Supernovae

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1.1. ICRANet participants

- Massimo Della Valle

1.2. Past collaborators

- Nino Panagia (STScI, Baltimore)
- Piero Madau (Santa Cruz, California University)
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- Robert Williams (STScI, Baltimore)

1.3. Ongoing collaborations

- Nino Panagia (STScI, Baltimore)
- Guido Chincarini (Bicocca University, Milano) and the SWIFT team

- Francesca Matteucci (Trieste University, Trieste)
- Filippo Mannucci (INAF-Arcetri, Firenze)
- Daniele Malesani (DARK-Centre, Niels Bohr Institute, Copenhagen)
- Roberto Gilmozzi (ESO, Garching, Munchen)
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- Dani Maoz (Tel-Aviv University)
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1.4. Sabatical Visits, 2005-2007

- European Southern Observatory, Munchen (2005)
- STScI, Baltimore, (2005)
- KAVLI Institute, Santa Barbara (2006, 2007)
- Tokyo University (2006)
- Dark Cosmology Center, Niels Bohr Institute, Copenhagen (2007)
- Queen's University, Belfast (2007)
- European Southern Observatory, Munchen (2008-2009)

2. Brief description

My ongoing research concern the study of several classes of transient phenomena such as: supernovae, gamma-ray bursts and novae .

Gamma-ray bursts and their Afterglows. My interest in this area started in 2000 when I became member of the SWIFT follow-up team. Most efforts were (and still are) devoted to the study of the connection between Supernovae and GRBs. Currently, I'm PI of a VLT proposal *A spectroscopic study of the Supernova/GRB connection* aimed at following the spectroscopic evolution of nearby SN-GRB associations. This project is carried out in collaboration with other members of SWIFT follow-up team. The highlights of this programme are reported in the Appendix. (In collaboration with G. Chincarini, D. Malesani and the Swift team).

Supernovae. Photometric and the spectroscopic study of all types of SNe (Ia, Ib/c, II-linear, II-plateau) near maximum light and at late stages and their theoretical modeling. The observations at maximum provide us with the necessary data for using SNe (Ia and II) as standard candles. The observations at later stages allow one to discriminate among different energy sources (i.e. radioactive decay, pulsar, light-echo), to model the mechanisms of the explosion, and to shed light on the nature of the progenitor (In collaboration with N. Panagia and the Padova SN group.)

Supernovae at high z. The study of Supernovae has been extended to objects at high (in collaboration with the Supernova Cosmology Project). The search for SNe at high z is twofold important. On the one hand the evolution of the SN rate with redshift contains unique information on the star formation history of the universe, the IMF of stars and the nature of the progenitors in Type Ia events. On the other hand SNeI-a at $z \sim 1 - 1.5$ are valuable tracers of cosmological models . Both aspects are currently investigated both on observational and theoretical grounds.

Search for obscured Supernovae. The "true" value of the SN rate is considerably underestimated because of extinction. This problem can be partially solved by observing in the infrared. We have started two NIR SN searches in ultra-luminous galaxies, the former at NTT and TNG the latter with HST-NICMOS (In collaboration with F. Mannucci).

Search for environmental effects on the properties of type Ia SNe. This is a long-term project (in collaboration with F. Mannucci, Nino Panagia, R.

Gilmozzi and F. Matteucci) aimed at throwing light on the still unknown origin of the progenitors of type Ia Supernovae. Our results have been reported in 8 papers so far published (since 2005).

Extragalactic Novae. The systematic study of extragalactic novae in galaxies of different Hubble types has shown, that nova frequency (number of nova outburst per year) depends on the Hubble type of the parent galaxy. In particular, we find that spiral galaxies are more prolific nova producers, by a factor about 4, in units of K-band luminosity, than ellipticals and S0's. We show that this result could be explained by assuming that novae in late– and early–type galaxies originate from two different classes of progenitors.

The use of the maximum magnitude *vs.* rate of decline relationship, calibrated on the nova population of M31 and LMC, has allowed us to re-define the distance scale from the Local Group up to Fornax cluster and to measure the Hubble constant. The distance moduli so derived compare very well (i.e. within 0.2 mags) with those obtained via Cepheids, thus demonstrating that classical novae are indeed good distance indicators perfectly suitable to calibrate the absolute magnitude at maximum of type Ia occurred in early type galaxies. In collaboration with R. Gilmozzi we have explored the possibility to use nova stars as standard candles for measuring the cosmological parameters, with an Extremely Large Telescope (40m).

Cosmological Parameters with GRBs. Observations of SNe-Ia in the range of redshift $z \approx 0.3 \div 1.3$ (Perlmutter et al. 1998; Perlmutter et al. 1999; Riess et al. 1998; Riess et al. 2004) have shown that their peaks magnitude appear (at $z \sim 0.5$) dimmer than expected by ~ 0.2 mag. This result has been taken as evidence for the existence of a "cosmic jerk", then suggesting that the Universe may accelerate its expansion. On the other hands the cosmological interpretation rely on the lack of evolutionary effects on progenitors of type Ia SNe. Recent results on SNe-Ia progenitors, which imply the existence of two different classes of progenitors for SNe-Ia (Della Valle & Panagia 2003, Della Valle et al. 2005, Mannucci et al. 2005, 2006, 2007, Sullivan et al. 2006, Aubourg et al. 2007) occuring in different environments and at different redshift, may cast some doubts on this assumption. In addition recent versions of the Hubble diagramm for SNe-Ia (e.g. Wood-Vasey et al. 2006) display peculiar distributions of the residuals, which are also suggestive for the presence of systematics. This situation calls for an independent measurement of the cosmological parameters besides the one obtained via SNe-Ia. We show that GRBs can be used to measure Ω_M (see Amati et al. 2008; Della Valle & Amati 2008).

3. Publications (2005 - 2007)

[1] *Chandra observations of the recurrent nova IM Nor* M.Orio, E. Tepedelenlioglu, S. Starrfield, C. E. Woodward, M. Della Valle 2005, ApJ, 620, 938

The recurrent nova IM Nor was observed twice in X-rays with the Chandra ACIS-S, 1 and 6 months after the optical outburst. It was not detected in the first observation, with an upper limit on the X-ray luminosity in the $0.2 - 10$ keV range $LX < 4.81030(dkpc^{-1})^2$ ergs s^{-1} (where d is the distance to the nova). Five months later, a hard X-ray source with $LX = (1.4 - 2.5) \times 10^{32}(dkpc)^2$ ergs s^{-1} was detected. The X-ray spectrum appears to be thermal, but we cannot rule out additional components due to unresolved emission lines. A blackbody component is likely to contribute to the observed spectrum, but it has bolometric luminosity $L_{bol} = 2.5 \times 10^{33}(\mathrm{dkpc}^{-1})^2$ ergs s^{-1} therefore, it is not sufficiently luminous to be caused by a central white dwarf that is still burning hydrogen on the surface. An optical spectrum, taken 5 months postoutburst, indicates no intrinsic reddening of the ejecta. Therefore, we conclude that the shell had already become optically thin to supersoft X-rays, but nuclear burning had turned off or was in the process of turning off at this time. We discuss why this implies that recurrent novae, even the rare ones with long optical decays like IM Nor, indicating a large envelope mass, are not statistically significant as Type Ia supernova candidates.

[2] *The supernova rate per unit mass* Mannucci, F., Della Valle, M., Panagia, N., Cappellaro, E., Cresci, G., Maiolino, R., Petrosian, A., Turatto, M. 2005, A&A, 433, 807

We compute the rate of supernovae (SNe) of different types along the Hubble sequence normalized to the near-infrared luminosity and to the stellar mass of the parent galaxies. This is made possible by the new complete catalog of near-infrared galaxy magnitudes obtained by 2MASS. We find that the rates of all SN types, including Ia, Ib/c and II, show a sharp dependence on both the morphology and the (B-K) colors of the parent galaxies and, therefore, on the star formation activity. In particular we find, with a high statistical significance, that the type Ia rate in late type galaxies is a factor ~ 20 higher than in E/S0. Similarly, the type Ia rate in the galaxies bluer than B-K=2.6 is about a factor of 30 larger than in galaxies with B-K>4.1. These findings can be explained by assuming that a significant fraction of Ia events in late spirals/irregulars originates in a relatively young stellar component.

[3] *Why are Radio-Galaxies Prolific Producers of type Ia Supernovae?* Della Valle, M., Panagia, N., Padovani, P. Cappellero, E., Mannucci, F., Turatto, M. 2005, ApJ, 629, 750

An analysis of SN Ia events in early-type galaxies from the database of Cappellaro and coworkers provides conclusive evidence that the rate of SNe Ia in radio-loud galaxies is about 4 times higher than the rate measured in radio-quiet galaxies, i.e., SN Ia rate(radio-loud galaxies)=0.43 + 0.19 − 0.14 h^2_{75} SNu as compared to SN Ia rate(radio-quiet galaxies)=0.11+0.06-0.03 h^2_{75} SNu. The actual value of the enhancement is likely to be in the range $\sim 2-7$ (P$\sim 10^{-4}$). This finding puts on robust empirical grounds the results obtained by Della Valle & Panagia on the basis of a smaller sample of SNe. We analyze the possible causes of this result and conclude that the enhancement of the SN Ia explosion rate in radio-loud galaxies has the same origin as their being strong radio sources, but there is no causal link between the two phenomena. We argue that repeated episodes of interaction and/or mergers of early-type galaxies with dwarf companions, on timescales of about 1 Gyr, are responsible for both inducing strong radio activity observed in $\sim$ 14% of early-type galaxies and supplying an adequate number of SN Ia progenitors to the stellar population of elliptical galaxies.

[4] *Radial distributions of Gamma Ray Bursts and Supernovae: clues to their progenitors*, Della Valle, M., Marziani, P., Panagia, N. 2005, NCimC, 28, 613

In this paper we compare the observed radial distributions of Gamma Ray Bursts and of Supernov with respect to the host galaxy center. We investigate the possibility that the observed Gamma Ray Burst offset distribution (in kpc) is in fact the distribution of I-b/c supernov modified by the kick received by the binary system when the first supernova explosion occurs. Our analysis lends support to the scenario in which all long-duration GRBs are produced by type Ib/c SNe. We ruled out that a significant fraction of long-duration GRBs could be due to merging of compact remnants of stellar evaluation.

[5] *Early decline spectra of Nova SMC 2001 and Nova LMC 2002*, Mason, E., Della Valle, M., Gilmozzi, R., Lo Curto, G., Williams, R.E. 2005, A&A, 435, 1031

We report results on the spectroscopic follow-up of Nova SMC 2001 and Nova LMC 2002 carried out at La Silla. The analysis of the spectroscopic evolution shows that these objects belong to the Fe II class, according to the Cerro Tololo scheme. From the line fluxes and the expansion velocities, we have derived an approximate mass for the ejected shells of $2 \div 3 \times 10^{-4} M_{\odot}$. The filling factor measurements ($\sim 10^{-4} \div 10^{-1}$) suggest a clumpy structure for the ejecta.

[6] *Supernovae shedding light on gamma-ray bursts*, Della Valle, M. 2005, NCimC, 28, 563

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 $2.6 \times 10^{-4} yr^{-1}$ 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 0.008 ÷ 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.

[7] *Out of the darkness: the infrared afterglow of the INTEGRAL burst GRB 040422 observed with the VLT*, Filliatre, P. et al. 2005, A&A, 438 793

GRB 040422 was detected by the INTEGRAL satellite at an angle of only 3 degrees from the Galactic plane. Analysis of the prompt emission observed with the SPI and IBIS instruments on INTEGRAL are presented. The IBIS spectrum is well fit by the Band model with a break energy of $E_0 = 56 \pm 2$ keV and $E_{peak} = 41 \pm 3$ keV. The peak flux is $1.8 \times 10^{-7} erg cm^{-2} s^{-1}$ and fluence 3.4×10^{-7} erg cm^{-2} in the range 20–200 keV. We then present the observations of the afterglow of GRB 040422, obtained with the ISAAC and FORS 2 instruments at the VLT less than 2 h after the burst. We report the discovery of its near-infrared afterglow, for which we give the astrometry and photometry. No detection could have been obtained in the R and I bands, partly due to the large extinction in the Milky Way. We imaged the position of the afterglow again two months later in the Ks band, and detected a likely bright host galaxy. We compare the magnitude of the afterglow with those of a compilation of promptly observed counterparts of previous GRBs, and show that the afterglow of GRB 040422 lies at the very faint end of the distribution, brighter only than that of GRB 021211, singled out later and in the optical bands, and GRB 040924 after accounting for Milky Way extinction. This observation suggests that the proportion of dark GRBs can be lowered significantly by a more systematic use of 8-m class telescopes in the infrared in the very early hours after the burst.

[8] *GRB 050904 at redshift 6.3: observations of the oldest cosmic explosion after the Big Bang*, Tagliaferri, G., Antonelli, A., Chincarini, G., Fernndez-Soto, A., Malesani, D., Della Valle, M. et al. 2005, A&A, 443, L1

We present optical and near-infrared observations of the afterglow of the gamma-ray burst GRB 050904. We derive a photometric redshift z = 6.3, estimated from the presence of the Lyman break falling between the I and J filters. This is by far the most distant GRB known to date. Its isotropic-equivalent energy is 3.4×10^{53} erg in the rest-frame 110-1100 keV energy band. Despite the high redshift, both the prompt and the afterglow emission are not peculiar with respect to other GRBs. We find a break in the J-band light curve at $t_b = 2.6 \pm 1.0 d$ (observer frame). If we assume this is the jet break, we derive a beaming-corrected energy $E_\gamma (4 \div 12) \times 10^{51}$ erg. This limit shows that GRB 050904 is consistent with the Amati and Ghirlanda relations. This detection is consistent with the expected number of GRBs at $z > 6$ and shows that GRBs are a powerful tool to study the star formation history up to very high redshift.

[9] *Optical emission from GRB 050709: a short/hard GRB in a star forming galaxy*, Covino, S. et al. 2006, A&A, 447, L5

We present optical observations of the short/hard gamma-ray burst GRB 050709, the first such event with an identified optical counterpart. The object is coincident with a weak X-ray source and is located inside a galaxy at redshift z = 0.1606 $\pm$ 0.0002. Multiband photometry allowed us to study the broad-band spectral energy distribution. Late-time monitoring places strong limits on any supernova simultaneous with the GRB. The host galaxy is not of early type. Spectra show that the dominant stellar population is relatively young ($\sim$ 1 Gyr), and that ongoing star formation is present at a level of $2 - -3L/L_{\odot} \sim M_{\odot}yr^{-1}$. This is at least 2 orders of magnitude larger than that observed in the elliptical hosts of the short GRB 050509B and GRB 050724. This shows that at least some short GRBs originate in a young population. Short/hard GRB models based on the merger of a binary degenerate system are compatible with the host galaxy characteristics, although there is still the possibility of a connection between young stars and at least a fraction of such events.

[10] *Gamma–Ray Bursts associated with Supernovae: A systematic analysis of BATSE GRB candidates*, Bosnjak, Z., Celotti, A., Ghirlanda, G., Della Valle, M., Pian, E. 2006, A&A, 447, 121

We examined the properties of a sample of BATSE Gamma-Ray Bursts (GRBs) comprising events which have indications of association with a supernova (SN), some on the basis of indications of re-brightening in the optical afterglow light curve, but in most cases based only on the "loose" temporal and directional coincidence inferred from the cross correlation of catalogs. Despite the large uncertainties in the latter selection method, the temporal and spectral analysis reveal three interesting statistical results when the sample is compared with that of all the BATSE GRBs: the GRBs tentatively associated with SNe are found to predominantly (in $\sim$ 80% of the cases) have single-peaked light curves, a softer spectrum (i.e. low energy power law index $t_{\alpha} \sim 1.5$) and tend not to follow the Lag-Luminosity and Isotropic Energy-Peak Energy correlations. These three independent statistical properties point toward the existence of a significant number of under-luminous, GRB 980425-like events constituting - at least from an observational point of view - a tail or a separate class with respect to the whole of the BATSE GRB events. The unusually high percentage of SN Ibc among those identified by the catalog cross-correlation (a factor $\sim$ four higher than expected from SN catalog statistics) reinforces the non-randomness of some of the selected events.

