}}$; $M = 9.5 \times 10^{10} M_{\odot}$; and morphological Hubble type Sbc, data from [21]) we obtain a rate of type Ib/c SNe of $\sim 3.2 \times 10^{-3}$ yr^{-1} (after assuming a rate of 0.14 SNe per century and per 10^{10} $L_{B,\odot}$; [14]), and therefore the Hypernova rate turns out to be $\sim 2.6 \times 10^{-4}$ yr^{-1}. This rate has to be compared with the rate of GRBs in the Milky Way. This quantity can be estimated by combining the local rate of 0.5 GRB event Gpc^{-3} yr^{-1} [105], the local density of B luminosity of $\sim 1.2 \times 10^8 L_{B,\odot}$ per Mpc^3 (*e.g.*, [73]) and the B luminosity of the Milky Way ($2.3 \times 10^{10} L_{B_{\odot}}$). This approach gives $R_{GRB} \sim 3.8 \times 10^{-7}$ yr^{-1} that has to be rescaled for the beaming factor f_b^{-1}. There exist different estimates for this parameter: from ~ 500 [38] to ~ 75 [51, 93]. These figures implies that the ratio GRB/Hypernovae spans the range $\sim 0.7 \div 0.11$. Following [76], who provide the SN rates normalized to the mass in stars of the host galaxies, the same kind of computation yields a ratio GRB/Hypernovae of $\sim 0.20 \div 0.03$. These data as a whole do not support a ratio GRB/Hypernova = 1, unless to assume large values of f_b^{-1} (*e.g.*, [38, 126]). A piece of evidence in this direction comes from observations of the radio properties exhibited by SN 2002ap [3] that do not

Table III. – *Supernova-Gamma Ray Burst time lag. A negative time lag indicates that the SN explosion precedes the GRB.*

GRB	SN	$+\Delta t$(days)	$-\Delta t$(days)	Ref.
GRB 980425	1998bw	0.7	–2	[56]
GRB 000911	bump	1.5	–7	[66]
GRB 011121	2001ke	0	–5	[9]
		–	a few	[44]
GRB 021211	2002lt	1.5	–3	[24]
GRB 030329	2003dh	2	–8	[58]
		–	–2	[79]
GRB 031203	2003lw	0	–2	[75]

support the association of this Hypernova with a GRB. For $f_b^{-1} \sim 50 - 100$ [50, 93] the ratio GRB/Hypernova should be of the order of ~ 0.1 (or even less). Incidentally we note that the ratio GRBs/SNe-Ibc $\sim 0.05 \div 0.008$ (which can be obtained from the rates reported above) is consistent with the results independently obtained by [4] (see also [108]), who derived, from radio observations of 33 "local" SNe-Ib/c, an incidence of 1998bw-like events over the total number of SNe-Ibc of < 0.03 (see also [48]).

7. – SN-GRB time lag

Several authors have reported the detection of Fe and other metal lines in GRB X-ray afterglows (*e.g.*, [92,1,101]). If valid (see [104] for a critical view) these observations would have broad implications for both GRB emission models and would strongly link GRBs with SN explosions. For example, [11] have reported the detection in a Chandra spectrum of emission lines whose intensity and blueshift would imply that a supernova occurred > 2 months prior to the γ event. This kind of observations can be accommodated in the framework of the *supranova* model [117], where a SN is predicted to explode months or years before the γ burst. In Table III we have reported the estimates of the lags between the SN explosions and the associated GRBs, as measured by the authors of the papers. After taking the data of table III at their face value, it is apparent that the SNe and the associated GRBs occur simultaneously, providing support to the *collapsar* scenario [124, 90, 72]. Data in table III provide useful constraints to those models that predict the SNe to occur before [117] or after [103] the gamma-ray event.

8. – . . . There is an Expanding Frontier of Ignorance . . . (R. Feynman, *Six Easy Pieces*)

Data presented in previous sections provide robust empirical grounds to the idea that some types of core-collapse SNe are the progenitors of long-duration GRBs (see also [80, 110]). On the other hand, the existence of SN/GRB associations (see also [57]) poses intriguing questions which have not yet been answered.

