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Open issues in Gamma-Ray Bursts: Polarimetry and dark GRBs(*)

D. Malesani(1), S. Covino(2), E. M. Rossi(3), D. Lazzati(4), A. De Luca(5)
P. Filliatre(6)(7) and G. Tagliaferri(2)

(1) *SISSA, International School for Advanced Studies - via Beirut 2-4, I-34014 Trieste, Italy*
(2) *INAF/Osservatorio Astronomico di Brera*
via E. Bianchi 46, I-23807, Merate (LC), Italy
(3) *Max Planck Institut für Astrophysik*
Karl-Schwarzschild-Str. 1, 85741 Garching, Germany
(4) *JILA, 440 UCB, University of Colorado - Boulder, CO, 80309-0440, USA*
(5) *INAF/IASF, sezione di Milano "G. Occhialini" - via Bassini 15, I-20133 Milano, Italy*
(6) *Laboratoire Astroparticule et Cosmologie, UMR 7164*
11 place Marcelin Berthelot, F-75213 Paris Cedex 05, France
(7) *Service d'Astrophysique, CEA/DSM/DAPNIA/SAp, CE-Saclay*
Orme des Merisiers, Bât. 709, F-91191 Gif-sur-Yvette Cedex, France

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Summary. — We review some open problems in the physics of afterglows, namely their polarization properties and the existence of dark/faint bursts. Polarization studies yield precious insights in the physical structure and dynamical evolution of GRB jets, revealing their magnetization properties and their energy profile. Polarimetric observations of GRB 020813 already allowed to exclude a homogeneous jet for this event. We then present observations of faint/dark bursts, showing that some of them may be obscured by dust, while others are possibly just intrinsically dim.

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1. – Polarization

In 1999 the first successful detection of optical polarization from a Gamma-Ray Burst (GRB) afterglow was obtained [1, 2]. Since then, several polarimetric measurements of GRB afterglows have been performed (see [3] and [4] for a review). Albeit being an observationally challenging task, the scientific community has shown wide interest in this field. Indeed, polarization has a high diagnostic power over a broad range of physical

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processes, from the emission mechanisms to the fireball structure and the properties of the close and far environment of the burst.

The search for polarizion was driven by the hypothesis that the afterglow emission is due to synchrotron emission [5-7]. Its discovery, by itself, is now regarded as a strong evidence for this emission mechanism. For unresolved sources, like distant GRB afterglows, polarimetry also offers a unique opportunity to probe the geometry of the system. In fact, in order to have a net nonzero polarization, some kind of asymmetry is required, provided for example by a collimated fireball. Time-resolved polarimetry is also a reliable tool to discriminate among different scenarios for the blastwave evolution. Last, polarimetry of GRB afterglows also offers a direct way to study the interstellar medium around GRB progenitors and in general along the line of sight.

The diagnostic power of polarimetry rests upon the characteristic time evolution of the polarization degree and position angle [8, 9] produced by an ultrarelativistic outflow. In the simplest case, the angular energy distribution is homogeneous. More physical models consider more complex beam and magnetic field patterns [10-12]. These works show that, even if the light curve is barely affected by these parameters, the polarization and position angle evolutions change substantially (fig. 1). In the homogeneous jet (HJ) model, the polarization curve has two maxima bracketting the jet break, and, more important, the polarization angle has a sudden rotation of 90° at the same moment (fig. 1, dashed line). On the contrary, the structured jet (SJ) model predicts that the maximum of the polarization curve is reached right at the time of the break in the light curve, the position angle keeping constant throughout the afterglow evolution (fig. 1, solid line). At early and late time the polarization should essentially vanish in either cases.

This latter fact constitutes an important point because, indipendently of the model details, the prediction for the early-time polarization changes substantially if the fireball expansion is driven by a large-scale magnetic field. This important issue has been recently developed and discussed, *e.g.*, by [10, 11] and [12]. Like hydrodynamic jets, magnetized ones can be homogeneous and structured. In any case, a non-negligible degree of polarization at early times is expected, a strong difference with respect to purely hydrodynamical models. Polarimetry may therefore be the most powerful available tool to investigate the fireball structure and its early dynamical evolution.