[11] *The weak INTEGRAL bursts GRB040223 and GRB040624: an emerging population of dark afterglows*, Filliatre, P. et al. 2006, A&A, 448, 971

We report here γ-ray, X-ray and near-infrared observations of GRB 040223 along with γ-ray and optical observations of GRB 040624. GRB 040223 was detected by INTEGRAL close to the Galactic plane and GRB 040624 at high Galactic latitude. Analyses of the prompt emission detected by the IBIS instrument on INTEGRAL are presented for both bursts. The two GRBs have long durations, slow pulses and are weak. The γ-ray spectra of both bursts are best fit with steep power-laws, implying they are X-ray rich. GRB 040223 is among the weakest and longest of INTEGRAL GRBs. The X-ray afterglow of this burst was detected 10h after the prompt event by XMM-Newton. The measured spectral properties are consistent with a column density much higher than that expected from the Galaxy, indicating strong intrinsic absorption. We carried out near-infrared observations 17h after the burst with the

NTT of ESO, which yielded upper limits. Given the intrinsic absorption, we find that these limits are compatible with a simple extrapolation of the X-ray afterglow properties. For GRB 040624, we carried out optical observations 13 h after the burst with FORS 1 and 2 at the VLT, and DOLoRes at the TNG, again obtaining upper limits. We compare these limits with the magnitudes of a compilation of promptly observed counterparts of previous GRBs and show that they lie at the very faint end of the distribution. These two bursts are good examples of a population of bursts with dark or faint afterglows that are being unveiled through the increasing usage of large diameter telescopes engaged in comprehensive observational programmes.

[12] *Two Populations of Progenitors for the type Ia Supernovae?*, Mannucci, F., Della Valle, M., Panagia, N. 2006, MNRAS, 370, 773

We use recent observations of the evolution of the Type Ia supernova (SN Ia) rate with redshift, the dependence of the SN Ia rate on the colours of the parent galaxies, and the enhancement of the SN Ia rate in radio-loud early-type galaxies to derive on robust empirical grounds, the delay time distribution (DTD) between the formation of the progenitor star and its explosion as an SN. Our analysis finds: (i) delay times as long as 3-4 Gyr, derived from observations of SNe Ia at high redshift, cannot reproduce the dependence of the SN Ia rate on the colours and on the radio-luminosity of the parent galaxies, as observed in the local Universe; (ii) the comparison between observed SN rates and a grid of theoretical 'single-population' DTDs shows that only a few of them are possibly consistent with observations. The most successful models are all predicting a peak of SN explosions soon after star formation and an extended tail in the DTD, and can reproduce the data but only at a modest statistical confidence level; (iii) present data are best matched by a bimodal DTD, in which about 50 per cent of SNe Ia (dubbed 'prompt' SNe Ia) explode soon after their stellar birth, in a time of the order of 10^8 yr, while the remaining 50% ('tardy' SNe Ia) have a much wider distribution, well described by an exponential function with a decay time of about 3 Gyr. The presence in the DTD of both a strong peak at early times and a prolonged exponential tail, coupled with the well-established bimodal distribution of the decay rate (Δm15) and the systematic difference observed in the expansion velocities of the ejecta of SNe Ia in ellipticals and spirals, suggests the existence of two classes of progenitors. We discuss the cosmological implications of this result and make simple predictions, which are testable with future instrumentation.

[13] *Hypernova Signatures in the late rebrightening of GRB 050525A*, Della Valle et al. 2006, ApJ, 642, L103

We report observations of GRB 050525A, for which a Gemini North spectrum shows its redshift to be z=0.606. This is the third closest long GRB discovered by Swift. We observed its afterglow using the VLT, Gemini, and TNG telescopes to search for an associated supernova. We find that the early-time light curve is described by a broken power law with a break at $t \sim 0.3$ days after the burst. About 5 days after the burst, a flattening is apparent, followed by a further dimming. Both the magnitude and the shape of the light curve suggest that a supernova was emerging during the late decay of the afterglow. This supernova, named SN 2005nc, had a rise time faster than SN 1998bw and a long-lasting maximum. A spectrum obtained about 20 days (rest frame) after the GRB resembles the spectrum of SN 1998bw obtained close to maximum light.

[14] *Models for the type Ic Hypernova SN 2003lw associated with GRB 031203*, Mazzali et al. 2006, ApJ, 645, 1323

The gamma-ray burst GRB 031203 at a redshift z=0.1055 revealed a highly reddened Type Ic supernova, SN 2003lw, in its afterglow light. This is the third well-established case of a link between a long-duration GRB and a Type Ic SN. The SN light curve is obtained by subtracting the galaxy contribution and is modeled together with two spectra at near-maximum epochs. A red VLT grism 150I spectrum of the SN near peak is used to extend the spectral coverage, and in particular to constrain the uncertain reddening, the most likely value for which is $EG + H(B - V) \sim 1.07 \pm 0.05$. Accounting for reddening, SN 2003lw is $\sim$ 0.3 mag brighter than the prototypical GRB-SN 1998bw. Light curve models yield a ^{56}Ni mass of ~ 0.55 $M_\odot$. The optimal explosion model is somewhat more massive (Mej ~ 13 $M_\odot$) and more energetic ($E \sim 6 \times 10^{52}$ ergs) than the model for SN 1998bw, implying a massive progenitor (40-50 $M_\odot$). The mass at high velocity is not very large (1.4 $M_\odot$ above 30,000 km s^{-1}, but only 0.1 $M_\odot$ above 60,000 km s^{-1}), but it is sufficient to cause the observed broad lines. The similarity of SNe 2003lw and 1998bw and the weakness of their related GRBs, GRB 031203 and GRB 980425, suggest that both GRBs may be normal events viewed slightly off-axis or a weaker but possibly more frequent type of GRB.

[15] *The association of GRB 060218 with a supernova and the evolution of the shoch wave*, Campana et al. 2006, Nature, 442, 1008

Although the link between long γ-ray bursts (GRBs) and supernovae has been established, hitherto there have been no observations of the beginning of a supernova explosion and its intimate link to a GRB. In particular, we do not know how the jet that defines a γ-ray burst emerges from the star's surface, nor how a GRB progenitor explodes. Here we report observations of the relatively nearby GRB 060218 and its connection to supernova SN 2006aj. In addition to the classical non-thermal emission, GRB 060218 shows a thermal component in its X-ray spectrum, which cools and shifts into the optical/ultraviolet band as time passes. We interpret these features as arising from the break-out of a shock wave driven by a mildly relativistic shell into the dense wind surrounding the progenitor. We have caught a supernova in the act of exploding, directly observing the shock break-out, which indicates that the GRB progenitor was a Wolf-Rayet star.

[16] *The multiwavelength afterglow of GRB 050721: a puzzling rebrightening seen in the otical but not in the X-ray*, Antonelli et al. 2006, A&A, 456, 509

GRB 050721 was detected by Swift and promptly followed-up, in the X-ray by Swift itself and, in the optical band, by the VLT operated, for the first time, in rapid response mode starting observations about 25 m after the burst. A multiwavelength monitoring campaign was performed in order to study its afterglow's behavior. We present the analysis of the early and late afterglow emission in both the X-ray and optical bands, as observed by Swift, a robotic telescope, and the VLT. We compare early observations with late afterglow observations obtained with Swift and the VLT in different bands in order to constrain the density of the medium in which the fireball is expanding. We have analyzed both the X-ray and the optical light curves and compared the spectral energy distribution of the afterglow at two different epochs.We observed an intense rebrightening in the optical band at about one day after the burst which was not seen in the X-ray band. This is the first observation of a GRB afterglow in which a rebrightening is observed in the optical but not in the X-ray band. The lack of detection in X-ray of such a strong rebrightening at lower energies may be described with a variable external density profile. In such a scenario, the combined X-ray and optical observations allow us to derive that matter located at $\sim 10^{17}$ cm from the burst is about a factor of 10 higher than in the inner region.

[17] *A new formulation of the type Ia supernova rate and its consequances on galactic chemical evolution*, Matteucci, F., Panagia, N., Pipino, A., Mannucci, F., Recchi, S., Della Valle, M. 2006, MNRAS, 372, 265

In recent papers, Mannucci et al. and Mannucci, Della Valle & Panagia suggested, on the basis of observational arguments, that there is a bimodal distribution of delay times for the explosion of Type Ia supernovae (SNe). In particular, a percentage from 35 to 50 per cent of the total Type Ia SNe should be composed by systems with lifetimes as short as 10^8 yr, whereas the rest should arise from smaller mass progenitors with a much broader distribution of lifetimes. In this paper, we test this hypothesis in models of chemical evolution of galaxies of different morphological type: ellipticals, spirals and irregulars. We show that this proposed scenario is compatible also with the main chemical properties of galaxies. In this new formulation, we simply assume that Type Ia SNe are originating from C-O white dwarfs in binary systems without specifying if the progenitor model is the single-degenerate or the double-degenerate one or a mixture of both. In the framework of the single-degenerate model, such a bimodal distribution of the time delays could be explained if the binary systems with a unitary mass ratio are favoured in the mass range $5 - 8M_{\odot}$, whereas for masses $< 5M_{\odot}$ the favoured systems should have the mass of the primary much larger than the mass of the secondary. When the new rate is introduced in the two-infall model for the Milky Way, the derived Type Ia SN rate as a function of cosmic time shows a high and broad peak at very early epochs thus influencing the chemical evolution of the galactic halo more than in the previous widely adopted formulations for the SN Ia rate. As a consequence of this, the [O/Fe] ratio decreases faster for $[Fe/H] > -2.0$ dex, relative to the old models. For a typical elliptical of $10^{11} M_o dot$ of luminous mass, the new rate produces average $[\alpha/Fe]$ ratios in the dominant stellar population still in agreement with observations. The Type Ia SN rate also in this case shows an earlier peak and a subsequent faster decline relative to the previous results, but the differences are smaller than in the case of our Galaxy. We have also checked the effects of the new Type Ia SN rate on the evolution of the Fe content in the intracluster medium (ICM), as a consequence of its production from cluster ellipticals and we found that less Fe in the ICM is produced with the new rate, due to the higher fraction of Fe synthesized at early times and remaining locked into the stars in ellipticals. For dwarf irregular galaxies suffering few bursts of star formation, we obtain [O/Fe] ratios larger by 0.2 dex relative to the previous models.

[18] *Early spectral evolution of Nova Sgr 2004*, Ederoclite, A., Mason, E., Della Valle, M., Gilmozzi, R., Williams, R.E., et al. 2006, A&A, 459, 875

We present optical and near-infrared spectral evolution of the Galactic nova V5114 Sgr (2004) during few months after the outburst. Methods: .We use multi-band photometry and line intensities derived from spectroscopy to put constrains on the distance and the physical conditions of the ejecta of V5114 Sgr. The nova showed a fast decline (t2 $<$ 11 days) and spectral features of Fe II spectroscopic class. It reached M(V) = -8.7 ± 0.2 mag at maximum light, from which we derive a distance of 7700 $\pm$ 700 kpc and a distance from the galactic plane of about 800 pc. Hydrogen and oxygen mass of the ejecta are measured from emission lines, leading to $\sim 10^{-6}$ and 10^{-7} $M_o dot$, respectively. We compute the filling factor of the ejecta to be in the range $0.1 - 10^{-3}$. We found the value of the filling factor to decrease with time. The same is also observed in other novae, then giving support to the idea that nova shells are not homogeneously filled in, rather being the material clumped in relatively higher density blobs less affected by the general expanding motion of the ejecta.

[19] *GRB 050223: a dark GRB in a dusty starburst galaxy*, Pelizza, L. et al. 2006, A&A, 459, L5

We aim at detecting and determining the properties of the host galaxy of the dark GRB 050223. We use VLT optical/NIR images coupled to Swift X-ray positioning, and optical spectra of the host galaxy to measure its properties. We find a single galaxy within the Swift error box of GRB 050223. It is located at z = 0.584 and its luminosity is $L \sim 0.4L^{\star}$. Emission lines in the galaxy spectrum imply an intrinsic SFR $> 7M_{\odot}yr^{-1}$, and a large extinction $AV > 2$ mag within it. We also detect absorption lines, which reveal an underlying stellar population with an age between 40 Myr and 1.5 Gyr. Conclusions: .The identification of a host galaxy with atypical properties using only the X-ray transient suggests that a bias may be present in the former sample of host galaxies. Dust obscuration together with intrinsic faintness are the most probable causes for the darkness of this burst.

[20] *A light echo from type Ia Supernova 1995E*, Quinn, J., Garnavich, P., Li, W., Panagia, N., Riess, A., Schmidt, B., Della Valle, M. 2006, ApJ, 652, 512

We identify a light echo candidate from Hubble Space Telescope (HST) imaging of NGC 2441, the host galaxy of the Type Ia supernova 1995E. From the echo's angular size and the estimated distance to the host galaxy, we find a distance of 207 ± -35 pc between the dust and the site of the supernova. If confirmed, this echo brings the total number of observed nonhistorical Type Ia light echoes to three-the others being SN 1991T and SN 1998bu-suggesting that they are not uncommon. We compare the properties of the known Type Ia supernova echoes and test models of light echoes developed by Patat and coworkers. HST photometry of the SN 1991T echo shows a fading, which is consistent with scattering by dust distributed in a sphere or shell around the supernova. Light echoes have the potential to answer questions about the progenitors of Type Ia supernovae, and more effort should be made for their detection, given the importance of Type Ia supernovae to measurements of dark energy.

[21] *A NICMOS search for obscured Supernovae in starburst galaxies*, Cresci, G., Mannucci, F., Della Valle, M., Maiolino, R. 2006, A&A, 462, 927

The detection of obscured supernovae (SNe) in near-infrared monitoring campaigns of starburst galaxies has shown that a significant fraction of SNe is missed by optical surveys. However, the number of SNe detected in ground-based near-IR observations is still significantly lower than the number of SNe extrapolated from the FIR luminosity of the hosts. A possibility is that most SNe occur within the nuclear regions, where the limited angular resolution of ground-based observations prevents their detection. This issue prompted us to exploit the superior angular resolution of NICMOS-HST to search for obscured SNe within the first kpc from the nucleus of strong starbursting galaxies. A total of 17 galaxies were observed in SNAPSHOT mode. Based on their FIR luminosity, we did not expect to detect fewer than $\sim$ 12 SNe. However, no confirmed SN event was found. From our data we derived an observed nuclear SN rate $<$ 0.5 SN/yr per galaxy. The shortage of SN detections can be explained by a combination of several effects. The most important are: i) the existence of a strong extinction, $A_V > 11$; ii) most SNe occur within the first 0.5 arcsec (which corresponds in our sample to about 500 pc) where even NICMOS is unable to detect SN events.

