Chin. J. Astron. Astrophys. Vol.3 (2003), **Suppl.**, 483–488
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

# News on multifrequency behaviour of GRBs: polarized emission and optical flashes

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**Abstract** In this presentation the main advances occurred in the past years concerning the observational features of Gamma-Ray Burst (GRB) prompt event and afterglow polarization in the optical, as well as in other bands, are reviewed. Also, the observed cases of an 'optical flash' simultaneous with the GRB itself are presented, along with their theoretical interpretation and the description of present and future observational fast-response techniques to chase this emission.

**Key words:** gamma rays: bursts — techniques: polarimetric — techniques: photometric

## 1 INTRODUCTION

In this presentation I will deal with two topics of Gamma-Ray Burst (GRB) and afterglow science which are getting more and more attention in these hectic years of GRB obervations throughout the electromagnetic spectrum. These topics are GRB and afterglow polarization measurements, and the hunt for 'optical flashes', i.e. optical emission simultaneous with the GRB prompt event.

The outline of this paper is the following: concerning GRB and afterglow polarization, I will review the optical measurements available up to now (August 2003), along with the information on observations in other spectral ranges; then, an overview on theories which explain polarized emission in these objects will be presented. As regards instead the optical flashes, I will first show what is known about the (very few) observed cases and, after that, I will discuss the techniques needed to observe these fast events and what can be learnt, from their observation, on the emission mechanisms at work during the early GRB phases. I will then conclude by showing the future prospects regarding the two topics on both observational and experimental grounds.

## 2 GRB AND AFTERGLOW POLARIMETRY

Since the first polarimetric detection of an optical afterglow (that of GRB990510: Covino et al. 1999; Wijers et al. 1999), it has been realized that GRB afterglows show optical polarization at

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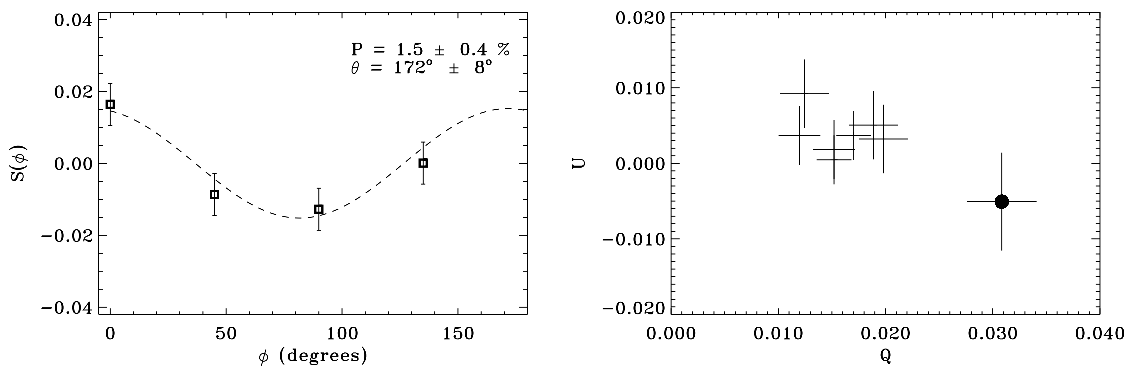


**Fig. 1** (*Left panel*): $R$-band polarization plot for the optical afterglow of GRB020405; the amplitude of the best-fit cosine function corresponds to the polarization level $P$, while the angle at which the cosine function reaches the maximum is the polarization angle $\theta$. (*Right panel*): positions of field stars and of the afterglow of GRB020405 (marked with a filled dot) in the plane of the Stokes $U$ and $Q$ parameters not corrected for spurious field polarization, mostly due to the Galactic interstellar dust. The afterglow position is clearly separated from the region occupied by the field stars: this indicates that it has net intrinsic polarization. Both panels are from Masetti et al. (2003).

a level which is between 1% and 3% (with the possible, controversial exception of GRB020405 for which polarization of about 10% has been measured in the $V$ band by Bersier et al. (2003). A polarization measurement plot is shown in Fig. 1, left panel.