From the observational point of view, besides several isolated measurements, a rich enough coverage of the polarization evolution could be obtained only in three cases: GRB 020813 [13,11], GRB 021004 [14-17], and GRB 030329 [18,19]. However, firm conclusions could be derived only for GRB 020813, the best available case for model testing. Its light curve was remarkably smooth [20,21] and a break in the light curve could be clearly singled out. A bunch of polarimetric observations were carried out providing for the first time polarization data both before and after the light curve break time [13]. The authors of ref. [11], with a quantitative approach, carried out a formal analysis by taking into account both the dust-induced (host galaxy + Milky Way) and the intrinsic afterglow polarization. All current jet models were considered, including homogeneous and structured jets, with and without a coherent magnetic field. The available dataset did not allow us to single out a unique best-fitting model. However, it was possible to rule out homogeneous jet models at a confidence level larger than 3σ, mainly due to the lack of the predicted 90° position angle rotation. This is an important result with possible consequences for the use of GRBs as probes for cosmology structure studies. All magnetized models and structured jets fit satisfactorily the data, the ambiguity being mainly due to the lack of early-time measurements, *i.e.* when the magnetization properties mostly matter (fig. 2).

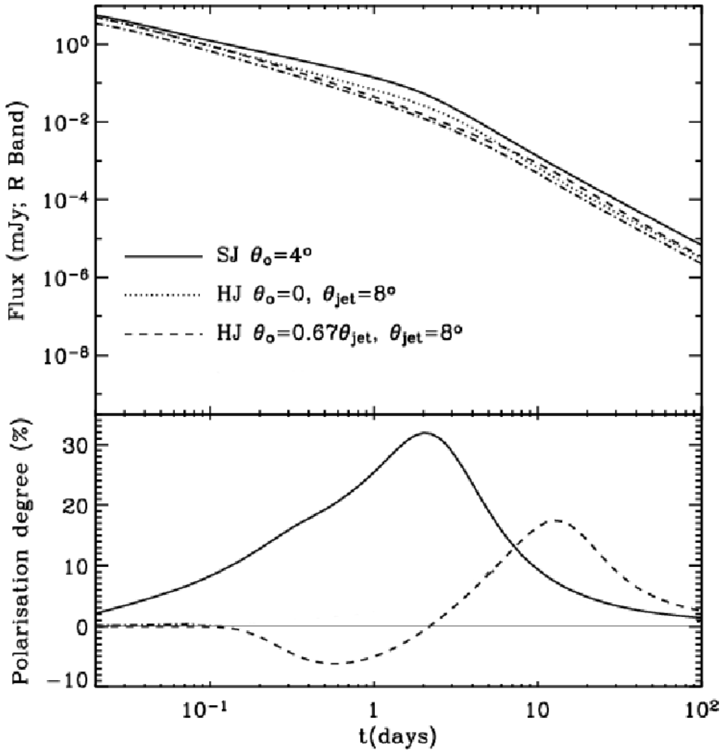

Fig. 1. – Light curve and polarization evolution for different jet structures. SJ stands for structured jet and HJ for homogeneous jet. The figure shows the similarity of the predicted light curves for the various models, in contrast with the considerable differences in the polarization curves. Negative polarization degrees indicate a 90° rotation for the position angle. From [12].

2. – Dark GRBs

Since the beginning of afterglow observations, it was apparent that a fraction of GRBs (the so-called dark GRBs) did not show any detectable optical counterpart, the first example being GRB 970828 [22]. Reaction times and sensitivity have constantly improved, allowing faster and deeper searches, and the dark GRB fraction has continuously decreased. Also, the definition of “darkness” is subject to discussion. Likely, a good classification should make use of information from other bands (especially the X-rays [23, 24]), in order to individuate anomalies in the spectral shape and single out the events with an optical deficit. The X-ray radiation is in fact much less affected by extinction, and does not suffer from Lyα suppression at large redshifts. Moreover, from the observational point of view, an X-ray afterglow was discovered in virtually all cases.