[22] *GRB 060614: an enigmatic long-duration gamma-ray burst not due to a hypernova*, Della Valle et al. 2006, Nature, 444, 1050

Gamma-ray bursts (GRBs) are short, intense flashes of soft γ-rays coming from the distant Universe. Long-duration GRBs (those lasting more than $\sim 2s$) are believed to originate from the deaths of massive stars, mainly on the basis of a handful of solid associations between GRBs and supernovae. GRB 060614, one of the closest GRBs discovered, consisted of a 5-s hard spike followed by softer, brighter emission that lasted for $\sim 100s$. Here we report deep optical observations of GRB 060614 showing no emerging supernova with absolute visual magnitude brighter than M(V)=-13.7. Any supernova associated with GRB 060614 was therefore at least 100 times fainter, at optical wavelengths, than the other supernovae associated with GRBs. This demonstrates that some long-lasting GRBs can either be associated with a very faint supernova or produced by different phenomena.

[23] *Supernovae and Gamma-ray Bursts*, Della Valle 2006, ChJAS, 6, 315.

I review the observational status of the Supernova/Gamma-Ray Burst (GRB) connection. Available data suggest that Supernovae (SNe) associated with GRBs form an heterogeneous class of objects including bright and faint hypernovae (Hyp) and perhaps also 'standard' Ib/c events. Current estimates of SN and GRB rates and beaming angles yield ratios GRB/SNe-Ibc $\sim$ 2% and GRB/Hyp $\sim$ 25%. In the few SN/GRB associations so far discovered the SN and GRB events appear to go off simultaneously, although data do not exclude that the SN may precede the GRB by a few days.

[24] *On the consistency of peculiar GRBs 060218 and 060614 with the $E_{p,i} - E_{iso}$ correlation*, Amati, L., Della Valle, M., Frontera, F. et al. 2007, A&A, 463, 913

We analyze and discuss the position of GRB 060218 and GRB 060614 in the $E_{p,i} - E_{iso}$ plane. GRB 060218 is important because of its similarity with GRB 980425, the prototypical event of the GRB-SN connection. While GRB 980425 is an outlier of the $E_{p,i} - E_{iso}$ correlation, we find that GRB 060218 is fully consistent with it. This evidence, combined with the "chromatic" behavior of the afterglow light curves, is at odds with the hypothesis that GRB 060218 was a "standard" GRB seen off-axis and supports the existence of a class of truly sub-energetic GRBs. GRB 060614 is a peculiar event not accompanied by a bright supernova. Based on published spectral information, we find that also this event is consistent with the $E_{p,i} - E_{iso}$ correlation. We discuss the implications of our results for the rate of sub-energetic GRBs, the GRB/SN connection and the properties of the newly discovered sub-class of long GRBs not associated with bright supernovae. We have included in our analysis other recent GRBs with clear evidence (or clear evidence of lack) of associated SNe.

[25] *On the Rates of Gamma-Ray Bursts and Type Ib/c Supernovae*, Guetta, D, Della Valle, M. 2007, ApJ, 657, L73

We measure the local rates of "low-luminosity" gamma-ray bursts (LL GRBs; i.e., $L \sim 10^{49} ergs^{-1}$) and "high-luminosity" gamma-ray bursts (HL GRBs). The values are in the range $n_0 = 100 - 1800 Gpc^{-3} yr^{-1}$ and $n_0 = 100 - 550 Gpc^{-3} yr^{-1}$, respectively, and their ratios to Type Ibc supernovae (SNe Ibc) are $\sim 1\% - 9\%$ and $0.4\% - 3\%$, respectively. These data may suggest the existence of two physically distinct classes of GRBs in which LL GRBs are (intrinsically) more frequent events than HL GRBs. However, with the present data, we cannot exclude the possibility of a single population of GRBs that gives rise to both an isotropic low-luminous emission (LL GRBs: detectable only in nearby GRBs) and to a highly collimated high luminous emission (HL GRBs: detectable preferentially at high z). We also compute the rate of SNe Ibc characterized by broad-lined spectra (hypernovae [HNe]) and find it to be about $1.5 \times 10^{-4} yr^{-1}$ per 10^{10} LB,$\odot$ (i.e., less than 10% of SNe Ibc occurring in spiral galaxies). This result implies that the ratio of HL GRBs to HNe is smaller than 1, possibly in the range of 0.04–0.3. We have used the ratio between HNe and LL GRBs to constrain their beaming factor to $f_b^{-1} \sim 10$ or less.

[26] *UVES/VLT high resolution spectroscopy of GRB 050730 afterglow: probing the features of the GRB environment*, D'Elia, V. et al. 2007, A&A, 467, 73

The aim of this paper is to study the Gamma Ray Burst (GRB) environment through the analysis of the optical absorption features due to the gas surrounding the GRB. Methods: To this purpose we analyze high resolution spectroscopic observations (R=20 000-45 000, corresponding to 14 km s-1 at 4200 Å and 6.6 km s-1 at 9000 Å) of the optical afterglow of GRB050730, obtained with UVES+VLT $\sim 4h$ after the GRB trigger. Results: The spectrum shows that the ISM of the GRB host galaxy at z = 3.967 is complex, with at least five components contributing to the main absorption system. We detect strong C II, Si II, O I and Fe II fine structure absorption lines associated to the second and third component. For the first three components we derive information on the relative distance from the site of the GRB explosion. Component 1, which has the longest wavelength, highest positive velocity shift, does not present any fine structure nor low ionization lines; it only shows very high ionization features, such as C IV and O VI, suggesting that this component is very close to the GRB site. From the analysis of low and high ionization lines and fine structure lines, we find evidences that the distance of component 2 from the site of the GRB explosion is 10-100 times smaller than that of component 3. We evaluated the mean metallicity of the z=3.967 system obtaining values $\sim 10^{-2}$ of the solar metallicity or less. However, this should not be taken as representative of the circumburst medium, since the main contribution to the hydrogen column density comes from the outer regions of the galaxy while that of the other elements presumably comes from the ISM closer to the GRB site. Furthermore, difficulties in evaluating dust depletion correction can modify significantly these values. The mean [C/Fe] ratio agrees well with that expected by single star-formation event models. Interestingly the [C/Fe] of component 2 is smaller than that of component 3, in agreement with GRB dust destruction scenarios, if component 2 is closer than component 3 to the GRB site.

[27] *How many supernovae are we missing at high redshift?*, Mannucci, F., Della Valle, M. & Panagia, N. 2007, MNRAS, 377, 1229

Near-infrared and radio searches for core-collapse supernovae (CC SNe) in the local universe have shown that the vast majority of the events occurring in massive starburst are missed by the current optical searches as they explode in very dusty environments. Recent infrared observations have shown that the fraction of star formation activity that takes place in very luminous dusty starbursts sharply increases with redshift and becomes the dominant star formation component at $z > 0.5$. As a consequence, an increasing fraction of SNe are expected to be missed by high-redshift optical searches. We estimate that 5-10 per cent of the local CC SNe are out of reach of the optical searches. The fraction of missing events rises sharply towards z = 1, when about 30 per cent of the CC SNe will be undetected. At z = 2 the missing fraction will be about 60 per cent. Correspondingly, for Type Ia SNe, our computations provide missing fractions of 15 per cent at z = 1 and 35 per cent at z = 2. Such large corrections are crucially important to compare the observed SN rate with the expectations from the evolution of the cosmic star formation history, and to design the future SN searches at high redshifts.

[28] *Swift observations of GRB 060614: an anomalous burst with a well behaved afterglow*, Mangano et al. 2007, A&A, 470, 105

GRB 060614 is a remarkable gamma-ray burst (GRB) observed by Swift with puzzling properties, which challenge current progenitor models. In particular, the lack of any bright supernova (SN) down to very strict limits and the vanishing spectral lags during the whole burst are typical of short GRBs, strikingly at odds with the long (102 s) duration of this event. Here we present detailed spectral and temporal analysis of the Swift observations of GRB 060614. We show that the burst presents standard optical, ultraviolet and X-ray afterglows, detected beginning 4 ks after the trigger. An achromatic break is observed simultaneously in the optical and X-ray bands, at a time consistent with the break in the R-band light curve measured by the VLT. The achromatic behaviour and the consistent post-break decay slopes make GRB 060614 one of the best examples of a jet break for a Swift burst. The optical and ultraviolet afterglow light curves have also an earlier break at 29.7 ± 4.4 ks, marginally consistent with a corresponding break at 36.6 ± 2.4 ks observed in the X-rays. In the optical, there is strong spectral evolution around this break, suggesting the passage of a break frequency through the optical/ultraviolet band. The very blue spectrum at early times suggests this may be the injection frequency, as also supported by the trend in the light curves: rising at low frequencies, and decaying at higher energies. The early X-ray light curve (from 97 to 480 s) is well interpreted as the X-ray counterpart of the burst extended emission. Spectral analysis of the BAT and XRT data in the ~ 80 s overlap time interval show that the peak energy of the burst has decreased to as low as 8 keV at the beginning of the XRT observation. Spectral analysis of following XRT data shows that the peak energy of the burst continues to decrease through the XRT energy band and exits it at about 500 s after the trigger. The average peak energy Ep of the burst is likely below the BAT energy band (< 24 keV at the 90% confidence level) but larger than 8 keV. The initial group of peaks observed by BAT (~ 5 s) is however distinctly harder than the rest of the prompt emission, with a peak energy of about 300 keV as measured by Konus Wind.

[29] *Multicolor observations of the afterglow of the short/hard GRB?050724*, Malesani et al. 2007, A&A, 473, 77

New information on short/hard gamma-ray bursts (GRBs) is being gathered thanks to the discovery of their optical and X-ray afterglows. However, some key aspects are still poorly understood, including the collimation level of the outflow, the duration of the central engine activity, and the properties of the progenitor systems. Aims: We want to constrain the physical properties of the short GRB 050724 and of its host galaxy, and make some inferences on the global short GRB population. Methods: We present optical observations of the afterglow of GRB 050724 and of its host galaxy, significantly expanding the existing dataset for this event. We compare our results with models, complementing them with available measurements from the literature. We study the afterglow light curve and spectrum including X-ray data. We also present observations of the host galaxy. Results: The observed optical emission was likely related to the large flare observed in the X-ray light curve. The apparent steep decay was therefore not due to the jet effect. Available data are indeed consistent with low collimation, in turn implying a large energy release, comparable to that of long GRBs. The flare properties also constrain the internal shock mechanism, requiring a large Lorentz factor contrast between the colliding shells. This implies that the central engine was active at late times, rather than ejecting all shells simultaneously. The host galaxy has red colors and no ongoing star formation, consistent with previous findings on this GRB. However, it is not a pure elliptical, and has some faint spiral structure. Conclusions: GRB 050724 provides the most compelling case for association between a short burst and a galaxy with old stellar population. It thus plays a pivotal role in constraining progenitors models, which should allow for long delays between birth and explosion.

[30] *The host galaxy of GRB 031203: a new spectroscopic study*, Margutti et al. 2007, A&A, 474, 815

The host galaxy of the long-duration gamma-ray burst (GRB) 031203 (HG 031203) offers a precious opportunity to study in detail the environment of a nearby GRB. The aim is to better characterize this galaxy and analyse the possible evolution with time of the spectroscopic quantities we derive. Methods: We analyse HG 031203 using a set of optical spectra acquired with the ESO-VLT and Keck telescope. We compare the metallicity, luminosity and star formation properties of this galaxy and of the other supernova-long gamma-ray burst hosts in the local universe ($z < 0.2$) against the KPNO International Spectroscopic Survey. Results: HG 031203 is a metal poor, actively star forming galaxy (star formation rate of $12.9 \pm 2.2 Myr^{-1}$) at z = 0.1054. From the emission-line analysis we derive an intrinsic reddening $EHG(B - V) \sim 0.4$. This parameter doesn't show a compelling evidence of evolution at a month time-scale. We find an interstellar medium temperature of $\sim$ 12500 K and an electronic density of $Ne = 160 cm^{-3}$. After investigating for possible Wolf-Rayet emission features in our spectra, we consider dubious the classification of HG 031203 as a Wolf-Rayet galaxy. Long gamma-ray burst (LGRB) and supernova hosts in the local universe ($z < 0.2$) show, on average, specific star formation rates higher than ordinary star forming galaxy at the same redshift. On the other hand, we find that half of the hosts follows the metallicity-luminosity relation found for star-burst galaxies; HG 031203 is a clear outlier, with its really low metallicity ($12 + log(O/H) = 8.12 \pm 0.04$).

[31] *Upper limit for circumstellar gas around the type Ia SN 2000cx*, Patat et al. 2007, A&A, 474, 931

The nature of the companion stars in type Ia Supernova (SNe) progenitor systems remains unclear. One possible way to discriminate between different scenarios is the presence (or absence) of circumstellar material, the left overs from the progenitor evolution that may be revealed by their interaction with the SN. Aims: A new method to probe the circumstellar environment has been exploited for the normal type Ia SN 2006X, leading for the first time to the direct detection of material which escaped the progenitor system. In this paper we apply the same analysis to the peculiar type Ia SN 2000cx, with the aim of constraining the properties of its progenitor system. Methods: Using multi-epoch, high-resolution spectroscopy we have studied the spectral region where narrow, time-variable Na ID absorption features are expected in case circumstellar material is present along the line of sight. Results: No Na ID absorption is detected in the rest-frame of the host galaxy to a level of a few m, setting a stringent upper limit to the column density of the absorbing material ($N(NaI) < 2 \times 10^{10} cm^{-2}$). Conclusions: In this respect the peculiar type Ia SN 2000cx is different from the normal Ia SN 2006X. Whether this is to be attributed to a different progenitor system, to viewing-angle effects or to a low metallicity remains to be clarified.

[32] *A very faint core-collapse supernova in M85*, Pastorello, A., Della Valle, M., Smartt, S. et al. 2007, Nature, 449, E1

An anomalous transient in the early Hubble-type (S0) galaxy Messier 85 (M85) in the Virgo cluster was discovered by Kulkarni et al.1 on 7 January 2006 that had very low luminosity (peak absolute R-band magnitude MR of about -12) that was constant over more than 80 days, red colour and narrow spectral lines, which seem inconsistent with those observed in any known class of transient events. Kulkarni et al.1 suggest an exotic stellar merger as the possible origin. An alternative explanation is that the transient in M85 was a type II-plateau supernova of extremely low luminosity, exploding in a lenticular galaxy with residual star-forming activity. This intriguing transient might be the faintest supernova that has ever been discovered.

4. Publications (2008)

[33] *The supernova rate in local galaxy clusters* Mannucci, F., Maoz, D., Sharon, K., Botticella, M. T., Della Valle, M., Gal-Yam, A., Panagia, N. 2008, MNRAS, 383, 1121

A measurement of the supernova (SN) rates (Type Ia and core-collapse) in galaxy clusters is reported. Early-type cluster galaxies show a Type Ia SN rate (0.066 SNuM) similar to that obtained by Sharon et al. and more than three times larger than that in field early-type galaxies (0.019 SNuM). This difference has a 98 per cent statistical confidence level. We examine many possible observational biases which could affect the rate determination, and conclude that none of them is likely to significantly alter the results. We investigate how the rate is related to several properties of the parent galaxies, and find that cluster membership, morphology and radio power all affect the SN rate, while galaxy mass has no measurable effect. The increased rate may be due to galaxy interactions in clusters, inducing either the formation of young stars or a different evolution of the progenitor binary systems. We present the first measurement of the core-collapse SN rate in cluster late-type galaxies, which turns out to be comparable to the rate in field galaxies. This suggests that no large systematic difference in the initial mass function exists between the two environments.

