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The Afterglow Onset for GRB 060418 and GRB 060607A

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Abstract Gamma-ray burst are thought to be produced by highly relativistic outflows. Although upper and lower limits for the outflow initial Lorentz factor Γ_0 are available, observational efforts to derive a direct determination of Γ_0 have so far failed or provided ambiguous results. As a matter of fact, the shape of the early-time afterglow light curve is strongly sensitive on Γ_0 which determines the time of the afterglow peak, i.e. when the outflow and the shocked circumburst material share a comparable amount of energy. We now comment early-time observations of the near-infrared afterglows of GRB 060418 and GRB 060607A performed by the REM robotic telescope. For both events, the afterglow peak was singled out and allowed us to determine the initial fireball Lorentz, $\Gamma_0 \sim 400$.

Key words: gamma rays: bursts — relativity

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1 INTRODUCTION

The early stages of gamma-ray burst (GRB) afterglow light curves display a rich variety of phenomena at all wavelengths and contain significant information which may allow determining the physical properties of the emitting fireball. The launch of the *Swift* satellite (Gehrels et al. 2004), combined with the development of fast-slewing ground-based telescopes, has hugely improved the sampling of early GRB afterglow light curves.

Since many processes work in the early afterglow, it is often difficult to model them well enough to be able to determine the fireball characteristics. The simplest case is a light curve shaped by the forward shock only. This case is particularly interesting because, while the late-time light curve is independent of the initial conditions (the so-called self-similar solution), the time at which the afterglow peaks depends on the original fireball Lorentz factor Γ, thus allowing a direct measurement of this fundamental parameter (Sari & Piran 1999). The short variability timescales, coupled with the nonthermal GRB spectra, indeed imply that the sources emitting GRBs have a highly relativistic motion (Ruderman 1975; Fenimore et al. 1993; Piran 2000; Lithwick & Sari 2001), to avoid suppression of the high-energy photons due to pair production. This argument, however, can only set a lower limit to the fireball Lorentz factor. Late-time measurements (weeks to months after the GRB) have shown $\Gamma \sim$ a few (Frail et al. 1997; Taylor et al. 2005), but a direct measure of the initial value (when Γ is expected to be ~ 100 or more) is still lacking.

We present here the NIR early light curves of the GRB 060418 and GRB 060607A afterglows observed with the REM robotic telescope[1] (Zerbi et al. 2001; Chincarini et al. 2003) located in La Silla (Chile). These light curves show the onset of the afterglow and its decay at NIR wavelengths as simply predicted by the fireball forward shock model, without the presence of flares or other peculiar features. A detailed discussion of these data has also been reported by Molinari et al. (2007) and Malesani et al. (2007).

2 OBSERVATIONS

GRB 060418 and GRB 060607A were detected by *Swift* at 03:06:08 UT (Falcone et al. 2006) and 05:12:13 UT (Ziaeepour et al. 2006), respectively. The BAT light curve of the former ($T_{90} = 52 \pm 1$ s) showed three overlapping peaks (Cummings et al. 2006). For the latter, the light curve is dominated by a double-peaked structure with a duration $T_{90} = 100 \pm 5$ s (Tueller et al. 2006). The *Swift* XRT started observing the fields 78 and 65 s after the trigger, respectively. UVOT promptly detected bright optical counterparts for both events. The redshift is $z = 1.489$ for GRB 060418 (Dupree et al. 2006; Vreeswijk & Jaunsen 2006) and $z = 3.082$ for GRB 060607A (Ledoux et al. 2006).

The REM telescope reacted promptly to both GCN alerts and began observing the field of GRB 060418 64 s after the burst (39 s after the reception of the alert) and the field of GRB 060607A 59 s after the burst (41 s after the reception of the alert). For both targets a bright NIR source was identified (Covino et al. 2006a,b).

3 RESULTS AND DISCUSSION

3.1 Light Curve Modelling

Figure 1 shows the NIR and X-ray light curves of the two afterglows. The X-ray data have been taken with the *Swift* XRT. The NIR light curves of the two events show a remarkable similarity. Both present an initial sharp rise, peaking at 100–200 s after the burst. The NIR flux of GRB 060418 decays afterwards as a regular power law. The NIR light curve of GRB 060607A shows a similar, smooth behaviour up to ~ 1000 s after the trigger, followed by a rebrightening lasting ~ 2000 s.

To quantitatively evaluate the peak time, we fitted the NIR light curves using a smoothly broken power-law (Beuermann et al. 1999). We obtain for GRB 060418 and GRB 060607A peak times of 153 ± 10 and 180 ± 6 s, respectively. The complete set of fit results is reported in Table 1.