Several solutions are viable to explain the existence of dark bursts, and probably more than one mechanism is at work. The simplest idea is that dark GRBs have just very faint afterglows [25, 26], due perhaps to the different conditions in the environment or in the emission mechanism. This hypothesis is supported by the analysis of BeppoSAX X-ray data [27]. Another possibility is that these afterglows are heavily extinguished by material along the line of sight [28, 29], a likely possibility given the association between GRBs and young stars [30, 31]. Last, an intriguing possibility is that some GRBs are

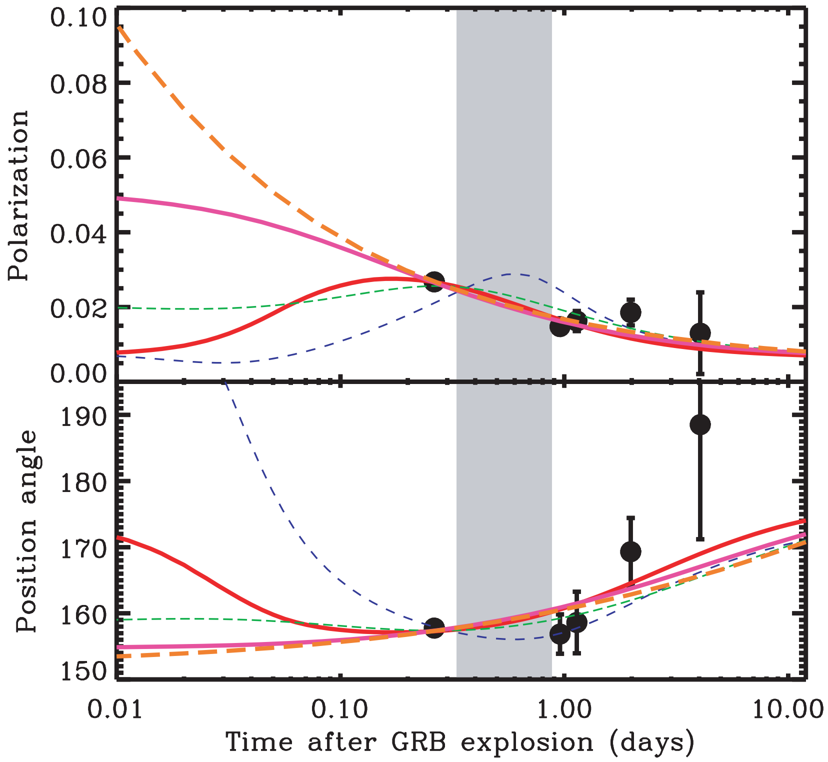

Fig. 2. – Polarization data for GRB 020813 [13]. Different curves refer to different models. The gray lane indicates the position of the jet break as measured from the light curve. From [11].

optically dark since they are at high redshift ($z > 7$), so that the Lyα dropout suppresses visible radiation. In the last two cases, observing in the near infrared (NIR) alleviates the problem, since this band is less affected by dust and dropout (up to $z = 20$) extinction.

To tackle this issue, our group has undertaken an observing campaign devoted to detect and follow-up GRB afterglows both in the optical and in the NIR, in order to spot dark/faint/extinguished events. We report here about three INTEGRAL bursts.

GRB 040223. The long-duration GRB 040223 had a peak flux of 3×10^{-8} erg cm^{-2} s^{-1} (20–200 keV [32]). Following the discovery of the X-ray afterglow by XMM-Newton [33-35], we observed the field with the ESO-NTT telescope at several epochs, in the JHK_{s} filters. Despite our images are quite deep, no variable NIR afterglow was detected [36]. Figure 3 shows the NIR-to-X-ray spectral energy distribution, showing that the K_{s} datum lies well below the X-ray extrapolation (dashed lines). Also, the presence of a break (*e.g.*, due to the cooling frequency) cannot explain the NIR faintness: given the X-ray spectral index $\alpha_X = 1.8 \pm 0.2$ [35], in the standard syncrotron model the slope redward of the break should be $\alpha = \alpha_X - 0.5 = 1.3 \pm 0.2$ (dotted lines). Even assuming that this break is just at the edge of the observed X-ray band, the NIR point is still a factor at least ~ 20 below the extrapolation. Given the large measured column density, $N_{\mathrm{H}} = (1.75 \pm 0.20) \times 10^{22}$ cm^{-2}, well in excess with respect to the Galactic value, we therefore conclude that this burst is likely significantly extinguished (S. Covino *et al.*, manuscript in preparation).

