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### Article

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# The origin of the prompt optical emission in GRB 060111B

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## Abstract

The detection of a bright optical emission measured with good temporal resolution during the prompt phase makes GRB 060111B a rare event that is especially useful for constraining theories of the prompt optical emission. We discuss some interesting properties of this burst in comparison with other GRBs for which an optical peak emission has been observed.

*Key words:* first keyword, second keyword, more keywords

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## 1 Introduction

Rapid-response telescopes and developments in technique of wide field optical surveys are fundamental to measure the multi-wavelength spectrum of gamma-ray bursts (GRBs) prompt emission, needed to constrain the origin of the observed radiation. So far, few dozen of GRBs have been detected at optical wavelengths when the gamma-ray burst was still active, or soon after its end. The common interpretation of the observed optical prompt emission relies on the fireball internal-external shock model (e.g. Sari and Piran 1997a, Sari 1997b). Alternatively, the Cannonball model is also providing good match with the observations (e.g. Dado et al. 2009).

In Stratta et al. (2009) we presented the results of a multiwavelength campaign performed up to several months after the burst trigger for GRB 060111B, for which a prompt optical emission was observed with the robotic telescope TAROT (Klotz et al. 2006). From the analysis of the detected host galaxy and from the early afterglow temporal and spectral properties, we estimated a redshift of about  $z \sim 2$  and found that a reverse shock origin of the prompt optical emission is consistent with the observations.

In this paper we compare the rest frame properties of GRB 060111B with those from other GRBs for which an early optical peak flux was observed and we discuss some possible implications.

## 2 Analysis and Results

The upper limit of the optic peak of GRB 060111B is among the most constraining so far. At  $z \sim 2$ , the rest frame peak time is  $t_p < 9$  s after the BAT trigger (Klotz et al. 2006). At the same time, the brightness of this burst in optic ( $m_R \sim 13.8$  mag), although a non negligible dust extinction may affect this burst (see Stratta et al. 2009), is relatively moderate if compared with other prompt optical emissions at similar epochs. To further investigate these properties, we have compared the rest frame optical peak time and the burst energetics with other GRBs in which early optical emission was detected. Contrary to Liang et al. (2009) we do not make any selection on the physical interpretation of the optical peaks. Among GRBs at known redshift  $z$ , with well monitored R-band early optical counterpart, we found 12 GRBs for which a peak flux is unambiguously observed and 8 GRBs showing optical light curves already decaying at least early than 200 s after GRB trigger (see Stratta and Pozanenko 2010 for further details).

In Figure 1 we have plotted the burst equivalent isotropic energy  $E_{iso}$

against the rest frame optical peak epochs  $t_p$ . In addition, we have coloured each GRB according to the post-peak optical decay index value  $\alpha_2$ . A visual inspection shows a general trend that the burst energy is anti-correlated with the optical peak epochs. The GRBs with  $\alpha_2 > 2$  are those that show largest scatter from the anti-correlation. Taking all GRBs with observed optical peak and with  $\alpha_2 < 2$ , we estimate a chance probability of the anti-correlation of  $< 0.01\%$ , in agreement with what found by Liang et al. (2009). In the context of the fireball model, a large fraction of the GRBs in our sample with  $\alpha_2 > 2$ , have been interpreted with a reverse shock (RS) origin, although other interpretations cannot be excluded. GRB 060111B is among the latter: its optical peak has been interpreted as originating from RS in the thick shell case (Stratta et al. 2009), and indeed it is not consistent with the anticorrelation. The GRBs that better follow the anti-correlation, have  $\alpha_2 < 2$  and are consistent with the forward shock emission for which the  $E_{iso} - t_p$  anti-correlation is naturally expected (e.g. Sari 1997b, Liang et al. 2009).

An anti-correlation between the optical peak time and the burst energy is also expected in the context of the Cannonball (CB) model due to the dependence of both variables from the large Doppler boosting, relativistic collimation and time aberration due to the relativistic motion of the ejected material toward the observer (Dado and Dar 2010). In this scenario, an anti-correlation between  $t_p$  and  $E_{iso}$  is expected for individual peaks, while most of the observed peaks are interpreted as unresolved multi-peaks. We have attempted to test the CB model for the optical light curve of GRB 060111B. Following Dado et al. (2009, 2010), we interpreted the observed optical emission as early synchrotron radiation produced by the ionized external matter entering in the CB and interacting with internal magnetic field. Describing the external matter density profile as  $n \propto e^{-a/(r-r_w)}/(r-r_w)^2$  for  $r > r_w$  (and  $n = 0$  for  $r < r_w$ ), the flux is  $F_\nu \propto e^{-a/(t-t_i)} R^2 (t-t_i)^{(1-\beta)} \nu^{-\beta}$  where  $a$  is the wind opacity time scale,  $t_i$  is the time at which the CB enters into the wind (i.e. when the CB is ejected),  $\beta$  is the energy spectral index, and  $R^2 \sim R_{CB}^2 \frac{(t-t_i)^2}{(t-t_i)^2 + (t_{exp}-t_i)^2}$  is the cannonball radius where  $t_{exp}$  is the time at which the CB expansion slows down. When the density profile turns to a constant one (at  $t_{ISM}$ ), the light curve decay shows a plateau phase up to the time  $t_b$  when the bend frequency (the frequency at which the bulk of the electrons emits synchrotron radiation) crosses the optical energy range: at that time a steepening in the light curve is produced. As a preliminar analysis, we have approximated the CB model at this epoch with a broken power law model, plus a constant component for the underlying host galaxy (a more accurate description can be found in Dado et al. 2010). Comparison with the data provides a marginally good fit with  $\chi^2 = 27$  (for 13 d.o.f.) with  $a = 7.5$  s,  $t_i = 24.9$  s,  $t_{exp} = 25.2$  s,  $t_b = 749$  s, fixing the spectral index before and after the bend frequency to  $\beta = 0.5$  and 1, respectively and the wind-to-constant density profile transition epoch at  $t_{ISM} = 300$  s (Fig. 2). The inconsistency of GRB 060111B with the anti-