[34] *Measuring the cosmological parameters with the Ep-Eiso correlation of Gamma-Ray Bursts* Amati, L., Guidorzi, C., Frontera, F., Della Valle, M., Finelli, F., Landi, R., Montanari, E. 2008, MNRAS, in press

The Ep-Eiso correlation of GRBs has been used to measure the cosmological parameter $Omega_M$. By adopting a maximum likelihood approach which allows us to correctly quantify the extrinsic (i.e. non–Poissonian) scatter of the correlation, we constrain (for a flat universe) $Omega_M$ to 0.04-0.40 (68% confidence level), with a best fit value of $Omega_M \sim 0.15$, and exclude $Omega_M = 1$ at 99.9% confidence level. If we release the assumption of a flat universe, we still find evidence for a low value of $Omega_M$ (0.04-0.50 at 68% confidence level) and a weak dependence of the dispersion of the Ep-Eiso correlation on $Omega_\Lambda$ (with an upper limit of $Omega_\Lambda \sim 1.15$ at 90% confidence level). Our approach makes no assumptions on the Ep,i-Eiso correlation and it does not use other calibrators to set the "zero' point of the relation, therefore our treatment of the data is not affected by circularity and the results are independent of those derived via type Ia SNe (or other cosmological probes). Unlike other multi-parameters correlations, our analysis grounds on only two parameters, then including a larger number (a factor ∼3) of GRBs and being less affected by systematics. Simulations based on realistic extrapolations of ongoing (and future) GRB experiments (e.g., Swift, Konus-Wind, GLAST) show that: i) the uncertainties on cosmological parameters can be significantly decreased; ii) future data will allow us to get clues on the "dark energy" evolution.

[35] *Massive stars exploding in a He-rich circumstellar medium - I. Type Ibn (SN 2006jc-like) events*. Pastorello, A.; Mattila, S.; Zampieri, L.; Della Valle, M.; Smartt, + 24 Co-Is, 2008, MNRAS, in press

New spectroscopic and photometric data of the Type Ibn supernovae 2006jc, 2000er and 2002ao are presented. We discuss the general properties of this recently proposed supernova family, which also includes SN 1999cq. The early-time monitoring of SN 2000er traces the evolution of this class of objects during the first few days after the shock breakout. An overall similarity in the photometric and spectroscopic evolution is found among the members of this group, which would be unexpected if the energy in these core-collapse events was dominated by the interaction between supernova ejecta and circumstellar medium. Type Ibn supernovae appear to be rather normal Type Ib/c supernova explosions which occur within a He-rich circumstellar environment. SNe Ibn are therefore likely produced by the explosion of Wolf-Rayet progenitors still embedded in the He-rich material lost by the star in recent mass-loss episodes, which resemble known luminous blue variable eruptions. The evolved Wolf-Rayet star could either result from the evolution of a very massive star or be the more evolved member of a massive binary system. We also suggest that there are a number of arguments in favour of a Type Ibn classification for the historical SN 1885A (S-Andromedae), previously considered as an anomalous Type Ia event with some resemblance to SN 1991bg.

[36] *The Metamorphosis of Supernova SN 2008D/XRF 080109: A Link Between Supernovae and GRBs/Hypernovae* Mazzali,P., Valenti,S., Della Valle, M., Chincarini, G., Sauer, D. +36 Co-Is Science, 2008, 321, 1185

The only supernovae (SNe) to show gamma-ray bursts (GRBs) or early x-ray emission thus far are overenergetic, broad-lined type Ic SNe (hypernovae, HNe). Recently, SN 2008D has shown several unusual features: (i) weak x-ray flash (XRF), (ii) an early, narrow optical peak, (iii) disappearance of the broad lines typical of SN Ic HNe, and (iv) development of helium lines as in SNe Ib. Detailed analysis shows that SN 2008D was not a normal supernova: Its explosion energy (E $\sim$ 610^{51} erg) and ejected mass [$\sim$ 7 times the mass of the Sun (are intermediate between normal SNe Ibc and HNe. We conclude that SN 2008D was originally a $\sim 30 M_s un$. When it collapsed, a black hole formed and a weak, mildly relativistic jet was produced, which caused the XRF. SN 2008D is probably among the weakest explosions that produce relativistic jets. Inner engine activity appears to be present whenever massive stars collapse to black holes.

[37] *Outliers from the Mainstream: How a Massive Star Can Produce a Gamma-Ray Burst* Campana et al. 2008, ApJ, 683, L9

It is now recognized that long-duration gamma-ray Bursts (GRBs) are linked to the collapse of massive stars, based on the association between (low redshift) GRBs and (Type Ic) core-collapse supernovae (SNe). The census of massive stars and GRBs reveals, however, that not all massive stars produce a GRB. Only 1are able to produce a highly relativistic collimated outflow, and hence a GRB. The extra crucial parameter has long been suspected to be metallicity and/or rotation. We find observational evidence strongly supporting that both ingredients are necessary in order to make a GRB out of a core-collapsing star. A detailed study of the absorption pattern in the X-ray spectrum of GRB 060218 reveals evidence of material highly enriched in low-atomic-number metals ejected before the SN/GRB explosion. We find that, within the current scenarios of stellar evolution, only a progenitor star characterized by a fast stellar rotation and subsolar initial metallicity could produce such a metal enrichment in its close surrounding.

[38] *Novae as a Class of Transient X-Ray Sources*. Mukai, K., Orio, M., Della Valle, M. 2007, 677, 1248

Motivated by the recently discovered class of faint (1034-1035 ergs s-1) X-ray transients in the Galactic center region, we investigate the 2-10 keV properties of classical and recurrent novae. Existing data are consistent with the idea that all classical novae are transient X-ray sources with durations of months to years and peak luminosities in the 1034-1035 ergs s-1 range. This makes classical novae a viable candidate class for the faint Galactic center transients. We estimate the rate of classical novae within a 15′ radius region centered on the Galactic center (roughly the field of view of XMM-Newton observations centered on Sgr A*) to be 0.1 yr-1. Therefore, it is plausible that some of the Galactic center transients that have been announced to date are unrecognized classical novae. The continuing monitoring of the Galactic center region carried out by Chandra and XMM-Newton may therefore provide a new method to detect classical novae in this crowded and obscured region, where optical surveys are not, and can never hope to be, effective. Therefore, X-ray monitoring may provide the best means of testing the completeness of the current understanding of the nova populations.

[39] *SN 2006gy: was it really extra-ordinary?* Agnoletto et al. 2008, A&A, in press

Optical photometric and spectroscopic data of the very luminous type IIn SN 2006gy, for a time period spanning more than one year, are presented and discussed. In photometry, a broad, bright ($M_R \sim -21.7$) peak characterizes all BVRI light curves. Afterwards, a rapid luminosity fading is followed by a phase of slow luminosity decline between day ~ 170 and ~ 237. At late phases (> 237 days), because of the large luminosity drop (> 3 mag), only upper visibility limits are obtained in the B, R and I bands. In the near-infrared, two K-band detections on days 411 and 510 open new issues about dust formation or IR echoes scenarios. At all epochs the spectra are characterized by the absence of broad P-Cygni profiles and a multi-component Halpha profile, which are the typical signatures of type IIn SNe. After maximum, spectroscopic and photometric similarities are found between SN 2006gy and bright, interaction-dominated SNe (e.g. SN 1997cy, SN 1999E and SN 2002ic). This suggests that ejecta-CSM interaction plays a key role in SN 2006gy about 6 to 8 months after maximum, sustaining the late-time light curve. Alternatively, the late luminosity may be related to the radioactive decay of $\sim 3M_{\odot}$ of ^{5}6Ni. Models of the light curve in the first 170 days suggest that the progenitor was a compact star ($R \sim 6 - 810^{(}12)$cm, $M_{ej} \sim 5 - 14M_{\odot}$), and that the SN ejecta collided with massive ($6-10M_{\odot}$), opaque clumps of previously ejected material. These clumps do not completely obscure the SN photosphere, so that at its peak the luminosity is due both to the decay of 56Ni and to interaction with CSM. A supermassive star is not required to explain the observational data, nor is an extra-ordinarily large explosion energy.

[40] *Using Spatial Distributions to Constrain Progenitors of Supernovae and Gamma Ray Bursts*. Raskin, C., Scannapieco, E., Rhoads, J., Della Valle, M. 2008, ApJ, in press

We carry out a comprehensive theoretical examination of the relationship between the spatial distribution of optical transients and the properties of their progenitor stars. By constructing analytic models of star-forming galaxies and the evolution of stellar populations within them, we are able to place constraints on candidate progenitors for core-collapse supernovae (SNe), long-duration gamma ray bursts, and supernovae Ia. In particular we first construct models of spiral galaxies that reproduce observations of core-collapse SNe, and we use these models to constrain the minimum mass for SNe Ic progenitors to approximately 25 solar masses. Secondly, we lay out the parameters of a dwarf irregular galaxy model, which we use to show that the progenitors of long-duration gamma-ray bursts are likely to have masses above approximately 43 solar masses. Finally, we introduce a new method for constraining the time scale associated with SNe Ia and apply it to our spiral galaxy models to show how observations can better be analyzed to discriminate between the leading progenitor models for these objects.

[41] *The short GRB070707 afterglow and its very faint host galaxy*. Piranomonte et al. 2008, A&A, in press

We present the results from an ESO/VLT campaign aimed at studying the afterglow properties of the short/hard gamma ray burst GRB 070707. Observations were carried out at ten different epochs from 0.5 to 80 days after the event. The optical flux decayed steeply with a power-law decay index greater than 3, later levelling off at R 27.3 mag; this is likely the emission level of the host galaxy, the faintest yet detected for a short GRB. Spectroscopic observations did not reveal any line features/edges that could unambiguously pinpoint the GRB redshift, but set a limit z ¡ 3.6. In the range of allowed redshifts, the host has a low luminosity, comparable to that of long-duration GRBs. The existence of such faint host galaxies suggests caution when associating short GRBs with bright, offset galaxies, where the true host might just be too dim for detection. The steepness of the decay of the optical afterglow of GRB 070707 challenges external shock models for the optical afterglow of short/hard GRBs. We argue that this behaviour might results from prolonged activity of the central engine or require alternative scenarios.

[42] *The complex light curve of the afterglow of GRB071010A* Covino et al. 2008, MNRAS, 388, 347

The results of an extensive observational campaign devoted to GRB071010A, a long-duration gamma-ray burst detected by the Swift satellite, are presented. This event was followed for almost a month in the optical/near-infrared (NIR) with various telescopes starting from about 2min after the high-energy event. Swift XRT observations started only later at about 0.4d. The light-curve evolution allows us to single out an initial rising phase with a maximum at about 7min, possibly the afterglow onset in the context of the standard fireball model, which is then followed by a smooth decay interrupted by a sharp rebrightening at about 0.6d. The rebrightening was visible in both the optical/NIR and X-rays and can be interpreted as an episode of discrete energy injection, although various alternatives are possible. A steepening of the afterglow light curve is recorded at about 1d. The entire evolution of the optical/NIR afterglow is consistent with being achromatic. This could be one of the few identified GRB afterglows with an achromatic break in the X-ray through the optical/NIR bands. Polarimetry was also obtained at about 1d, just after the rebrightening and almost coincident with the steepening. This provided a fairly tight upper limit of 0.9 per cent for the polarized-flux fraction.

[43] *Transient Heavy Element Absorption Systems in Novae: Episodic Mass Ejection from the Secondary Star* Williams, Robert; Mason, Elena; Massimo Della Valle; Ederoclite, Alessandro

A high-resolution spectroscopic survey of post-outburst novae observed at ESO, reveals short-lived heavy element absorption systems in a majority of novae near maximum light, having expansion velocities of 400-1000 km s-1 and velocity dispersions between 35 and 350 km s-1. A majority of systems are accelerated outward, and they all progressively weaken and disappear over timescales of weeks. A few of the systems having narrow, deeper absorption reveal a rich spectrum of singly ionized Sc, Ti, V, Cr, Fe, Sr, Y, Zr, and Ba lines. Analysis of the richest such system, in LMC 2005, shows the excitation temperature to be 10^4 K and elements lighter than Fe to have abundance enhancements over solar values by up to an order of magnitude. The gas causing the absorption systems must be circumbinary and its origin is most likely mass ejection from the secondary star. The absorbing gas exists before the outburst and may represent episodic mass transfer events from the secondary star that initiate the nova outburst(s). If SNe Ia originate in single degenerate binaries, such absorption systems could be detectable before maximum light.

5. Invited talks at international conferences (2005 - 2008)

[1] *Della Valle, M., Gilmozzi, R., Panagia, N., Bergeron, J., Madau, P., Spyromilio, J., Dierickx, P. ELT Observations of Supernovae at the Edge of the Universe*, Exploring the Cosmic Frontier, ESO Astrophysics Symposia European Southern Observatory, Springer, 2007, p. 95

[2] *The Rate and the Origin of type Ia SNe in Radio-Galaxies*, Della Valle, M., 2005, in "Cosmic Explosions", IAU Coll. n. 192, Valencia 2004, eds. J.M. Mercaide, K. Weiler, p. 361

[3]*The effects of the environment on the SNI-a rate*, Della Valle, M. 2005, in the proceedings of the conference "Supernovae as cosmological lighthouses", Padova 2004, ASP conference, pg

[4]*The Supernova-Gamma Ray Burst Connection*, Della Valle, M. 2005, in "Interacting binaries: Accretion, Evolution and Outcomes", held in Cefal, Sicily.

[5]*Supernovae shed light on Gamma-Ray Bursts*, Della Valle, M. 2005, in "Gamma-Ray Bursts in the Afterglow Era: 4th Workshop", held in Rome.

[6]*The evolution of the cosmic SN rate*, Della Valle, M. in "A Wide Field Survey Telescope at DOME C/A", Beijing, China, June, 2005

[7]*Supernovae and Gamma-ray burst: Observations and Questions*, Della Valle, M. 2005, in "Gamma-Ray Bursts in the Swift Era", held in Washington, November, 2005, Edited by S.S. Holt, N. Gehrels, and J.A. Nousek. AIP Conference Proceedings, Vol. 836, American Institute of Physics, 2006., p.367-379

[8]*New Supernovae and old GRBs*, Della Valle, M., in " The Multicoloured Landscape of Compact Objects and their Explosive Origins: Theory vs. Observations", held in Cefalù 11-24 Jun, 2006

[9]*Observations of the bump associated with GRB 050525A* Della Valle, M. in "Swift and GRBs: unveiling the relativistic Universe", Venice, June 2006

[10]*The diversity of type Ia Progenitors* Della Valle, M., in "One Millenium after Supernova 1006", Hangzhou, China, May 2006.

[11]*Supernova with and without SN fireworks*,Della Valle, M. in "Circumstellar Media and Late Stages of Massive Stellar Evolution" held in Ensenada, Mexico, Sept, 2006.

[12] *Supernovae and GRBs at ESO*, Della Valle, M. in the Forum Corea-Italy, April 2007, Seul.

[13]*Supernova-GRB Connection: recent observations*, Della Valle, M. in the

X-Forum Italy-China, ICRANet, Pescara , Jul, 2007.

[14]*Measuring the cosmological parameters with the Amati correlation of GRBs* Della Valle, M. 5th Italian-Sino Workshop May 28-June 1, 2008 - Teipei-Hualian, Taiwan

[15]*Supernovae and GRBs: Flashy and Somber Explosions* Della Valle, M. III Cefalú Conference, September 2008

6. APPENDICES

A. The SN-GRB Connection: Clues from VLT Observations

A.1. Abstract

We review the observational status of the Supernova/Gamma-Ray Burst connection. Observations of long duration Gamma-ray bursts suggest that they are associated with very bright SNe-Ibc. However recent VLT observations of GRB 060614 puzzle this scenario, pointing out the existence of long-duration Gamma-ray Burst not accompanied by a bright supernova. Current estimates of the SN and GRB rates yield a ratio GRB/SNe-Ibc in the range $\sim 0.4\% - 3\%$, then pointing out that some special circumstances are requested to a star, other being massive, to become a GRB progenitor. Swift observations of GRB060218/SN 2006aj suggest that the progenitors of long duration GRBs are Wolf-Rayet stars.