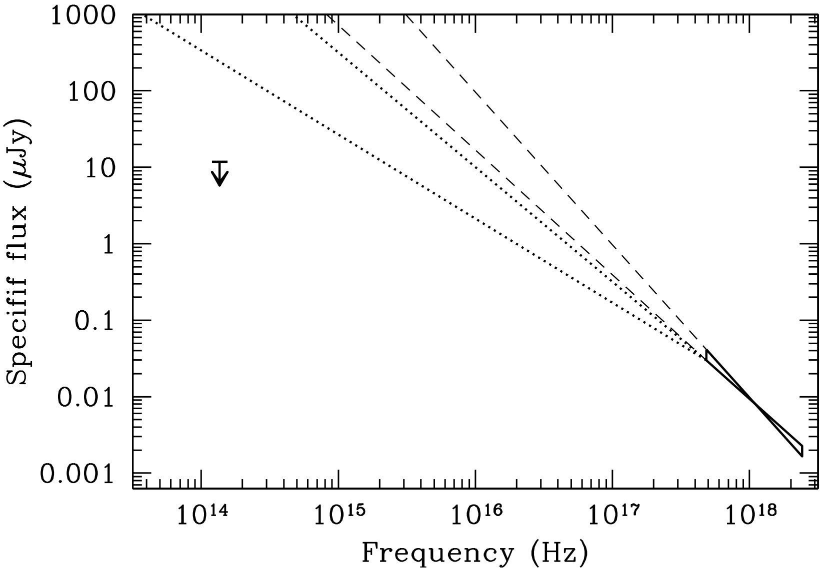

Fig. 3. – Broad-band spectral energy distribution of the afterglow of GRB 040223, 0.7 days after the GRB. See text for the meaning of the lines.

GRB 040422. This faint burst was observed by INTEGRAL, lasting 8 s [37]. VLT observations started very soon, just 2 hours after the GRB, in the R, I, and K_s bands. In this case, despite the large extinction and the field crowding, an afterglow could be discovered in the K_s band [38]. This is one of the faintest objects ever detected, and only by promptly reacting with a large telescope could the afterglow be discovered. A redshift is lacking for this event, thereby the energetics is unknown. However, a bright host galaxy ($K_\mathrm{s} = 20.3 \pm 0.2$, one of the brightest among GRB hosts) was discovered coincident with the afterglow, suggesting a closeby event. Also, the afterglow was quite faint when compared to its host galaxy (being 2.3 mag brighter 2 h after the GRB). All these facts suggest a very faint event, perhaps bridging classical GRBs and dim events like GRB 980425 and GRB 031203 (the "w's").

GRB 040827. This burst was also discovered by INTEGRAL [39], showing no remarkable properties in its gamma-ray emission. Unlike most INTEGRAL triggers, it was not on the Galactic plane, allowing more effective observations. In this case, an X-ray afterglow was discovered [40], in turn allowing the discovery of a NIR transient by several groups [41-43]. Also in this case, the afterglow was quite faint when compared with the host galaxy (no redshift is available), suggesting an intrinsically faint event. Analysis of X-ray data [44] showed a significant extinction ($N_\mathrm{H} \sim 10^{22}$ cm^{-2}, somewhat uncertain due to the unknown redshift), well in excess with respect to the Galactic value. This case may indeed be the best example of an extiguished GRB. Optical limits are consistent with this column.

Observation of a large number of bursts is now possible, thanks to Swift [45]. Many Swift afterglows are indeed among the faintest ever observed, promising to have soon a large sample. Among these events, some will be just "faint", and some will be extinguished. Coupling optical and X-ray observations will allow to clearly disentangle this issue, and to select really dark bursts, possibly at very high redshift.

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