The polarization detected in GRB optical afterglows is indeed intrinsic, and this can be stated for two reasons. First, as can be seen e.g. in the case of GRB020405 (Fig. 1, left panel), the optical afterglow is well separated from the field stars in the Stokes' parameters $U$ vs. $Q$ plane; this segregation indicates that indeed the afterglow has intrinsic polarization other than that spuriously induced by the Galactic interstellar dust (e.g., Serkowski et al. 1975). Second, the optical afterglow polarization sometimes shows variations in both amplitude $P$ and/or angle $\theta$ (e.g. Rol et al. 2000, 2003; Lazzati et al. 2003), this variability again indicating intrinsic polarization properties.

The detection of this significant polarization in the optical further strengthens the idea that the afterglow emission is produced via synchrotron mechanism in a collimated fireball (e.g. Sari et al. 1999).

Optical spectropolarimetry was also performed recently on the bright afterglows of GRB020813 (Barth et al. 2003) and GRB021004 (Wang et al. 2003). The results indicate, as expected from the theory in case of synchrotron emission, that there are no substantial variations of $P$ and $\theta$ in the continuum with wavelength. Possibly, in the case of the GRB021004 afterglow there might be an increase in the polarization value bluewards of Lyman $\alpha$ absorption, where the Lyman-$\alpha$ forest begins; so, it may be a non-intrinsic effect, but rather induced by absorbers along the line of sight.

To summarize the results concerning optical polarimetry of GRB afterglows, up to date (August 2003) six optical afterglows showed detectable polarization, with values ranging from about 1% to about 3%; for four more optical afterglows only upper limits around 2%–3% (thus consistent with the above detections) were found. Surprisingly, the measured polarization angles $\theta$ appear to be clustered between 140° and 160°, and generally they are larger than 90°; the reason for this is still unknown. For a deeper insight on each single case one can refer to the review by Covino et al. (2003).

Concerning other wavebands, up to now only near-infrared (NIR) and radio polarization measurements of GRB afterglows were attempted, but they just led to very loose upper limits: e.g., $<30\%$ for the NIR afterglow of GRB000301c (Klose et al. 2001) and $<8\%$ for the radio afterglow of GRB980703 (Frail et al. 1998). Very recently, however, a $\gamma$–ray polarization measure was acquired for a GRB prompt event. GRB021206, localized by the IPN network of satellites (Hurley et al. 2002), was observed by the *RHESSI* spacecraft which has $\gamma$–ray polarimetric capabilities. The result was noteworthy: during the 5 s of the GRB prompt emission, polarization at a level $P = (80 \pm 20)$ % was detected (Coburn & Boggs 2003).

According to the theory, this very high value of $P$ can be explained assuming synchrotron emission in a highly ordered magnetic field (e.g., Gruzinov & Waxman 1999). Therefore, the low values of $P$ detected from the optical afterglows can be due to: (*i*) highly tangled magnetic fields within the fireball (Medvedev & Loeb 1999), or (*ii*) high symmetry in the observed emitting area (e.g. Waxman 1997). In case of intrinsic polarization from the afterglow, theoretical works (Sari 1999; Ghisellini & Lazzati 1999) predict various kinds of variability of $P$ and $\theta$ in case of collimated emission, so the monitoring of these variations can help us to understand the GRB jet structure. However, it should also be noted that scintillation induced by the circumburst medium as well as microlensing can induce spurious variations in the polarization parameters (Medvedev & Loeb 1999).

## 3 OPTICAL FLASHES

On January 23, 1999, GRB990123 triggered the BATSE instrument onboard *Compton-GRO* and the GRB detection system of *BeppoSAX*. The prompt BATSE trigger coupled with the accurate *BeppoSAX* localization allowed the robotic telescope ROTSE to detect the first (and so far unique) optical counterpart of a GRB prompt event (Akerlof et al. 1999). This 'optical flash' was observed to rise in brightness and to reach a $V \sim 9$ magnitude peak $\sim 50$ s after the GRB onset; subsequently it decayed fast, following a power law with temporal index $\alpha \sim 2$.

Since the demise of *Compton-GRO* in June 2000 no chance of receiving real-time GRB alert was possible until the *HETE-2* satellite became fully operational on late 2001. After this date four cases of early OT searches by means of automated telescopes were successful, although these were not as fast as in the case of GRB990123. Indeed, the four early OTs of GRBs 020813 (Li et al. 2003a), 021004 (Fox et al. 2003), 021211 (Li et al. 2003b) and 030329 (Smith et al. 2003) were detected few minutes to $\sim 2$ hours after the prompt event, and in any case well after the GRB high-energy prompt emission was ended.