A.2. 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 (Kouveliotou et al. 1993), with "long" bursts characterized by $T > 2$ s. In the discovery paper, Klebesadel, Strong & Olson (1973) pointed out the lack of evidence for a connection between GRBs and Supernovae (SNe), as proposed by Colgate (1968), 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 mystery for almost three decades and only at the end of the 1990s the discovery of GRB afterglows (Costa et al. 1997, van Paradijs et al. 1997, Frail et. al 1997) at cosmological distances (Metzger et al. 1997) and the discovery of SN 1998bw in the error-box of GRB 980425 (Galama et al. 1998) have started shedding light upon the nature of GRB progenitors.

A.3. Core-Collapse Supernovae

Core-Collapse Supernovae represent about 70% of the exploding stars in the universe (Cappellaro et al. 1999, Mannucci et al. 2005). They are not usually discovered in elliptical galaxies and this led to the idea that their progenitors should be massive stars $> 8 - 10 M_{\odot}$ (e.g. Iben & Renzini 1983) that undergo core-collapse. This fact was perceived by Baade and Zwicky (1934): *"a supernova represents the transition of an ordinary star into a neutron star consisting mainly of neutrons"*. The gravitational binding energy of the imploding core ($\sim 10^{53}$ erg) is almost entirely (99%) released as neutrinos whereas only $\sim 10^{51}$ erg are converted in kinetic energy of the ejecta and a very tiny fraction, $\sim 10^{49}$ erg, in luminous energy.

The spectroscopic classification of SNe dates back to Minkowski (1941): *"Spectroscopic observations indicate at least two types of supernovae. Nine objects form an extremely homogeneous group provisionally called "type I". The remaining five objects are distinctly different; they are provisionally designed as type II. The individual differences in this group are large..."*. Particularly type-II SNe include objects with prominent hydrogen lines while type-I class is defined by the lack of hydrogen in the spectra. Nowadays we designated as *type-Ia* those type-I SNe that are characterized by a strong absorption observed at $\sim$ 6150 Å (attributed to the P-Cyg profile of Si II, $\lambda\lambda 6347, 6371$) and lack of H. The absence of H, and the fact that these SNe are discovered also in elliptical galaxies, hint that they arise from a different explosive phenomenon, such as the thermonuclear disruption of a white dwarf approaching the Chandrasekhar limit, after accreting material from a binary companion or coalescing with it (e.g. Livio 2001 and references therein). The spectroscopic classification of SNe has been substantially reviewed in the last 20 years (e.g. Filippenko 1997a) and several distinct classes of core-collapse SNe can be recognized from their spectra obtained close to maximum light or during the nebular stages.

a) *Normal type II.* SNe with prominent Balmer lines flanked by P-Cyg profiles (*"...the spectrum as a whole resembles that of normal novae in the transition stage..."*, Minkowski 1941). These SNe are believed to undergo the collapse of the core when the progenitor star still retains a huge H envelope ($\sim 10 - 60 M_{\odot}$, Hamuy 2003). The most outstanding feature is the Hα line flanked by a P-Cyg profile. These SNe show a very high degree of individuality that is reflected in wide range of observed line widths, that indicates the existence of a significant range in expansion velocities (Fig. 1).

b) *Interacting type II.* SNe belonging to this class show strong H lines in emission without absorptions. Chugai (1997) pointed out that these SNe undergo a strong interaction with a "*dense wind*" generated by the progenitor during repeated episodes of mass loss prior to exploding (e.g. SN 1994aj Benetti et al. 1998). Their spectra are dominated by a broad H_{α} line

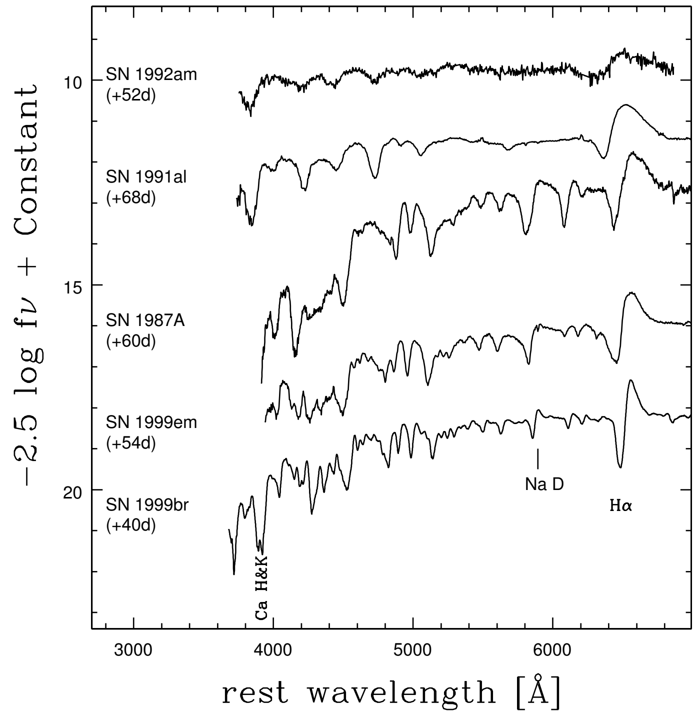

Figure A.1.: Optical spectra of type II SNe obtained a few weeks past maximum, illustrating different expansion velocities. Plots from Hamuy 2003.

(FWHM$\sim$ 10000 km/s) sometimes superimposed by a narrow emission component (FWHM$\sim$ $200-300$ km/s, see Fig. 2). In this case the SN is dubbed as II-n ("*n*arrow", Schlegel 1990). Sporadically a narrow P-Cyg profile can be observed as in Benetti et al. (1999) and in this case the designation II-d indicates "*d*ouble profile".

SNe belonging to class **a)** and **b)** can be crudely grouped into two photometric varieties: type II-P (*plateau*) and type II-L (*linear*) (Barbon, Ciatti & Rosino 1979, Doggett & Branch 1985). Shortly after the explosion all SN light curves are powered by the radioactive decay of ^{56}Ni $\rightarrow^{56}$ Co and later on by ^{56}Co $\rightarrow^{56}$ Fe, therefore the respective luminosities are mostly determined by the amount of ^{56}Ni that has been synthesized during the SN explosion. The magnitudes at maximum of type-II SNe span a range of about 5 mag (see Fig. 3), which may imply that the amount of ^{56}Ni produced in SN explosions varies by at least a factor 100 ($\sim 0.002 \div 0.2 M_{\odot}$, e.g. Turatto et al. 1998) or even more (see Pastorello 2007a and references therein).

c) *Type-Ib/c.* This class of SNe was first noted by Bertola (1964) *"It is well known that one of the most conspicuous features in the visual spectrum of type I supernovae is a very deep absorption at λ 6150 Å...Such absorption*

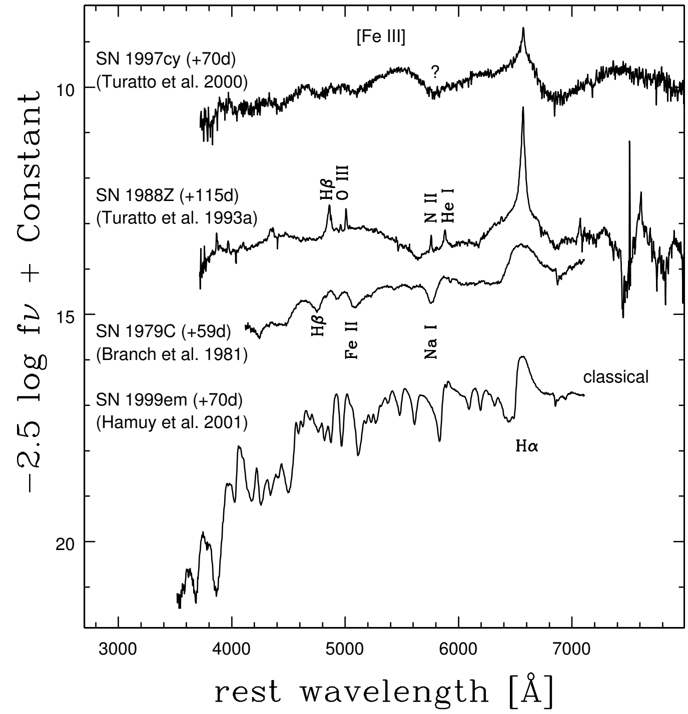

Figure A.2.: Optical spectra of interacting type II SNe, compared with the normal type II SN 1999em. Plots from Hamuy 2003.

is missing in the present SN[1]". The criteria to classify the members of this subclass of type-I SNe just as 'peculiar' objects were adopted in the literature for the following 20 years. Only in the mid-1980s (Panagia 1985, Elias et al. 1985; Uomoto & Kirshner 1985; Wheeler & Levreault 1995) it was realized that sufficient observational differences did exist to justify having two separate classes of objects (see Matheson et al. 2001 for a recent comprehensive study). Type-Ib SNe are characterized by spectra with no presence of H (Fig. 4) or very weak lines (Branch et al. 2002) and strong He I lines at $\lambda\lambda$ 4471, 5876, 6678 and 7065 Å (Porter & Filippenko 1987). Type-Ic (Wheeler & Harkness 1986) are characterized by weak or absent H and Si II $\lambda\lambda 6347, 6371$ lines, and no prominent (if not totally absent) He lines. They show Ca II H & K, NIR Ca II triplet and O I lines with P-Cyg profiles. Type-Ib/c SNe have been so far observed only in late type galaxies and their most outstanding spectroscopic feature is the lack of H in the spectra. Both facts suggest that their progenitors are massive stars, possibly in binary systems (e.g. Mirabel 2004, Maund et al. 2004), which undergo the collapse of their cores after they have lost the respective H or He envelopes, via strong stellar wind or transfer to a

[1]SN 1962L in NGC 1073

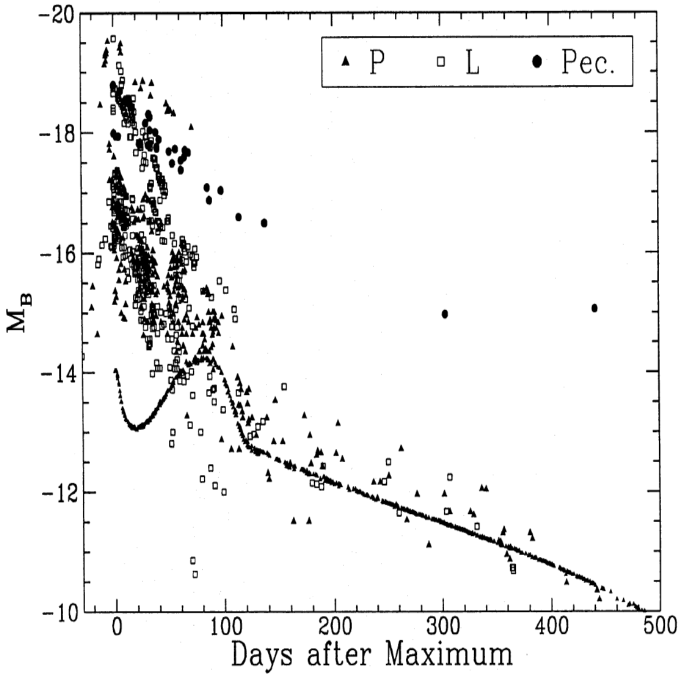

Figure A.3.: Absolute *B* light curves for 34 SNe-II, dereddened only for galactic extinction (plot from Patat et al. 1994).

binary companion via Roche overflow. This scenario is fully consistent with observations at radio wavelengths that reveal the existence of a strong radio emission due to the interaction of the ejecta with a dense pre-explosion stellar wind ($10^{-5/-6}$ $M_\odot$ yr^{-1})/established circumstellar medium, produced by the progenitor (Weiler et al. 2002).

d) *Type-IIb*. Members of this meagre class of SNe are objects that evolve from type-II, as inferred by observations of H lines in the spectra at maximum light, into type Ib (lack of H lines during the nebular stage, for example). The precursors are thought to be massive stars that still retain a thin H envelope prior to exploding. Prototypical objects of this SN class are SN 1987K (Filippenko 1988) and SN 1993J (Swartz et al. 1993; Filippenko, Matheson & Ho 1993). The discovery of these SNe provides a robust piece of evidence for the existence of a continuous sequence of SNe having decreasing envelope mass, i.e. type II–IIb–Ib–Ib/c–Ic.

e) *type Ib-n* or Interacting type Ib/c. Members of this SN type show spectra with blue continuum and relatively narrow (2000km/s) He I lines (hence the label Ib-n) overimposed on broader (5000-9000km/s) features of intermediate-mass elements (O I, Ca II, Mg I). While the broad lines are due to the SN ejecta, the narrow lines arise in a photoionised, slowly moving He-rich circumstellar medium (Fig. 5). These SNe are thought to be the result of the core-collapse explosion of a Wolf Rayet C/O star still embedded in the He-

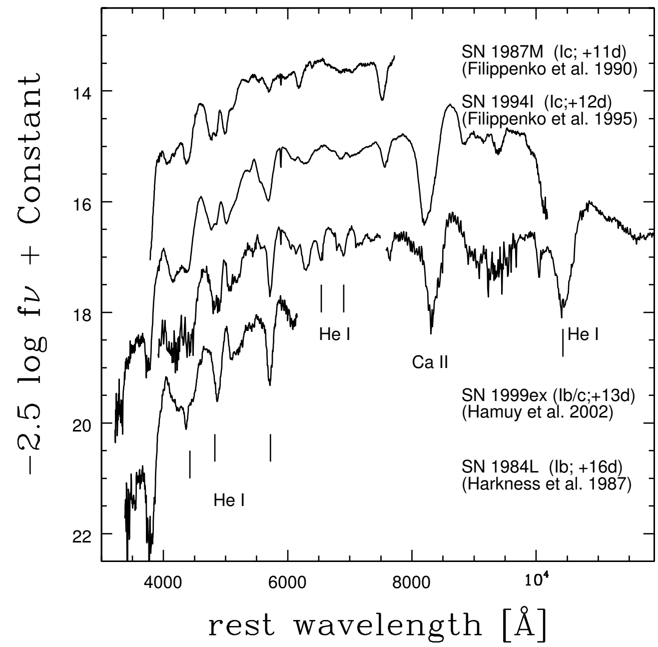

Figure A.4.: Optical spectra of type-Ib and type-Ic SNe obtained a few weeks past maximum. Plots from Hamuy 2003.

rich circumstellar material produced by recurrent, major mass loss episodes occurred during the very final stages of the star's life. One of these episodes was observed as a luminous outburst only two years before the explosion of SN 2006jc (Pastorello et al. 2007b).

f) *Hypernovae* (Fig. 6). In 1998 a 'weird' SN (1998bw) was discovered to be spatially and temporally coincident (chance probability $P \sim 10^{-4/-5}$) with the Gamma Ray Burst 980425 (Galama et al. 1998). The early spectroscopic classification of this object was not an easy task, indeed. The spectrum at maximum light was: *"...not typical of type-Ic supernovae; indeed, the spectrum does not match any of the known spectral classes, but perhaps 'peculiar type Ic' is the best choice at this time"* (Filippenko 1998). Only observations at late stages (Patat et al. 2001, Stathakis et al. 2000, Sollerman et al. 2000) have allowed to unambiguously classify SN 1998bw as type Ib/c. To date (November 2007) 13 SNe (see Tab. 1) have been found to display spectra, at maximum light, with similar characteristics, i.e. an almost featureless continuum, characterized by broad undulations, without H lines. The comparison with the prototypical Ic event, SN 1994I (Filippenko et al. 1995, Clocchiatti et al. 1996), has confirmed that these 'peculiar' objects are SNe-Ib/c with ex-

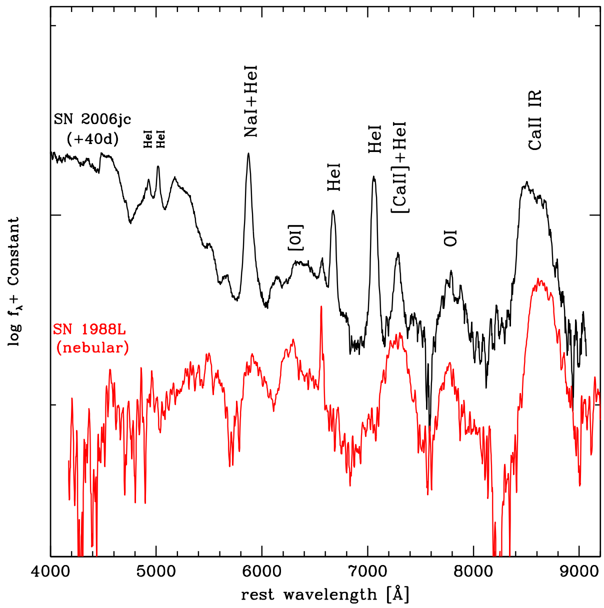

Figure A.5.: Comparison between a spectrum of the type Ib-n SN 2006jc taken about 40 days after explosion and that of an ordinary Type Ic in the nebular phase. The main spectral features are marked. The most evident differences are the flux excess exhibited by SN 2006jc in the blue wavelengths and the presence, at the same time, of a relatively narrow He I lines from the circumstellar medium. These lines are not observed in the classic type Ic spectrum.

pansion velocities of the order of 30-40000 km/s that lead to large Doppler broadening and blending of the emission lines (Fig. 7).