1) *What kind of SNe are connected with long-duration GRBs and XRFs?*

Evidence based on the associations between SN 1998bw/GRB 980425, SN 2003dh/GRB 030329, and SN 2003lw/GRB 031203 would suggest that the parent SN population of GRBs is formed by the bright tail of Hypernovae. However, there is growing evidence that other types of SNe-Ib/c, such as 'standard' *Ic* events like SN 1994I or faint Hypernovae can contribute to produce GRBs/XRFs [24, 41, 113, 69, 77, 96, 97, 108, 47]. Available data suggest the existence of ~ 5 mag spread ($M_V \sim -16 \div -21$) in the absolute magnitudes at maximum of SNe-Ib/c associated with GRBs/XRFs, which may be similar to the magnitude spread exhibited by local SNe-Ib/c (see fig. 11 in [108]).

Possible associations between GRBs and other types of core-collapse SNe (particularly with type IIn) have been claimed in the past on the basis of spatial and temporal SN/GRB coincidences by [46] and [114] (SN 1997cy/GRB 970514) and by [102] (SN 1999E/GRB 980910). However, in a recent study, [115] were not able to confirm these associations to be statistically significant (see also [119, 59]). Currently the best evidence for the case of an association between a Supernova IIn and a gamma ray burst has been provided by [44] who find that the color evolution of the bump associated with GRB 011121 is consistent with the color evolution of an underlying SN (dubbed as SN 2001ke) strongly interacting with a dense circumstellar gas due to the progenitor wind (as confirmed by radio observations, see [95]).

2) *What are the most frequent gamma-ray events in the Universe?*

GRB 031203 was quite similar to GRB 980425, albeit more powerful. Both events consisted in a single, under-energetic pulse. Their afterglows were very faint or absent in the optical, and showed a very slow decline in the X-rays. Moreover, they were both accompanied by a powerful Hypernova. Therefore, GRB 980425 can no longer be considered as a peculiar, atypical case. Both bursts were so faint, that they would have been easily missed at cosmological distances. Since the volume they sample is $10^5 \div 10^6$ times smaller than that probed by classical distant GRBs, the rate of these events could be dramatically larger, perhaps they are the most common GRBs in the Universe. However, we are still left with the question of whether or not these bursts belong to a different local population of γ-bursts [6, 106] or they are typical cosmological bursts observed off-axis ([87, 28, 125, 100]; see also [122] for a *pro* and *con* discussion). Naively one may expect that the spectroscopic and photometric similarities exhibited by SNe 1998bw, 2003dh and 2003lw may indicate a common origin for the associated GRBs, in spite of the fact that they have exhibited dramatic differences in their γ-energy budgets and in the properties of their afterglows. We note that this inference is supported by statistical arguments provided by [50].

3) *What is the relationship between the SN magnitudes at maximum light and the gamma-ray energy budget?*

Simple statistical analysis of available data points shows that the absolute magnitude at maximum of SNe associated with GRBs does not appear to correlate with the respective gamma energy (although this conclusion should be taken with caution because of the usage of scanty statistic). The distribution of the data points reflects an obvious bias, namely the detection of over-bright SNe is favored because most GRBs are discovered at cosmological distances and/or their bright afterglows can easily outshine “standard” SNe-Ib/c or faint Hypernovae. However it is not clear if the lack of faint SNe associated with intrinsically faint (and nearby) GRBs is the result of an exiguous statistic or this finding has a deeper physical meaning.

4) *May it be that GRBs, which occur in the inner and outer regions of hosts, have different progenitors?*

Ramirez-Ruiz *et al.* [99] found some evidence that outer bursts appear to have systematically greater isotropic equivalent energies (or narrower jets). These results may be interpreted in terms of different environmental properties, between inner and outer regions of the hosts (*e.g.*, metallicity, fraction of binary systems), which can affect the evolution of the progenitors of core-collapse SNe (see [10] for a discussion).