Observationally it can be seen that only the early OT of GRB021211 shows a behaviour similar to the tail of the GRB990123 optical flash, with a steeper early light curve decay and a subsequent flattening. The other three cases follow the opposite trend, the most remarkable example being GRB021004, which showed an almost flat light curve between 4 minutes and $\sim$ 2 hours after the GRB, and then a power-law decay with index $\alpha \sim 1$ (Fox et al. 2003).

From the theoretical point of view, the optical flash is interpreted, in the context of the fireball model, as produced by a short-lived reverse shock propagating through the shocked GRB ejecta (Sari & Piran 1999). This reverse shock originates when the relativistic blastwave interacts with the ejecta, as opposed to the forward shock which occurs when the blastwave starts interacting with the circumburst medium, producing the afterglow emission.

The difference in the light curve behaviours of the optical flash emission is still not clear, but according to Zhang et al. (2003) it may depend on both the GRB intrinsic luminosity and magnetic field: the higher the magnetic field and/or the lower the luminosity, the steeper the optical decay.

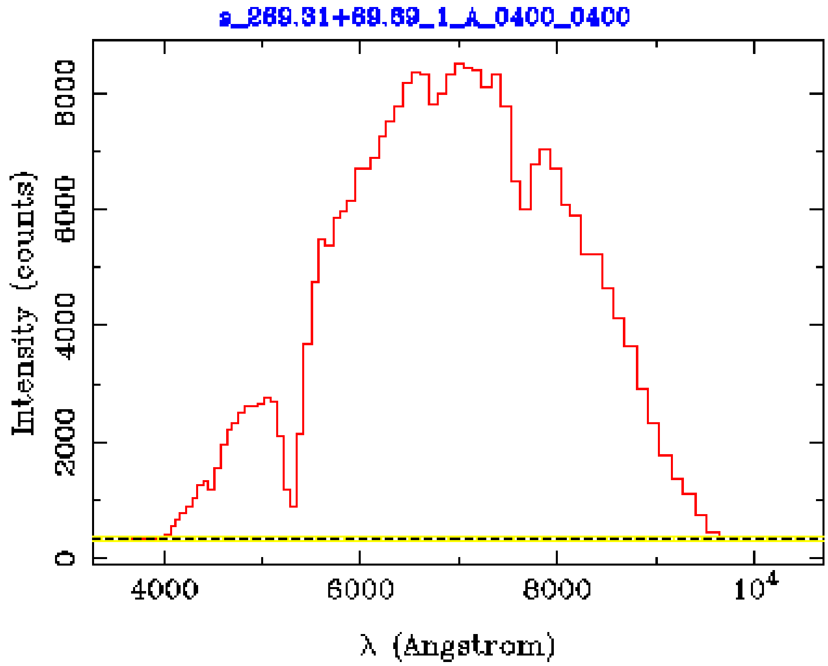


**Fig. 2** Simulated spectrum of the GRB030323 optical afterglow (Vreeswijk et al. 2003) as it could have been seen by ROSS plus Amici prism, assuming a magnitude $R = 10$ and an exposure time of 1 s. The Lyman-$\alpha$ absorption trough, located around 5300 Å, is easily detected on an overall high signal-to-noise continuum. The features around 6700 Å and 7600 Å are due to the Earth's atmosphere absorption (telluric bands).

However, the number of observed optical flashes is still too low to produce meaningful studies on this phenomenon. Moreover, their light curves were acquired in a single filter ($R$ or white light), thus no information on the spectral shape and evolution thereof is available up to now. It is therefore important to monitor the very first phases of the GRB also in the optical band for the following reasons: (*i*) these observations will be a test bench for the current theoretical models describing the optical flash; (*ii*) the data will help us to map the evolution of the broadband spectral variations during the event; (*iii*) the emission mechanism(s) at work during the early GRB phases will be better understood; (*iv*) the optical-to-$\gamma$–ray emission ratio can be computed and correlated with other burst properties.