The very high expansion velocities of the ejecta suggest that these SNe are hyper-kinetic (Nomoto et al. 2001), although not necessarily hyper-luminous. Indeed their magnitudes at maximum span a broad range of luminosities: $M_B \sim -17.0 \div -19.5$ (see Fig 8). These "broad lined" Supernovae of type Ibc, have been dubbed as *Hypernovae* (HNe hereafter, note that this designation was used by Paczyǹski (1998) with a different meaning).

A.4. The GRB-SN Connection

A decade of observations of Gamma-ray Bursts (GRBs) from space and ground-based telescopes have established the existence of a link between long-duration GRBs and the death of massive stars. This conclusion is based on three pieces of evidence:

- the discovery of four associations between "broad lined" Supernovae

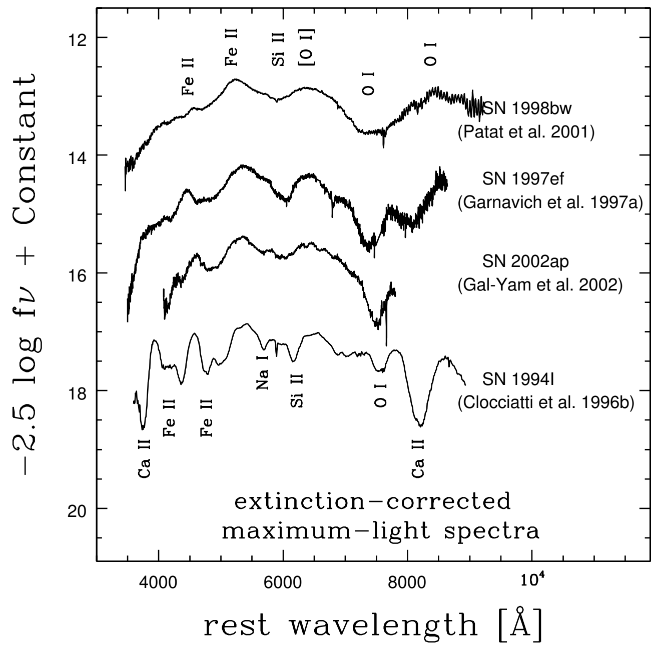

Figure A.6.: Optical spectra at maximum light of Hypernovae, compared with the prototypical SN-Ic 1994I. Plots from Hamuy 2003.

Ibc and GRBs: GRB 980425/SN 1998bw (Galama et al. 1998), GRB 030329 /SN 2003dh (Stanek et al. 2003, Hjorth et al. 2003), GRB 031203 /SN 2003lw (Malesani et al. 2004) and GRB 060218/ SN 2006aj (Campana et al. 2006; Pian et al. 2006);

- in three cases, spectroscopic observations of the rebrightenings observed during the late decline of the afterglows (Bloom et al. 1999) have revealed the presence of SN features, in GRB 021211/SN 2002lt (Della Valle et al. 2003), in XRF 020903 (Soderberg et al. 2005), and possibly in GRB 050525A/SN 2005nc (Della Valle et al. 2006a);

- the host galaxies of long GRBs are star forming galaxies (Djorgovski et al. 1998, Fruchter et al. 2006).

A plausible theoretical scenario (e.g. Woosley & Bloom 2006) suggests that long duration GRBs are produced in the collapse of the core of Wolf-Rayet (H/He stripped-off) stars, with an initial mass higher than $\sim$ 20 $M_\odot$ and a bright SNe-Ic is the final product. Indeed this fact has been recently observed (Campana et al. 2006). On the other hand, very recent observations of GRB 060614 (Della Valle et al. 2006b, Fynbo et al. 2006, Gal-Yam et al. 2006) puzzle

SN	cz (km/s)	References
1997dq	958	Mazzali et al. 2004
1997ef	3539	Filippenko 1997b
1998bw	2550	Galama et al. 1998
1999as	36000	Hatano et al. 2001
2002ap	632	Mazzali et al. 2002, Foley et al. 2003
2002bl	4757	Filippenko et al. 2002
2003bg	1320	Filippenko & Chornack 2003
2003dh	46000	Stanek et al. 2003, Hjorth et al. 2003
2003jd	5635	Filippenko et al.2003; Matheson et al. 2003b
2003lw	30000	Malesani et al. 2004
2004bu	5549	Foley et al. 2004
2005da	4495	Modjaz et al. 2005
2006aj	9000	Pian et al. 2006

Table A.1.: List of SNe classified as Hypernovae on the basis of their spectra.

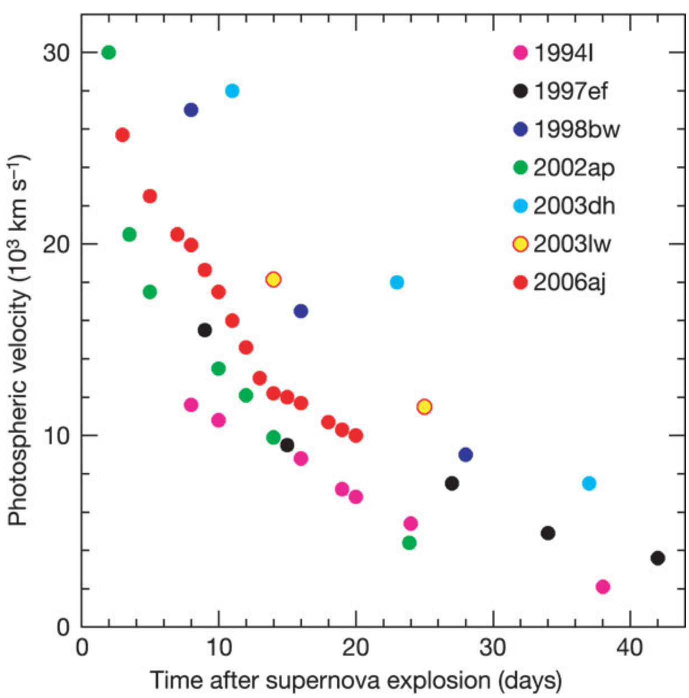

Figure A.7.: Expansion velocities of HNe and SN 1994I. Plot from Pian et al. 2006.

this neat scenario: long-duration GRBs without an accompanying (bright) SN do exist.

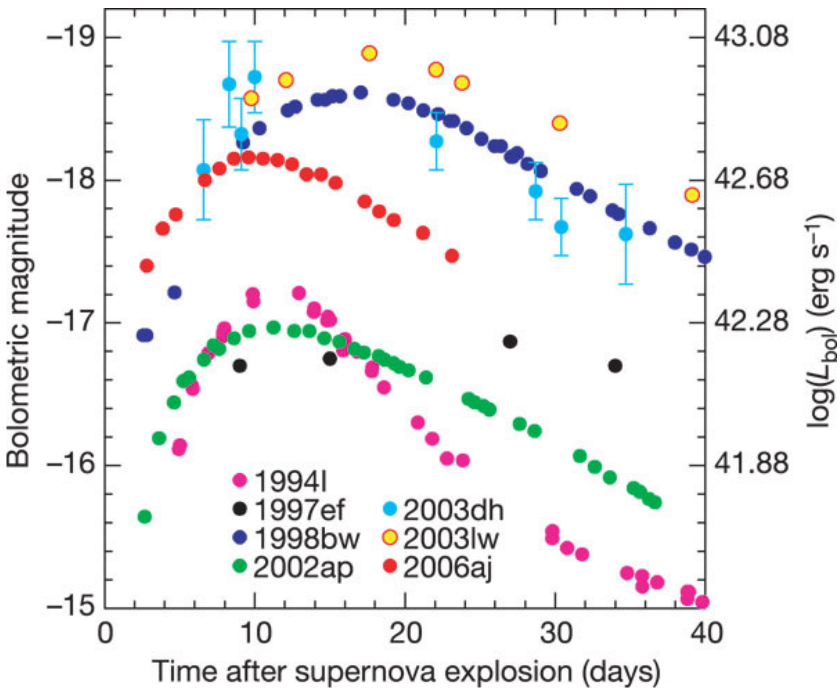

Figure A.8.: Absolute bolometric light curves of : i) the four spectroscopically identified supernovae associated with GRBs, namely SN 1998bw (GRB 980425, z = 0.0085), SN 2003dh (GRB 030329, z = 0.168), SN 2003lw (GRB 031203, z = 0.1055), and SN 2006aj (XRF 060218, z = 0.03342); ii) of two broad-lined supernovae (not accompanied by a GRB), SN 1997ef and SN 2002ap; and iii) of the "normal"SN-Ic, SN 1994I. Error bars are 1σ.From the plot is apparent that Hypernovae are not always overbright with respect to normal SNe-Ic. Plot from Pian et al. 2006.

A.5. GRB-SN Associations in the Local Universe

A.5.1. GRB 980425/SN 1998bw

SN 1998bw was the first SN found to be associated with a GRB. GRB 980425 was discovered in the nearby galaxy ESO 184-G82 at $d = 40Mpc$ and it was underenegetic by 4 orders of magnitudes with respect to typical "cosmological" γ–budget of about 10^{51} erg. Also the evolution of SN 1998bw was peculiar (Patat et al. 2001). It was very bright at maximum ($M_V \sim -19$), the ejecta exhibited unusual high expansion velocities (about 30,000 km/s) when compared to "standard Sne-Ib/c". The radio emitting region associated with the GRB-SN was expanding at mildly relativistic velocities ($\Gamma \sim 2$, Kulkarni et al. 1998).

The theoretical modeling of the light curve and spectra suggests that SN 1998bw can be well reproduced by the explosion of an H-envelope stripped

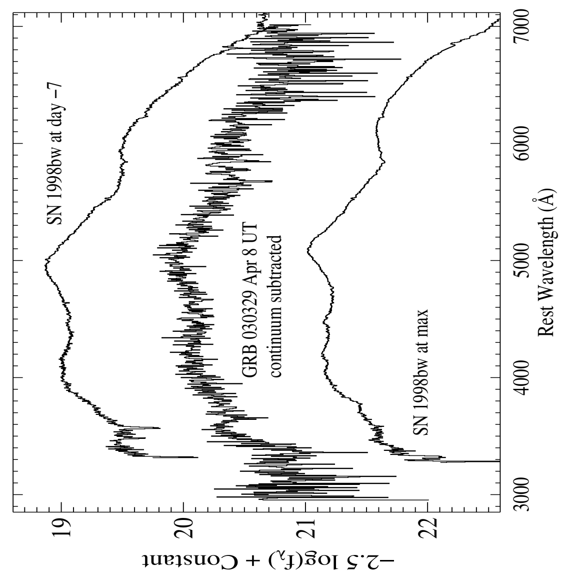

Figure A.9.: Spectrum of 2003 April 8 with the smoothed spectrum of April 4 scaled and subtracted. The residual spectrum shows broad bumps at approximately 5000 and 4200 Å (rest frame), which is similar to the spectrum of the peculiar type-Ic SN 1998bw a week before maximum light (Patat et al. 2001). Plot from Stanek et al. 2003.

star, of about $40M_\odot$ on the main sequence (see Tab. 2). This picture is consistent with the radio properties of SN 1998bw, which can be explained as due to the interaction of a mildly relativistic shock with the dense circumstellar medium (Tan et al. 2001, Weiler et al. 2002) due to the massive progenitor wind. Maeda et al. (2006) have recently modeled the bolometric lightcurve of SN 1998bw with a smaller amount of ^{56}Ni ($\sim 0.4\,M_\odot$) by assuming that the SN explosion was highly asymmetric (see also Höflich, Wheeler & Wang 1999). In 1998, the association between two peculiar astrophysical objects such as GRB 980425 (very faint gamma-ray emission, unusual afterglow properties) and SN 1998bw (overluminous SN characterized by unusual spectroscopic features) was believed to be only suggestive, rather than representative, of the existence of a general SN/GRB connection.

A.5.2. GRB 030329/SN 2003dh: The smoking gun

GRB 030329 was discovered by the HETE–2 satellite at a redshift $z = 0.1685$ (Greiner et al. 2003). SN features were detected in the spectra of the afterglow

$E_K(10^{52})$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	Iwamoto et al. 1998
2	0.45	6-11	25-35	~ 2	Woosley et al. 1999
0.7-5	0.4	14	40	~ 3	Nakamura et al. 2001

Table A.2.: SN 1998bw: basic data.

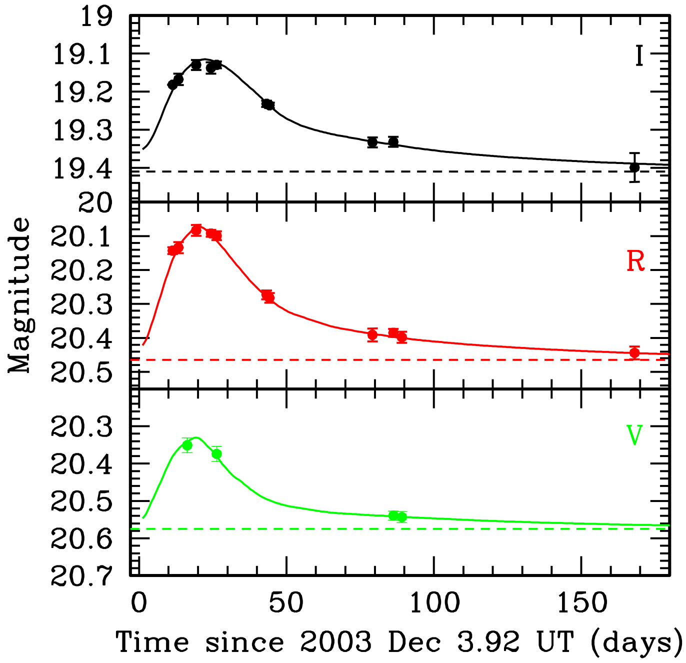

Figure A.10.: Optical and NIR light curves of GRB 031203 (circles). The solid curves show the evolution of SN 1998bw, rescaled at $z = 0.1055$, stretched by a factor 1.1, extinguished with $E(B-V) = 1.1$, and brightened by 0.5 mag. The dashed lines indicate the host galaxy contribution. The vertical dotted lines mark the epochs of our spectra. Plot from Malesani et al. 2004.

by several groups (Stanek et al. 2003, Hjorth et al. 2003; Kawabata et al. 2003; Matheson et al. 2003a) about one week later (Fig. 9). The associated SN (2003dh) looked similar to SN 1998bw. Both the gamma-ray energy budget and afterglow properties of this GRB were similar to those observed in other GRBs, and therefore, the link between GRBs and SNe was finally established to be more general. The modeling of the early spectra of SN 2003dh. The progenitor was a massive envelope-stripped star of $\sim 35-40M_\odot$ on the main sequence (Mazzali et al. 2003).