5) *Are the "red bumps" always representative of the signatures of incipient SNe?*

Or can some of them be produced by different phenomena such as dust echoes [29] or thermal re-emission of the afterglow light [121]. To date, only for GRB 021211/SN 2002lt [24] and XRF 020903 [108] a spectroscopic confirmation was obtained. On the other hand, [44,41] did not find SN (spectroscopic) features in the bumps of GRB 011121 and XRF 030723 (see [12] for an alternative interpretation of the bump discovered in XRF 030723).

6) *Is the lack of an optical bump indicative of the lack of a supernova?*

The authors of [97, 70, 108] have carried out unsuccessful HST searches for SN signatures in GRBs/XRFs light curves. For example [108] were able to set a firm upper limit to the magnitude of the SN associated with XRF 040701, of $M_V \lesssim -16.2$. This behaviour can be explained in a number of ways: i) the SN parent population of GRBs/XRFs is formed by a heterogeneous class of objects that span (at maximum light) a broad range of luminosities (about a factor 100); ii) some "long" GRBs may originate by merging compact objects (*e.g.*, [2, 25]) rather than in SN explosions; iii) sometimes SN and GRB do not occur simultaneously (*e.g.*, [117]). For a delay of a few weeks/months, the supernova would have faded before the GRB was detected, and this may explain why supernovae are not discovered after every GRB. Finally we note that the light curve of the afterglow of GRB 030329 (associated with SN 2003dh) did not show the bump which is believed to be caused by the emerging SN [78, 71].

7) *What causes some small fraction of SNe Ib/c to produce observable GRBs, while the majority do not?*

With the obvious exceptions of SN 1998bw, 2003dh and 2003lw, none of the Hypernovae reported in table II have been associated with GRBs by direct observations (the association GRB 971115/SN 1997ef, for example, has been proposed by [119] on the basis of spatial and temporal coincidences). The situation is even more intriguing if one considers that Hypernovae are only a small fraction of "normal" SNe-Ibc (less than 10%) and thus only a very tiny fraction of SNe-Ib/c, about $0.8\% \div 5\%$, seems to be able to produce GRBs. This may imply that the evolution leading a star to produce a GRB requires very special circumstances (*e.g.*, rotation, binary interaction; see [94, 40]) other than being "only" a very massive star. As an alternative, one can argue that most SNe Ib/c (if not all of them) produce GRBs [65]. This fact would imply very small jet opening angles (~ 1 degree) and therefore one should be able to detect as GRBs only those events which are viewed at very small angles relative to the jet direction. More spherically symmetric jets or events viewed from angles (relative to the jet direction) which are larger than the typical viewing angles of long-duration GRBs, should yield XRFs (see also [23]). Finally, at even larger angles, relative to the jet direction, one should observe 'only' the SN(Ib/c) explosions. With a rate of discovery of about 2 event/week, the *Swift* satellite [45]) will allow the GRB community to obtain in the next $3 \div 4$ years an accurate spectroscopic classification for dozens SNe associated with GRBs and to provide conclusive answers to several of the above questions.

* * *

It is a pleasure to thank N. Panagia and D. Malesani for their useful comments and the critical reading of the manuscript. I am also indebted to S. Benetti, G. Chincarini, F. Frontera, N. Gehrels, K. Hurley, P. Mazzali, L. Stella, G. Tagliaferri and V. Trimble for suggestions and illuminating discussions and to M. Hamuy, K. Stanek, A. Levan, J. Fynbo and F. Patat to have made available their plots.