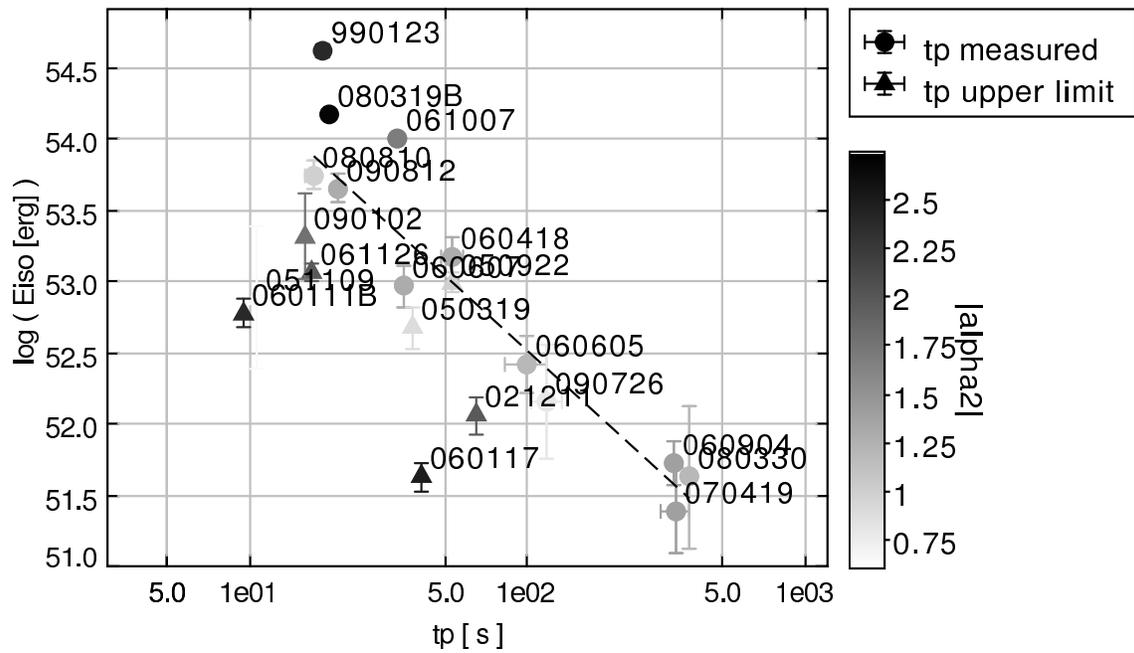


Fig. 1. The isotropic equivalent burst energy of a sample of GRBs at known redshift with evidence of prompt optical peak, versus the optical peak time rest frame epoch. Triangles are the peak time upper limits while circles are those for which the peak emission was unambiguously measured. Gray scale represents the post-peak decay power law index value. Dashed line is the correlation function for those GRBs with measured peak emission (circles) with  $\alpha_2 < 2$  (gradient  $\sim -1.8$ ).

correlation may be the evidence of an intrinsic large scatter. However, in the CB model, the optical peak time should be computed since the beginning of the optical flare rather than the burst trigger: this produces an overall "shift" towards shorter  $t_p$  values that may reduce the scatter for those GRBs with optic observations starting near the trigger time as GRB 060111B.

In conclusion, optical light curves as GRB 060111B, obtained thanks to the fast response of robotic telescopes, and their consistency with the discovered  $E_{iso} - t_p$  anti-correlation, are challenging for the physical origins of the observed emission.

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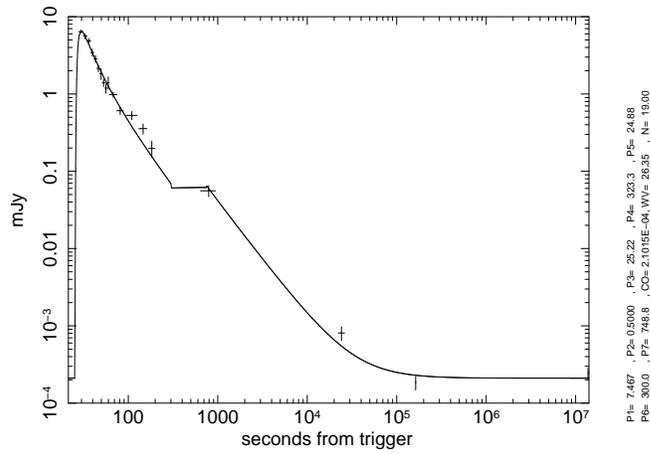


Fig. 2. The R-band light curve of GRB 060111B. The solid line is an approximation of the Cannonball model synchrotron radiation plus a constant component to model the underlying galaxy.

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