Of course, in order to do this we need fast and precise GRB localizations as well and fast-repointing (robotic) telescopes which are able to quickly point the GRB field. Thanks to the accurate real-time localizations provided by the satellites *HETE-2* and *INTEGRAL* (and, starting early 2004, by *Swift*), robotic telescopes already (or soon-to-be) active around the world will be capable to catch and monitor the optical counterpart of future GRBs.

One of the last-born robotic telescopes with high fast-response capabilities is REM (Zerbi et al. 2001; Chincarini, these proceedings). REM is a 60-cm diameter robotic facility located at the ESO observatory in La Silla (Chile) and which is capable to repoint each position in the sky in less than 10 seconds. The first light was obtained on June 25, 2003 and the telescope is now in the test phase; it will work in tight connection with the *Swift* satellite. The REM telescope carries two instruments which can operate at the same time by means of a dichroic beam splitter: a NIR camera (REMIR) and an optical spectrophotometer (ROSS). REMIR has imaging capabilities in $zJHK$ filters, while the ROSS spectrophotometer (Palazzi & Pian 2003) can either perform imaging in the $V$, $R$, $I$ and $H_\alpha$ filters or low-resolution ($\lambda/\Delta\lambda \sim 100$) slitless spectroscopy in the 4500-9000 Å range by means of an Amici prism.

The peculiarity of REM, and in particular of ROSS in the spectroscopic mode, is thus quite apparent: the above configuration allows mapping the optical-NIR flash emission in a broad wavelength range and its evolution during the very first GRB phases. Currently, REM is the only robotic telescope capable to simultaneously observe in the optical and NIR ranges.

In order to test the ROSS spectroscopic capabilities, we performed a series of simulations using template spectra of astrophysical objects and convolving them with the instrumental response, thus obtaining simulated count spectra of real sources. An example is reported in Fig. 2, in which the simulated optical spectrum of the afterglow of GRB030323 (Vreeswijk et al. 2003) is shown. The spectrum of this GRB afterglow, located at $z = 3.37$, shows a deep Lyman-$\alpha$ absorption trough redshifted to the optical range. Assuming that the optical flash reached magnitude $R = 10$ and using the spectrum of Vreeswijk et al. (2003) as a template, we simulated an observation of this GRB with an exposure time of 1 s: it can be seen in Fig. 2 that the optical continuum is detected with high signal-to-noise ratio; moreover, the Lyman-$\alpha$ trough is well detected.

Therefore, within the first minutes of the GRB event, ROSS in spectroscopic mode can map the overall continuum shape (and its time evolution) of optical flashes with acceptable spectral resolution and with a temporal sampling of the order of 1 s. Moreover, these observations can provide information on the GRB redshift practically few seconds after the prompt event onset; these can also give insights on the temporal variability of the broadest spectral features (and thus on how the GRB modifies with time the ionization level of the circumburst medium).

## 4 SUMMARY

Here I reviewed two topics concerning GRBs: polarimetry and longer-wavelength observations simultaneous with the high-energy prompt events. The main results and the future prospects can be summarized as follows:

- emission of GRBs and afterglows is polarized: prompt events show high polarization in the $\gamma$–ray domain, while afterglows are polarized at a few percent level;
- variations of $P$ and $\theta$ with time in optical afterglows suggest that the measured polarization is intrinsic to the source and produced by collimated synchrotron emission;
- polarimetric measurements can give insights on the rôle of magnetic fields in the jet structure of GRBs.
- GRB optical flashes decay with different rates: this is possibly due to the combined effect of the GRB intrinsic luminosity and magnetic field;
- according to the fireball model, the optical flash emission is produced by a reverse shock propagating in the GRB ejecta;
- in order to detect and study the optical emission simultaneous with the $\gamma$–ray prompt event robotic telescopes, coupled with satellites able to provide fast and precise GRB localizations, are needed.

**Acknowledgements** I would like to thank Franco Giovannelli for having given me the opportunity of presenting this review at this meeting and the LOC for the warm hospitality and the pleasant stay in Vulcano. I am grateful to my colleagues (and friends) Eliana Palazzi and Elena Pian for our long-standing and fruitful collaboration. I also want to thank Luciano Nicastro for having provided the ROSS simulated spectrum of the GRB030323 optical afterglow.

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