REFERENCES

[1] Antonelli L. A. *et al.*, *ApJ*, **545** (2000) L39.
[2] Belczynski K., Bulik T. and Rudak B., *ApJ*, **571** (2002) 394.
[3] Berger E., Kulkarni S. R., and Chevalier R. A., *ApJ*, **577** (2002) L5.
[4] Berger E., Kulkarni S. R., Frail D. A., Soderberg A. M., *ApJ*, **599** (2003) 408.
[5] Bersier D. *et al.*, *GCN Circ.*, **2544** (2004) .
[6] Bloom J. S. *et al.*, *ApJ*, **506** (1998) L105.
[7] Bloom J. S. *et al.*, *Nature*, **401** (1999) 453.
[8] Bloom J. S., Kulkarni S. R. and Djorgovski S. G., *AJ*, **123** (2002a) 1111.
[9] Bloom J. S. *et al.*, *ApJ*, **572** (2002b) L45.
[10] Bressan A., Della Valle M. and Marziani P., *MNRAS*, **331** (2002) L25.
[11] Butler N. R. *et al.*, *ApJ*, **597** (2003) 1010.
[12] Butler N. R. *et al.*, *ApJ*, **621** (2005) 884, astro-ph/0408453.
[13] Cappellaro E. *et al.*, *A&A*, **268** (1993) 472.
[14] Cappellaro E., Evans R. and Turatto M., *A&A*, **351** (1999) 459.
[15] Chevalier R. A. and Li Z., *ApJ*, **536** (2000) 195.
[16] Christensen L., Hjorth J. and Gorosabel J., *A&A*, **425** (2004) 913.
[17] Clocchiatti A. and Wheeler J. C., *ApJ*, **491** (1997) 375.
[18] Cobb B. E. *et al.*, *ApJ*, **608** (2004) L93.
[19] Colgate S., *Can. J. Phys.*, **46** (1968) 476.
[20] Costa E. *et al.*, *Nature*, **387** (1997) 783.
[21] Cox A.N., in *Allen's Astrophysical Quantities*, 4th ed. (AIP, New York; Springer) 2000.
[22] Crew G. B., *et al. ApJ*, **599** (2003) 387.
[23] Dado S., Dar A. and De Rjula A., *A&A*, **422** (2004) 381.
[24] Della Valle M. *et al.*, *A&A*, **406** (2003) L33.
[25] Della Valle M., Marziani P. and Panagia N., these proceedings (2005).
[26] Dezalay J.P. *et al.*, *GRB Workshop*, edited by W. S. Pociesas and G. J. Fishman, *AIP Conf. Proc*, **265** (1992) 304.
[27] Djorgovski S. G. *et al.*, *ApJ*, **508** (1998) L17.
[28] Eichler D. and Levinson A., *ApJ*, **521** () L117.
[29] Esin A. and Blandford R., 2000, *ApJ*, **534** (1999) L151.
[30] Filippenko A. V., *IAUC*, **n. 6783** (1997) .
[31] Filippenko A. V., Leonard D. C. and Moran E. C., *IAUC*, **n. 7845** (2002) .
[32] Filippenko A. V. and Chornock R., *IAUC*, **n. 8084** (2003a) .
[33] Filippenko A. V., Foley R.T. and Swift B., *IAUC*, **n. 8234** (2003b) .
[34] Foley R. J., Wong D. S., Moore M. and Filippenko A. V., *IAUC*, **n. 8353** (2004) .
[35] Foley R.J. *et al.*, *PASP*, **115** (2003) 1220.
[36] Fox D. W. *et al.*, *ApJ*, **586** (2003) L5.
[37] Frail D. A. *et al.*, *Nature*, **389** (1997) 261.
[38] Frail D. A. *et al.*, *ApJ*, **562** (2001) L55.
[39] Fruchter A. S. *et al.*, *ApJ*, **519** (1999) L13.
[40] Fryer C. L. and Heger A., *ApJ*, **623** (2005) 302, astro-ph/041224.
[41] Fynbo J. *et al.*, *ApJ*, **609** (2004) 962.
[42] Gal-Yam A. *et al.*, *ApJ*, **609** (2004) L59.
[43] Galama T. J. *et al.*, *Nature*, **395** (1998) 670.
[44] Garnavich P. M. *et al.*, *ApJ*, **582** (2003) 924.
[45] Gehrels N. *et al.*, *ApJ*, **611** (2004) 1005.
[46] Germany L., Reiss D. J., Sadler E.M., Schmidt B.P. and Stubbs C. W., *ApJ*, **533** (2000) 320.
[47] Gorosabel J. *et al.*, *A&A*, **437** (2005) 411, astro-ph/0504050.
[48] Granot J. and Ramirez-Ruiz E., *ApJ*, **609** (2004) L9.
[49] Greiner *et al.*, *GCN*, **2020** (2003) .
[50] Guetta D., Perna R., Stella L. and Vietri M., *ApJ*, **615** (2004) L73.
[51] Guetta D., Piran T. and Waxman E., *ApJ*, **619** (2005) 412.

