IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10114-5

Evidence for Supernova light in all GRB afterglows(*)

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(ricevuto il 23 Maggio 2005; pubblicato online il 19 Ottobre 2005)

Summary. — We present an update of our systematic reanalysis of all Gamma-Ray Burst (GRB) afterglow data published through the end of 2003, in an attempt to detect the predicted supernova light component in the optical bands. The total sample of afterglows with established redshifts contains 28 bursts (GRB 970228 to GRB 031203). For 12 of them a weak supernova excess was found (including GRB 030329). Among them are all bursts with redshift less than ~ 0.7. These results support our earlier finding (*ApJ*, **609** (2004) 952) that *all* afterglows of long-duration GRBs contain light from an associated supernova.

PACS 98.70.Rz – γ-ray sources; γ-ray bursts..
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

Observational and theoretical evidence suggest that the majority of GRB progenitors are stars at the endpoint in stellar evolution, *e.g.* [6, 12]. Since the discovery of a nearby type-Ic supernova (SN 1998bw) in the error circle of the X-ray afterglow for GRB 980425 [8, 15], evidence is accumulating that core-collapse supernovae are physically related to long-duration GRBs.

As a natural consequence of a physical relation between the explosion of massive stars and GRBs, the supernova light should contribute to the afterglow flux, and even dominate under favorable conditions. The most convincing example is GRB 030329 [18] at $z = 0.1685$ [10] with spectral confirmation of supernova light in its afterglow [13, 14, 17, 20]. Spectroscopic evidence for SN light in a GRB afterglow was later also reported for GRB 021211 [5] and GRB 031203 [16]. In contrast to these spectroscopic evidences, several cases of *photometric* evidence for extra light in GRB afterglows have been reported, starting with the pioneering work on GRB 980326 [2]. Various groups successfully fit SN 1998bw templates to explain these late-time bumps (see also [4]), the most convincing case being that of GRB 011121 [3, 9, 11].

(*) Paper presented at the "4th Workshop on Gamma-Ray Burst in the Afterglow Era", Rome, October 18-22, 2004.

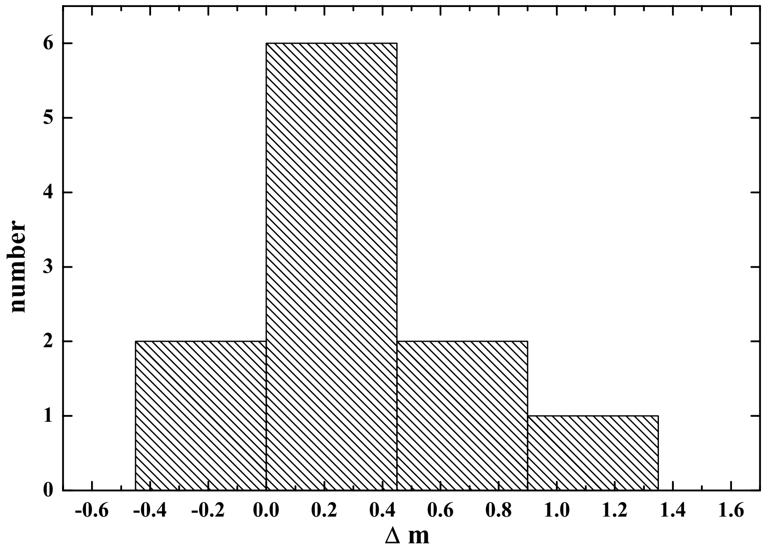

Fig. 1. – The distribution of the peak luminosity of all GRB-SNe in units of the corresponding peak luminosity of SN 1998bw in the R band (in the observer's frame). The corresponding stretch factor is shown in fig. 3. GRB 980703 is not included here and in the following figures since in this case s had to be fixed to 1.0.

2. – Numerical approach

We model the afterglow light curve either by a single or a double power law. The fitting equation was either [1]

$$m_{\rm OT}(t) = -2.5\,\log\{10^{-0.4\,m_c}[(t/t_{\rm b})^{\alpha_1\,n} + (t/t_{\rm b})^{\alpha_2\,n}]^{-1/n} + \\ + k\,10^{-0.4\,m_{\rm SN}(t/s)} + 10^{-0.4\,m_{\rm host}}\} \quad \text{or} \tag{1}$$

$$m_{\rm OT}(t) = -2.5\,\log\{10^{-0.4\,m_1}t^{\alpha} + \\ + k\,10^{-0.4\,m_{\rm SN}(t/s)} + 10^{-0.4\,m_{\rm host}}\}\,, \tag{2}$$

In eq. (2) the free parameters are the prebreak decay slope α_1, the postbreak decay slope α_2, the break time $t_{\rm b}$, the steepness of the break n, the brightness of the host galaxy $m_{\rm host}$, and the supernova parameters k (luminosity) and s (stretch factor). The parameter m_c is a constant. The same holds for the parameter m_1 in eq. (3). In the case of a simple power law α stands for the decay slope (eq. 3). For a more detailed description we refer to [21].