As for many other GRBs observed by *Swift*, the early X-ray light curves of both events show several, intense flares superimposed on the power-law decay (Chincarini et al. 2007). In particular, for GRB 060418 a bright flare was active between ~ 115 and 185 s. Excluding flaring times, the decay is then described by

[1] *http://www.rem.inaf.it*

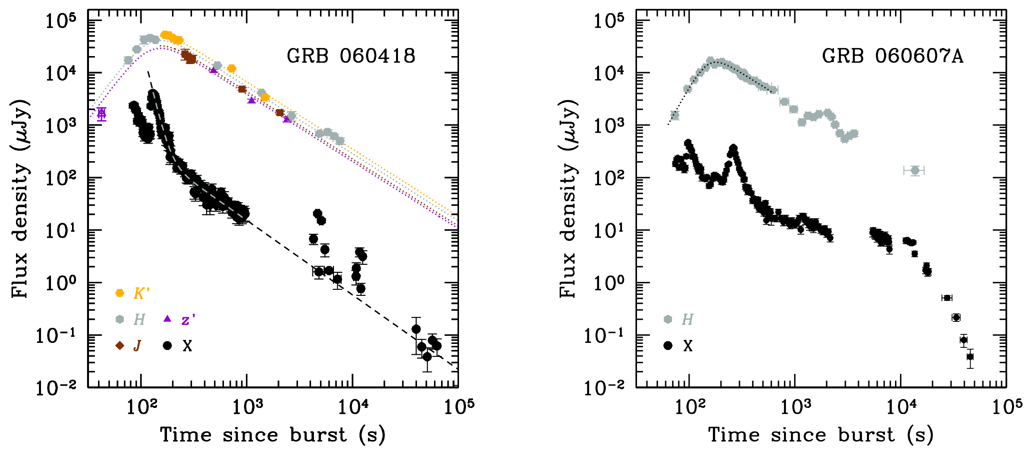

Fig. 1 NIR and X-ray light curves of GRB 060418 (left panel) and GRB 060607A (right panel). The dotted lines show the models of the NIR data using the smoothly broken power law (see Sect. 3.1). For GRB 060418 the dashed line shows the best-fit to the X-ray data.

Table 1 Best Fit Values of the Light Curves of the First Hour of Observations for GRB 060418 and the First 1000 s for GRB 060607A (1σ Errors), Using a Smoothly Broken Power-Law. Fit Parameters are Defined in Molinari et al. (2007). The Relatively Large χ^2 of the Fit Results from Small-Scale Irregularities Present Throughout the Light Curve (see Fig. 1).

GRB	$t_{\rm peak}$ (s)	$t_{\rm b}$ (s)	$\alpha_{\rm r}$	$\alpha_{\rm d}$	κ	χ^2/d.o.f.
060418	153^{+10}_{-10}	127^{+18}_{-21}	$-2.7^{+1.0}_{-1.7}$	$1.28^{+0.05}_{-0.05}$	$1.0^{+0.4}_{-0.4}$	33.3/16
060607A	180^{+5}_{-6}	153^{+12}_{-12}	$-3.6^{+0.8}_{-1.1}$	$1.27^{+0.16}_{-0.11}$	$1.3^{+0.9}_{-1.1}$	28.5/19

a power law with decay slope $\alpha_{\rm X} = 1.42 \pm 0.03$. The X-ray light curve of GRB 060607A is more complex and presents two large flares within the first 400 s. After that the flux density decreases following a shallow power law (with small-scale variability), until steepening sharply at $t \sim 10^4$ s.

By comparing the X-ray and NIR light curves of both bursts, it is apparent that the flaring activity, if any, is much weaker at NIR frequencies. It is thus likely that the afterglow peak, visible in the NIR, is hidden in the X-ray region.

3.2 Determination of the Lorentz Factor Γ_0

Our spectral and temporal analysis agrees with the interpretation of the NIR afterglow light curves as corresponding to the afterglow onset, as predicted by the fireball forward shock model (Sari & Piran 1999; Mészáros 2006). According to the fits, the light curves of the two afterglows peak at a time $t_{\rm peak} > T_{90}$ as expected in the impulsive regime outflow ('thin shell' case). In this scenario the quantity $t_{\rm peak}/(1+z)$ corresponds to the deceleration timescale $t_{\rm dec} \sim R_{\rm dec}/(2c\Gamma^2_{\rm dec})$, where $R_{\rm dec}$ is the deceleration radius, c is the speed of light and $\Gamma_{\rm dec}$ is the fireball Lorentz factor at $t_{\rm dec}$. It is therefore possible to estimate $\Gamma_{\rm dec}$ (Sari & Piran 1999), which is expected to be half of the initial value Γ_0 (Panaitescu & Kumar 2000; Mészáros 2006). For a homogeneous surrounding medium with particle density n, we have