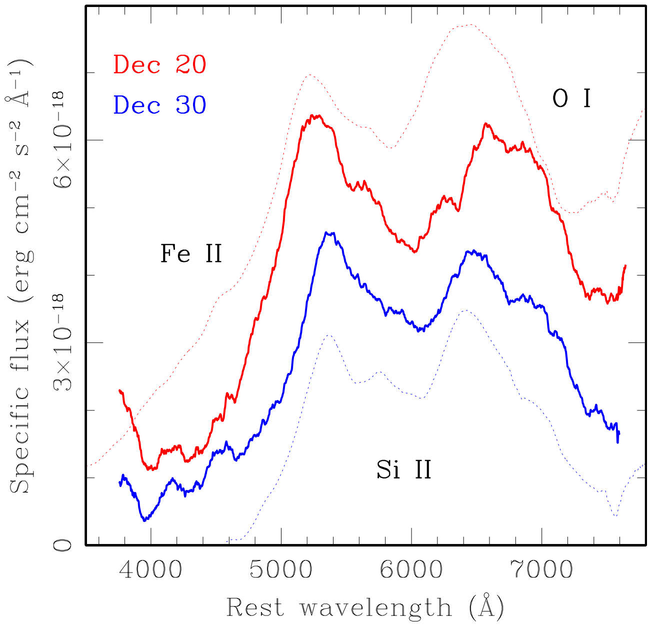

Figure A.11.: Spectra of SN 2003lw, taken on 2003 December 20 and 30 (solid lines), smoothed with a boxcar filter 250Å wide. Dotted lines show the spectra of SN 1998bw (from Patat et al. 2001), taken on 1998 May 9 and 19 (13.5 and 23.5 days after the GRB, or 2 days before and 7 days after the V-band maximum, respectively), extinguished with $E(B-V) = 1.1$ and a Galactic extinction law (Cardelli et al. 1989). The spectra of SN 1998bw were vertically displaced for presentation purposes. Plots from Malesani et al. 2004.

A.5.3. GRB 031203/SN 2003lw

GRB 031203 was a 30s burst detected by INTEGRAL (Mereghetti et al. 2003) at $z = 0.1055$ (Prochaska et al. 2004, Margutti et al. 2007). The burst energy was extremely low, of the order of 10^{49} erg, well below the "standard" $\sim 10^{51}$ erg of normal GRBs (Frail et al. 2001, Panaitescu & Kumar 2001). A few days after the GRB, a rebrightening was apparent in all optical bands (Fig. 10) (Malesani et al. 2004, Thomsen et al. 2004; Cobb et al. 2004; Gal-Yam et al. 2004). Spectra of the rebrightening obtained on 2003 Dec 20 and Dec 30 (14 and 23 rest-frame days after the GRB, see Fig. 11) are remarkably similar to those of SN 1998bw obtained at comparable epochs (Malesani et al. 2004). The light curve of SN 2003lw is characterized by a slower temporal evolution (about $\sim$ 10%) with respect to SN 1998bw. SN 2003lw may be brighter than SN 1998bw by 0.3 mag. However some words of caution are in order given the large uncertainty (about 0.5 mag) with affects the correction for reddening. An analysis of its photometric and spectroscopic evolution (Mazzali et al. 2006a) indicates that this Hypernova had a main sequence mass of 40-50 $M_{\odot}$.

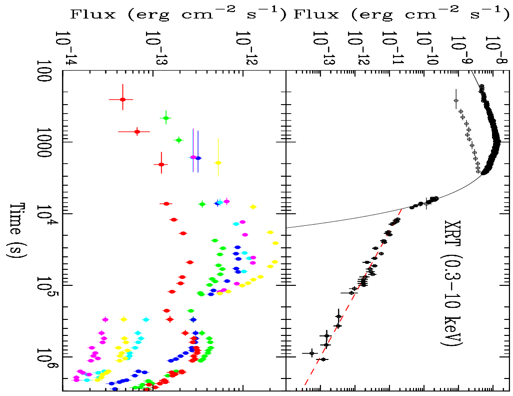

Figure A.12.: The XRT light curve between 0.3 and 10 keV is shown with open black circles. Filled grey circles represent the contribution to the 0.3-10-keV flux by the blackbody component. Its percentage contribution is increasing with time, becoming dominant at the end of the exponential decay. The X-ray light curve has a long, slow power-law rise followed by an exponential decay. At about 10,000 s the light curve breaks to a shallower power-law decay (dashed red line) with an index of ~ -1.2, which is typical of GRB afterglows. This classical afterglow can be naturally accounted for by a shock driven into the wind by a shell with kinetic energy of $\sim 10^{49}$ erg. The ultraviolet band light curve peaks at about 30 ks owing to the shock break-out from the outer stellar surface and the surrounding dense stellar wind, while the optical band peaks at about 800 ks owing to radioactive heating in the supernova ejecta. Plot from Campana et al. 2006.

A.5.4. GRB 060218/SN 2006aj

GRB 060218 was detected by Swift at z=0.033. This burst was unusually long, with $T_{90} \sim 2100s$ (Campana et al. 2006, Dainotti et al. 2006). The UVOT telescope found an emission peaking in a broad plateau first at UV wavelengths and later in the optical (see Fig. 12). The lightcurve showed a minimum at about 200 ks after the gamma event and a rebrightening peaking at about 700 ks (due to the Ni-Co-Fe decay). A few days after the Swift observations, low resolution spectra (Pian et al. 2006) pointed out the presence of a rising SN

(2006aj) with broad emission lines similarly to those observed in other GRB-SNe. The most striking feature exhibited by this gamma event (see Campana et al. 2006) is the presence of a thermal component observed in the XRT data, up to 10 ks, and in the UVOT data, up to about 100 ks. This black body component shows a decreasing temperature accompanied by an increasing luminosity, which implies an increase in the apparent emission radius from an initial 5×10^{11} cm to about 3×10^{14} cm, in about 100ks. This corresponds to an expansion velocity of the order of 30,000 km/s, which is quite typical for GRB-SNe (see Patat et al. 2001). After assuming linear expansion one can estimate the star radius of the progenitors to be of the order of 5×10^{11} cm which is comparable to the size of a Wolf-Rayet star. The (UV) black-body component has been interpreted in terms of a shock break-out wave produced after the collapse of the core to a Neutron Star (see Mazzali et al. 2006b) emerging from the region within which the stellar wind of the massive progenitor is optically thick (about 10^{13}cm, see Campana et al. 2006 and Panagia & Felli 1981).

A.6. SN/GRB Associations in the Distant Universe

A.6.1. SN 2002lt/GRB 021211

GRB 021211 was detected by the HETE–2 satellite at $z = 1.006$ (Vreeswijk et al. 2002). Late-time photometric follow-up, carried out with the ESO VLT–UT4, together with HST observations, show a rebrightening, starting ~ 15 days after the burst and reaching the maximum ($R \sim 24.5$) during the first week of January (see Fig. 13). 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 obtained with FORS 2, 27 days after the GRB, during the rebrightening phase showed broad low-amplitude undulations blueward and redward of a broad absorption, the minimum of which was measured at ~ 3770 Å (in the rest frame of the GRB), whereas its blue wing extends up to ~ 3650 Å (Della Valle et al. 2003). The comparison with the spectra of other SNe supports the identification of the broad absorption with a blend of the Ca II *H* and *K* absorption lines. The blueshift corresponding to the minimum of the absorption implies an expansion velocity of $v \sim 14\,000$ km/s, which is often observed in SN explosions (see Fig. 14).

A.6.2. SN 2005nc/GRB 050525A

The long-duration GRB 050525A was discovered by the *Swift* satellite (Gehrels et al. 2004) on 2005 May 25.002 UT. It was a bright event, with fluence

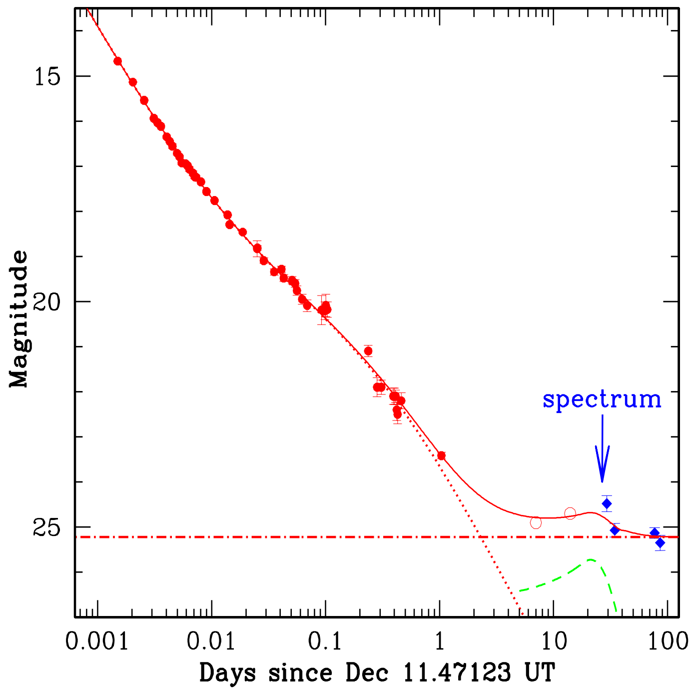

Figure A.13.: Light curve of the afterglow of GRB 021211. Filled circles represent data from published works (Fox et al. 2003; Li et al. 2003; Pandey et al. 2003), open circles are converted from HST measurements (Fruchter et al. 2002), while filled diamonds indicate our data; the arrow shows the epoch of our spectroscopic measurement. The dotted and dot-dashed lines represent the afterglow and host contribution respectively. The dashed line shows the light curve of SN 1994I reported at $z = 1.006$ and dereddened with $A_V = 2$ (from Lee et al. 1995). The solid line shows the sum of the three contributions. Plot from Della Valle et al. 2003.

$\mathcal{F} = (2.01 \pm 0.05) \times 10^{-5}$ erg cm^{-2} and duration $T_{90} = 8.8 \pm 0.5$ s (this is the time during which 90% of the photons are collected). Spectroscopic observation of the afterglow allowed to measure $z = 0.606$. Photometric data show a flattening of the light curve at $R \sim 24$, starting about 5 d after the burst (observer rest frame, Fig. 15) and lasting for about 20 d (Della Valle et al. 2006b). The contribution of the host galaxy during this phase is $\sim 40\%$, as estimated from our late-epoch images which show the host magnitude is fainter than $R \sim 25$. The afterglow contribution, as extrapolated from the earlier measurement, is negligible at these epochs ($< 3\%$ at 20 d after the GRB). This fact suggests that the flattening is powered by an additional source of energy. A spectrum, obtained at the ESO VLT-UT1 with the FORS 2 instrument on 2005 Jun 28 (36 d after the burst, observer frame) bears some similarities with the spectrum of SN 1998bw obtained 5d past maximum and dimmed by ≈ 0.9 mag. However the low S/N ratio of the spectrum obtained at VLT does not allow us to rule out more exotic interpretations of the observed flattening

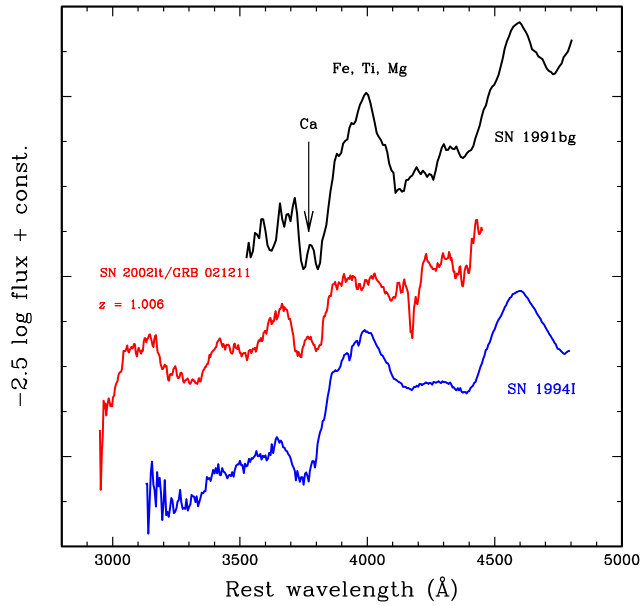

Figure A.14.: Spectrum of the afterglow+host galaxy of GRB 021211 (middle line), taken on Jan 8.27 UT (27 days after the burst). For comparison, the spectra of SN 1994I (type Ic, bottom) and SN 1991bg (peculiar type Ia, top) are displayed, both showing the Ca absorption. Plot from Della Valle et al. 2004.

such as a light-echo (Della Valle 2006b).

A.7. Hypernova and GRB Rates

A rate of $\sim 2 \times 10^4$ SNe-Ibc Gpc^{-3} yr^{-1} is derived by combining the local density of B luminosity (e.g. Madau, Della Valle & Panagia 1998) with the rate of 0.16 SNe-Ibc per century and per 10^{10} $L_{B,\odot}$ (SNu units, Cappellaro, Evans & Turatto 1999) measured in Sbc–Irr galaxies. This value of the SN rate has to be compared with the rate of "cosmological" GRBs of $\sim$ 1 GRB Gpc^{-3} yr^{-1} (Guetta, Piran & Waxman 2005, Schmidt 2001), rescaled for the jet beaming factor, f_b^{-1}: $\sim$ 75 (Guetta, Piran & Waxman 2005) up to $\sim$ 500 (Frail et al. 2001), corresponding to beaming angles $\sim 10°$–$4°$ respectively. Taking these figures at their face value, we find the ratio GRB/SNe to be in the range: $\sim 0.4\% - 3\%$ (see Della Valle 2006c, Guetta & Della Valle 2007). Radio surveys give independent and consistent constraints: Soderberg et al. (2006a) find the ratio GRB/SNe-Ibc to be $< 10\%$.