[52] Hamuy M., in *Core Collapse of Massive Stars*, edited by C. L. Fryer (Kluwer, Dordrecht) 2003 (astro-ph/0301006).
[53] Hatano K. *et al.*, *198th BAAS*, **33** (2001) p. 838.
[54] Hjorth J. *et al.*, *Nature*, **423** (2003) 847.
[55] Höflich P., Wheeler J. C. and Wang L., *ApJ*, **521** (1999) 179.
[56] Iwamoto K. *et al.*, *Nature*, **395** (1998) 672.
[57] Katz J. I., *ApJ*, **432** (1994) L27.
[58] Kawabata K. S. *et al.*, *ApJ*, **593** (2003) L19.
[59] Kippen R. M. *et al.*, *ApJ*, **506** (1998) L27.
[60] Klebesadel R. W., Strong I. B. and Olson R. A., *ApJ*, **182** (1973) L85.
[61] Klebesadel R. W., in *Los Alamos Workshop on GRBs*, edited by Cheng H., Richard I. Epstein, Edward E. Fenimore (Cambridge University Press) 1992, p. 161.
[62] Kouveliotou C. *et al.*, *ApJ*, **413** (1993) L101.
[63] Kosugi G. *et al.*, *PASJ*, **56** (2004) 61.
[64] Kulkarni S. R. *et al.*, *Nature*, **395** (1998) 663.
[65] Lamb D. Q., Donaghy T. Q., and Graziani C., *ApJ*, **620** (2005) 355.
[66] Lazzati D., *et al. A&A*, **378** (2001) 996.
[67] Le Floc'h E., *et al. A&A*, **400** (2003) 499.
[68] Leonard D. C., Filippenko A. V., Barth A. J. and Matheson T., *ApJ*, **536** (2000) 239.
[69] Levan A. *et al.*, *ApJ*, **624** (2005a) 880, astro-ph/0403450.
[70] Levan A. *et al.*, *ApJ*, **622** (2005b) 977.
[71] Lipkin Y. M. *et al.*, *ApJ*, **606** (2004) 381.
[72] MacFadyen A. I., Woosley, S.E. *ApJ*, **524** (1999) 262.
[73] Madau P., Della Valle M. and Panagia N., *MNRAS*, **297** (1998) L17.
[74] Maeda K. *et al.*, *ApJ*, **565** (2002) 405.
[75] Malesani D. *et al.*, *ApJ*, **609** (2004) L5.
[76] Mannucci F. *et al.*, *A&A*, **433** (2005) 807.
[77] Masetti N. *et al.*, *A&A*, **404** (2003) 465.
[78] Matheson T. *et al.*, *ApJ*, **599** (2003a) 394.
[79] Matheson T., Challis P. and Kirshner R., *IAUC*, **n. 8234** (2003b) .
[80] Matheson T., in *Proceedings of "Supernovae as Cosmological Lighthouses", Padua, 2004, ASP Conf. Ser.* astro-ph/0410668.
[81] Mazzali P. *et al.*, *ApJ*, **572** (2002) L61.
[82] Mazzali P. *et al.*, *ApJ*, **599** (2003) L95.
[83] Mazzali P. *et al.*, *ApJ*, **614** (2004) 858.
[84] Mereghetti S. and Götz D., *GCN Circ.*, **2460** (2003) .
[85] Metzger M. R. *et al.*, *Nature*, **387** (1997) 878.
[86] Mirabal, N. *et al.*, *ApJ*, **595** (2003) 935.
[87] Nakamura T., *ApJ*, **522** (1999) L101.
[88] Nakamura T., Mazzali P., Nomoto K. and Iwamoto, K., *ApJ*, **550** (2001) 991.
[89] Nomoto K. *et al.*, 2001 in *"Supernovae and gamma-ray bursts: the greatest explosions since the Big Bang",* edited by M. Livio, N. Panagia, and K. Sahu, *STScI Symp. Ser.*, **13** (1999) 144.
[90] Paczyňski B., *ApJ*, **494** (1998) L45.
[91] Panaitescu A. and Kumar, P., *ApJ*, **560** (2001) L49.
[92] Piro L. *et al.*, *ApJ*, **514** (1999) L73.
[93] Piran T., these proceedings (2005).
[94] Podsiadlowski P. *et al.*, *ApJ*, **607** (2004) L17.
[95] Price P. A., *et al.* 2002 *ApJ*, **572** (L51) .
[96] Price P. A., *et al. ApJ*, **589** (2003a) 838.
[97] Price P. A., *et al. ApJ*, **584** (2003b) 931.
[98] Prochaska J. X., *et al. ApJ*, **611** (2004) 200.
[99] Ramirez-Ruiz E., Lazzati D. and Blain A. W., *ApJ*, **565** (2002) L9.
[100] Ramirez-Ruiz E. *et al.*,*ApJ*, **625** (2005) L91, astro-ph/0412145.