3. – Results and discussion

The key finding is photometric evidence of a late-time bump in *all* afterglows with a redshift $z \lesssim 0.7$, including those of the year 2003 (GRBs 030329 and 031203; fig. 1 to 3). This, together with the the spectral confirmation of SN light in the afterglows of GRBs 021211, 030329, and 031203 further supports the view that in fact *all* long-duration GRBs show SN bumps in their late-time optical afterglows. For larger redshifts the data base is usually not of sufficient quality, or the SN is simply too faint, in order to search

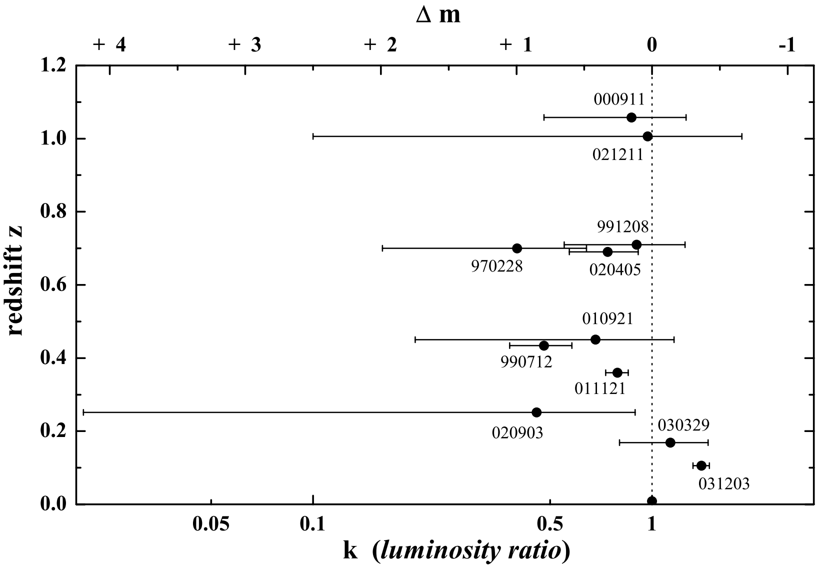

Fig. 2. – The deduced peak luminosities of all GRB-SNe in units of the peak luminosity of SN 1998bw. All data refer to the R band (in the observer's frame). The dotted line corresponds to SN1998bw. The parameter Δm equals $-2.5 \log k$, which measures the magnitude difference at maximum light between the GRB-SN and SN 1998bw in the corresponding wavelength regime. Note that the data are not corrected for a possible extinction in the GRB host galaxies.

for such a feature in the late-time afterglow light curve. Based on new observational data published in the literature we have also included in the SN list the afterglow of

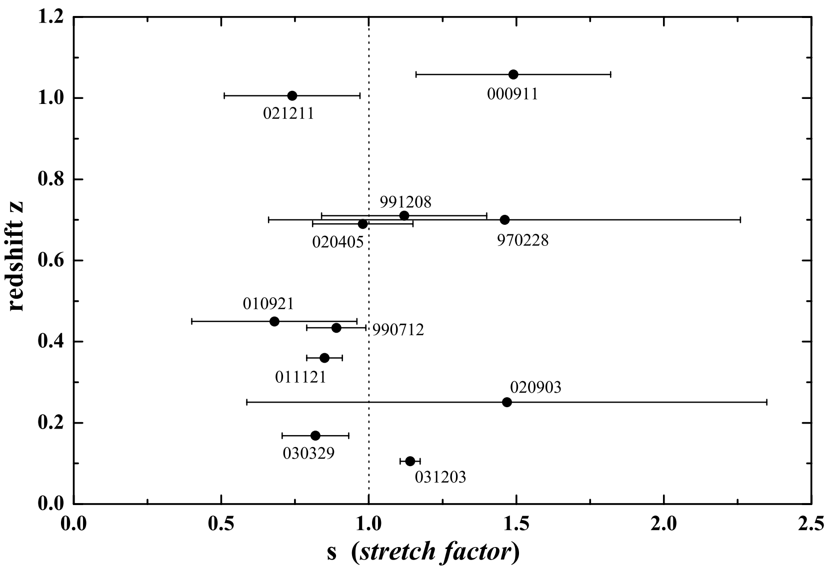

Fig. 3. – The distribution of the parameter s (eq. (2)) describing a stretching of the SN light curve relative to those of SN 1998bw (for which $s = 1$, dotted line). In general, $s < 0$ ($s > 0$) means that the evolution of the light curve of the SN was slower (faster) than those of the light curve of SN 1998bw in the corresponding wavelength band. The mean value is $s = 1.0$.

XRF 020903 (see also [19]). Again, together with the strong late-time bump seen in the afterglow of XRF 030723 [7] (where no redshift is known) this provides evidence that presumably also all XRF bursts are physically related to SN explosions.

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S. K. and A. Z. acknowledge financial support by DFG grant KL 766/11-1 and from the German Academic Exchange Service (DAAD) under grant No. D/0103745. D.H.H. acknowledges support for this project under NSF grant INT-0128882. This work has profited from the GCN data base maintained by Scott Barthelmy at NASA and the *GRB big table* maintained by Jochen Greiner, Max-Planck-Institut für extraterrestrische Physik, Garching.

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