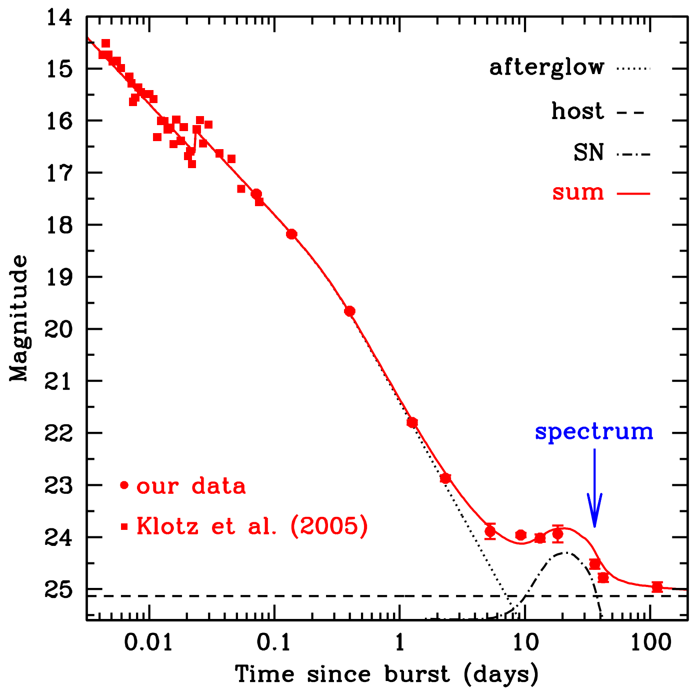

Figure A.15.: R-band light curve of the afterglow of GRB 050525A. Filled circles represent our observations (TNG, VLT). Squares are from Klotz et al. (2005) and were not included in the fit. The dotted, dashed, and dot-dashed lines indicate the afterglow, the host galaxy, and the SN contributions, respectively. The solid line is the sum of the three contributions.Plot from Della Valle et al. 2006a

Several authors (e.g., Della Valle 2005, Pian et al. 2006, Soderberg et al. 2006a, Cobb et al. 2006, Amati et al. 2007) have pointed out that, since the volume sampled by sub-energetic GRBs is much smaller than that probed by cosmological GRBs (a factor $\sim 10^6$) the number of sub–energetic GRBs may well be higher, by $\gtrsim 2$ orders of magnitude, than that of "cosmological" GRBs. However, Guetta & Della Valle (2007) have found that sub-energetic GRBs are, on average, much less collimated events than "cosmological" GRBs, likely $f_b^{-1} \lesssim 10$, (see also Soderberg et al. 2006b), therefore the discrepancy between the intrinsic frequency of occurence of the two types of GRBs may be considerably smaller, possibly of the order of $\gtrsim 3$. So, given the uncertainties, we cannot exclude that one single population of GRBs is responsible for producing both the sub-energetic/isotropic and highly beamed components.

GRB	SN	$+\Delta$t(days)	$-\Delta$t(days)	References
GRB 980425	1998bw	0.7	–2	Iwamoto et al. 1998
GRB 000911	bump	1.5	–7	Lazzati et al. 2001
GRB 011121	2001ke	0	–5	Bloom et al. 2002
		–	a few	Garnavich et al. 2003
GRB 021211	2002lt	1.5	–3	Della Valle et al. 2003
GRB 030329	2003dh	2	–8	Kawabata et al. 2003
		–	–2	Matheson et al. 2003a
GRB 031203	2003lw	0	–2	Malesani et al. 2004
GRB 041006	bump	2	0	Stanek et al. 2005
GRB 050525A	2005nc	0	2	Della Valle et al. 2006b
GRB 060218	2006aj	< 0.1	< 0.1	Campana et al. 2006

Table A.3.: Supernova-Gamma Ray Burst time lag. A negative time lag indicates that the SN explosion precedes the GRB.

A.8. GRB 060614: when a star dies in the shade

Recent observations of GRB 060614 (Della Valle et al. 2006b, Fynbo et al. 2006, Gal-Yam et al. 2006) challenge the simple idea that all long-duration GRBs are produced in SN explosions. Indeed any "potential" SN associated with this GRB was at least 200 times fainter (in R band) than the other GRB-SNe (see Fig. 16). This fact may suggest scenarios in which the GRB is produced without an accompanying SN, such as the vacuum polarization mechanism (Ruffini 1998), the transition neutron star to quark star (Berezhiani et al. 2003) or a merging event (Gherels et al. 2006, but see Amati et al. 2007 for a different view). These data are also consistent with the "Supranova" model where the SN has occurred months of years before the GRB (Vietri & Stella 1999). Della Valle et al. 2006 proposed as possible explanation for GRB 060614 that most ^{56}Ni produced during the latest stages of the stellar evolution of the progenitor is not ejected with the envelopes, as commonly observed in the broad-lined SNe-Ibc associated with GRBs, but it falls back and it is swallowed by the newborn black-hole (see Tominaga et al. 2007). If this mechanism is at play, a consequence is that only the tiny fraction of *Ni* in the jets can escape from the exploding progenitor. This fact implies that less than $\sim 10^{-4}$ $M_{\odot}$ of *Ni* are ejected and a so small amount can explain the very low luminosity (fainter than $M_B \sim -13$) of the SN associated with GRB 060614. This scenario is indirectly supported by the discovery of unusually faint core-collapse SNe (Pastorello et al. 2007a and references therein).

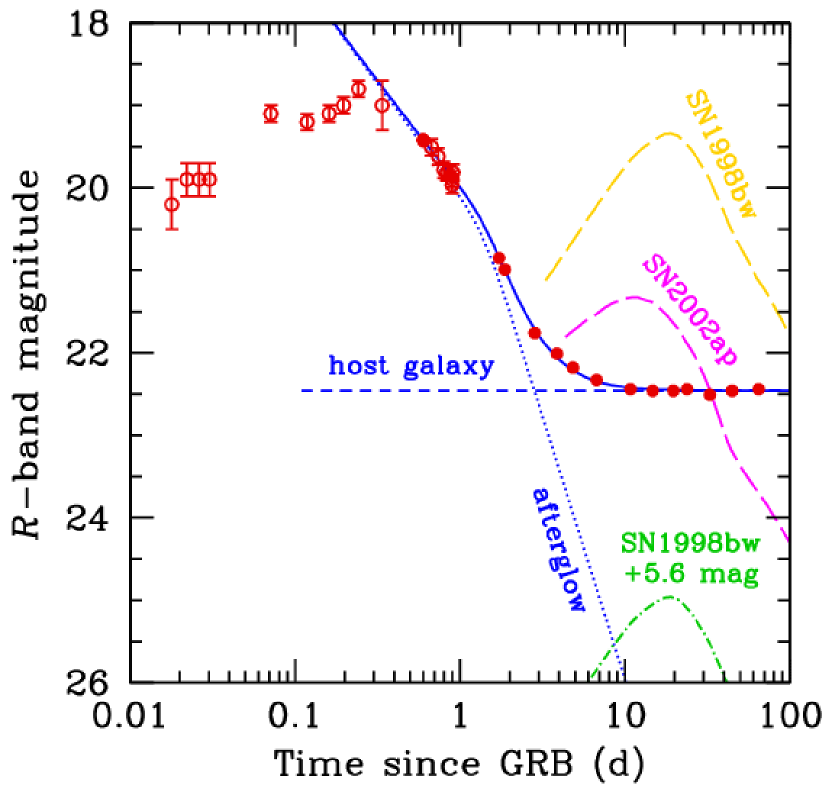

Figure A.16.: Light curve of the optical emission from GRB 060614. The circles represent the observed data. There is no sign of rebrightening due to a supernova. The light curve after about 0.3 day (blue solid line) has been decomposed in the sum of two components: the afterglow (blue dotted line) and the host galaxy (blue short-dashed lines). There is no need for a supernova component: the green dot-dashed line is the faintest supernova allowed by our data. For comparison, the long-dashed lines show the light curves of two supernovae: SN 1998bw, the proto-typical event associated with a GRB, and SN 2002ap, which is a faint broad-lined SN-Ib/c (adapted from Fig. 2 of Della Valle et al. 2006b).

A.9. SN-GRB time lag

Several authors have reported the detection of Fe and other metal lines in GRB X-ray afterglows (e.g. Piro et al. 1999; Antonelli et al. 2000; Reeves et al. 2002). If valid (see Sako et al. 2005 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, Butler et al. (2003) 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 (Vietri & Stella 1998), where a SN is predicted to explode months or years before the γ burst. In Tab. 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 Tab. III at their face value, it is apparent that in (at least) a significant fraction of cases the GRBs and SNe occur simultaneously.

A.10. SN 2008D/XRF 080109: a link between Supernovae and GRBs

On 2008 January 9.57 UT the X-Ray Telescope (XRT) on board Swift detected a X-ray Flash (XRF 080109) in the galaxy NGC2770(Berger & Soderberg 2008). Optical follow-up revealed the presence of a supernova coincident with the XRF (SN 2008D, Deng et al. 2008). Early spectra (Valenti et al. 2008) showed broad absorption lines superposed on a blue continuum, and lacked hydrogen or helium lines. The spectra resembled those of the XRF-SN 2006aj although much more reddened: we estimate that $E(B-V)_{tot} = 0.65$ mag (Mazzali et al. 2008).

In addition to the weak XRF, SN 2008D shows a number of peculiar features: i) the optical light curve had two peaks a first, dim maximum was reached less than 2 days after the XRF. After a brief decline the luminosity increased again, reaching principal maximum ($V = 17.37$) $\sim$ 19 days after the XRF. A 18-20 day risetime is typical of GRB-HNe while normal SNe Ic reach maximum in 10-12 days.

Another unusual feature is the spectral metamorphosis. Unlike SNe 2006aj and other GRB-SNe the broad absorptions did not persist. As they disappeared, He I lines developed (Modjaz et al. 2008). Broad lines require material moving with velocity $v > 0.1c$, therefore their quick disappearance implies that the mass moving at high velocities was small.

Mazzali et al. 2008 (see also Tanaka et al. 2008) have reproduced the spectral evolution and the light curve of SN 2008D after the first narrow peak using a model with $M_{\rm ej} \sim 7 M_\odot$ and spherically symmetric $E \sim 6 \cdot 10^{51}$ erg, of which $\sim 0.03 M_\odot$, with energy $\sim 5 \cdot 10^{50}$ erg, are at $v > 0.1c$. Our light curve fits indicate that SN 2008D synthesised $\sim 0.09 M_\odot$ of ^{56}Ni, like the non-GRB HN SN Ic 2002ap and the normal SN Ic 1994I but much less than the luminous GRB-HN SN 1998bw. Comparing the mass of the exploding He-star that we derived with evolutionary models of massive stars, we find that the progenitor had main sequence mass $\sim 25 - 30 M_\odot$. A star of this mass is likely to collapse to a black hole, as do GRB/SNe.

The X-ray spectrum of SN 2008D can be fitted with either a simple power-law indicating a non-thermal emission mechanism or a combination of a hot black body ($T = 3.8 \cdot 10^6$ K) and a power law. In the latter case, the unabsorbed luminosity of the black-body component is a small fraction of the total X-ray luminosity (about 14%) and the angular size (about 6°) of the emitting area (radius $R_{\rm ph} \sim 10^{10}$ cm) is typical of GRB jets. This leads naturally to a scenario, which is alternative to the shock break-out model proposed by Soderberg et al. 2008. XRF 080109 was the breakout of a failed relativistic jet powered by a central engine as in GRBs. The jet failed because its energy was initially low or because it was damped by the He layer, which is absent in GRB-HNe, or both. The scenario proposed by Mazzali et al. 2008 implies that GRB-like inner engine activity exists in all black hole-forming SNe Ibc, but only a small percentage of them (about 5%, see Guetta & Della Valle 2007) are able to produce a GRB, while mostly SNe-Ibc do not. SN 2008D has significantly higher energy than normal core-collapse SNe (although less than GRB/HNe), therefore, it is unlikely that all SNe Ibc, and even more so all core-collapse SNe produce a weak X-ray flash similar to XRF 080109. This conclusion is supported by the following argument. Type II SNe in late Spiral/Irr galaxies (the typical Hubble type of GRB hosts) are about 6 times more frequent than SNe Ib (Mannucci et al. 2005). Although the serendipitous discovery of an SN Ib by XRT may be a statistical fluctuation, it may also suggest that the soft X-ray emission accompanying SN 2008D is typical of overenergetic SNe Ib, and absent (or very weak) in normal core-collapse SNe.

A.11. Conclusions

Ten years of GRB observations have produced an amazing advance in our understanding of the GRB-SN phenomenon and a number of important results do emerge:

i) Long duration GRBs originates from the death of massive stars. This fact is well documented by: a) the direct observations of four SNe associated with GRBs; b) a dozen of rebrightenings (e.g. Zeh et al. 2004), detected during the late stages of the afterglows, are well reproduced by adding SN components to the afterglow lightcurves. In some cases SN features have been detected in the spectra of the "bumps"; c) most host galaxies of long GRBs exhibit an intense star forming activity.

ii) Observations of GRB 060218 coupled with simple theoretical arguments indicate that the progenitor star of the associated SN (2006aj) had a radius of about $\sim 5 \times 10^{11}$ cm. This is similar to the size of a Wolf-Rayet star and fully consistent with the fact that all GRB-SNe, so far observed, belong to Ic types, i.e., they derive from the collapse of H/He stripped-off massive stars.

iii) The near simultaneous observations of the non thermal (GRB) and thermal (SN) emissions in the GRB 060218/SN 2006aj association, indicate that the SN and the GRB are coeval events within ~ 0.1 day.

iv) Only 0.4% − 3% of SNe-Ibc (corresponding to less than 1% of all core-collapse SNe) are capable to produce GRBs. Therefore some special circumstances are requested to allow a massive star to become a GRB progenitor. Recent theoretical studies indicate that rotation (Woosley & Hegel 2006; Yoon & Langer 2005), metallicity (Fruchter et al. 2006, Modjaz et al. 2007), binarity (Podsiadlowski et al. 2004, Mirabel 2004) may play an important role (see also Campana et al. 2007).

v) 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. The recent discovery of GRB 060218 at z = 0.03, with similar properties, has raised the question of whether or not a population of "local" and "low-luminosity" GRBs ($\lesssim 10^{49}$ erg s^{-1}) with different properties from the energetically "high-luminosity" cosmological GRBs does exist ($\gtrsim 10^{51}$ erg s^{-1}). Since the volume they sample is $10^5 \div 10^6$ times smaller than that probed by cosmological GRBs, the rate of these events could be dramatically larger, perhaps they are the most common GRBs in the Universe. Naively one may expect that the spectroscopic and photometric similarities exhibited by SNe 1998bw, 2003dh, 2003lw and 2006aj 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 Guetta & Della Valle (2007).

vi) The properties of the four closest SNe associated with GRBs vary by at most ±30%, while the γ-budget covers about 4 order of magnitudes. This fact may imply that: **a)** we may be seeing intrinsically similar phenomena under different angles, GRB 030329/SN 2003dh may be viewed almost pole-on, GRB 980425/SN 1998bw considerably off-axis (about 30 deg), while GRB 031203/SN 2003lw and GRB 060218/SN 2006aj may lie in between. In this scenario the γ-properties are a strong function of the angle ($E_\gamma \sim \theta^{-4}$) whreas the optical properties are not much influenced by this relative small spread in viewing angles; or **b)** there is an intrinsic dispersion in the properties of the relativistic ejecta for SNe with similar optical characteristics. This possibility may apply every time the relativistic energy at play in a GRB event, i.e. $\sim 10^{-47} - 10^{51}$ erg, is only a tiny fraction of the kinetic energy associated with Hypernovae, $\sim 10^{52}$ erg.

vii) Recent VLT observations of GRB 060614 (Della Valle et al. 2006b, Fynbo et al. 2006, Gal-Yam et al. 2006) challenge the "well-established" idea that all long-duration GRBs are produced in bright Supernova explosions. Indeed any SN associated with this GRB was at least 200 times fainter (in R band) than the other GRB-SNe. This fact may suggest that GRB 060614 is the prototype of a new class of long-duration GRB which are produced in a new kind of massive star death ("fall-back" or "dark" Supernovae), different from those producing bright SNe-Ibc.

viii) Recent observations of SN 2008D/XRF 080109 have pointed out the existence of a continuum from GRB-SN to under-luminous GRB-SNe (i.e. XRF-SNe) to X-ray transient-SN and to ordinary Ibc SN.

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