[101] Reeves J. N. *et al.*, *Nature*, **416** (2002) 512.
[102] Rigon L. *et al.*, *MNRAS*, **340** (2003) 191.
[103] Ruffini R., Bianco C. L., Fraschetti F., Xue S. and Chardonnet P., *ApJ*, **555** (2001) L117.
[104] Sako M., Harrison F. and Rutledge R., *ApJ*, **623** (2005) 973, astro-ph/0406210.
[105] Schmidt M., *ApJ*, **552** (2001) 36.
[106] Soderberg A. M., Frail D. A. and Wieringa M. H., *ApJ*, **607** (2004) L13.
[107] Soderberg A. M., these proceedings (2005) .
[108] Soderberg A. M. *et al.*,, *ApJ*, **627** (2005) 877, astro-ph/0502553.
[109] Stanek K. Z. *et al.*, *ApJ*, **591** (2003) L17.
[110] Stanek K. Z. *et al.*, *ApJL*, **626** (2005) L5, astro-ph/0502319.
[111] Tan J. C., Matzner C. D., and McKee C. F., *ApJ*, **551** (2001) 946.
[112] Thomsen B. *et al.*, *A&A*, **419** (2004) L21.
[113] Tominaga N. *et al.*, *ApJ*, **612** (2004) L.105.
[114] Turatto M. *et al.*, , **534** (2000) L57.
[115] Valenti S. *et al.*, these proceedings (2005).
[116] van Paradijs J. *et al.*, *Nature*, **386** (1997) 686.
[117] Vietri M. and Stella L., *ApJ*, **507** (1998) L45.
[118] Vreeswijk P. M., Fruchter A., Hjorth J. and Kouveliotou C., *GCN Circ.*, **1785** (2002) .
[119] Wang L. and Wheeler J. C., *ApJ*, **504** (1998) L87.
[120] Wang L., Howell D. A., Höflich P. and Wheeler J. C., *ApJ*, **550** (2001) 1030.
[121] Waxman E. and Draine B. T., *ApJ*, **537** (2000) 796.
[122] Waxman E., *ApJ*, **602** (2004) 886.
[123] Weiler K. W., Panagia N., Montes M. J. and Sramek R. A., *ARA&A*, **40** (2002) 387.
[124] Woosley S., *ApJ*, **405** (1993) 273.
[125] Woosley S. E., Eastman R. G. and Schmidt B. P., *ApJ*, **516** (1999) 788.
[126] Yonetoku D., Yamazaki R., Nakamura T. and Murakami T., *MNRAS*, **362** (2005) 1114, astro-ph/0503254.
[127] Zeh A., Klose S. and Hartmann D. H., *ApJ*, **609** (2004) 952.
[128] Zwicky F., *ApJ*, **88** (1938) 529.