$$\Gamma(t_{\rm peak}) = \left[\frac{3E_\gamma(1+z)^3}{32\pi n m_{\rm p} c^5 \eta t^3_{\rm peak}}\right]^{1/8} \approx 160 \left[\frac{E_{\gamma,53}(1+z)^3}{\eta_{0.2} n_0 t^3_{\rm peak,2}}\right]^{1/8}, \tag{1}$$

where $E_\gamma = 10^{53} E_{\gamma,53}$ erg is the isotropic-equivalent energy released by the GRB in gamma rays, $n = n_0$ cm^{-3}, $t_{\rm peak,2} = t_{\rm peak}/(100\,{\rm s})$, $\eta = 0.2\,\eta_{0.2}$ is the radiative efficiency and $m_{\rm p}$ is the proton mass. We use

$E_\gamma = 9 \times 10^{52}$ erg for GRB 060418 (Golenetskii et al. 2006) and $E_\gamma \sim 1.1 \times 10^{53}$ erg for GRB 060607A (Tueller et al. 2006). Substituting the measured quantities and normalising to the typical values $n = 1$ cm $^{-3}$ and $\eta = 0.2$ (Bloom et al. 2003), we infer for both bursts $\Gamma_0 \approx 400\,(\eta_{0.2} n_0)^{-1/8}$.

3.2.1 How Model Dependent is the Derived Lorentz Factor?

In the context of the so-called standard afterglow model, the Lorentz Γ factor determined in Secttion 3.2 is only very weakly dependent on the unknown parameters n and η. Therefore, the determination of Γ_0 is robust. In principle, the only important factor is the hydrodynamical interaction of a relativistic outflow with the circumburst medium. Independently of the emission process or of the interaction physics, if the material collected by the outflow is able to radiate away the acquired energy, the phenomenon should be qualitatively the same, and again the Lorentz Γ factor estimate would be reliable. Of course, in this hypothetical case, lacking of a well developed theoretical framework we could not check the self-consistency of the proposed scenario studying the slopes of the rising (and decaying) phase.

3.3 The Reverse Shock

For both bursts, we could not detect any reverse shock emission. The lack of such flashes has already been noticed previously in a set of *Swift* bursts with prompt UVOT observations (Roming et al. 2006). Among the many possible mechanisms to explain the lack of this component, strong suppression (or even total lack) of reverse shock emission is naturally expected if the outflow is Poynting-flux dominated (Fan et al. 2004; Zhang & Kobayashi 2005). For GRB 060418, Mundell et al. (2007) derived an 8% upper limit for the polarization in the optical band roughly three minutes from the burst, i.e. one minute after the afterglow onset. In case the GRB prompt is driven by magnetic energy a high polarization degree is expected (Granot & Königl 2003; Lazzati et al. 2004; Sagiv et al. 2004). However, for photons emitted by material shocked by the forward shock the polarization degree would depend on the magnetic energy transfer from the blastwave to the shocked medium, that is at present poorly known (see Covino 2007, and references therein). As a matter of fact, Jin & Fan (2007) showed that for GRB 060418 and GRB 060607A the reverse shock emission predicted by the standard afterglow model might be too weak to be detected.

4 CONCLUSIONS

The REM discovery of the afterglow onset has demonstrated once again the richness and variety of physical processes occurring in the early afterglow stages. The very fast response observations presented here provide crucial information on the GRB fireball parameters, most importantly its initial Lorentz factor. This is the first time that $\Gamma(t_{\rm peak})$ is directly measured from the observations of a GRB. The measured Γ_0 value is well within the range ($50 \lesssim \Gamma_0 \lesssim 1000$) envisaged by the standard fireball model (Piran 2000; Guetta et al. 2001; Soderberg & Ramirez-Ruiz 2002; Mészáros 2006). It is also in agreement with existing measured lower limits (Lithwick & Sari 2001; Zhang et al. 2006).

Using $\Gamma_0 = 400$ we can also derive other fundamental quantities characterising the fireball of the two bursts. In particular, the isotropic-equivalent baryonic load of the fireball is $M_{\rm fb} = E/(\Gamma_0 c^2) \approx 7 \times 10^{-4}\, M_\odot$, and the deceleration radius is $R_{\rm dec} \approx 2ct_{\rm peak}[\Gamma(t_{\rm peak})]^2/(1+z) \approx 10^{17}$ cm. This is much larger than the scale of $\sim 10^{15}$ cm where the internal shocks are believed to power the prompt emission (Mészáros & Rees 1997; Rees & Mészáros 1994), thus providing further evidence for a different origin of the prompt and afterglow stages of the GRB.

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