

The GRB afterglow onset observed by REM: fireball Lorentz factor and afterglow fluence

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Abstract

We report observations of the early light curves of GRB 060418 and GRB 060607A, carried out with the pink robotic telescope REM. A clear peak is detected for both events, which is interpreted as the onset of the afterglow, that is the time at which the fireball starts decelerating. This detection allows to directly measure the initial fireball Lorentz factor, which was found to be $\Gamma_0 \approx 400$ for both events, fully confirming the ultrarelativistic nature of gamma-ray burst fireballs. Sampling the light curve before the peak also allows to compute the bolometric fluence of the afterglow, which is 16% of the prompt one in the case of GRB 060418.

Key words: Gamma-ray: bursts

1 Introduction

It has long been known that the plasma emitting gamma-ray bursts (GRBs) must be moving relativistically, and that its Lorentz factor Γ is much larger than unity. This follows by the so-called compactness argument (Ruderman et al., 1975). The high photon densities, coupled with the short variability timescales, imply that GRB sources should be

optically thick to pair production, leading to a huge suppression of the emitted flux and to thermal spectra, contrary to what is observed. The solution to the compactness problem requires the source to be in relativistic motion (Piran, 2000). Lower limits to the Lorentz factor $\Gamma \gtrsim 100$ are usually derived (Lithwick & Sari, 2001).

The discovery of long-lived afterglows has greatly advanced our

knowledge of GRBs. Afterglow radiation is powered by the deceleration of the relativistic fireball. The afterglow behaviour at late times, however, is insensitive to the initial Lorentz factor, since the fireball decelerates in a self-similar way (Blandford & McKee, 1976). The fireball Lorentz factor can be measured by observing the afterglow onset (Sari & Piran, 1999), which roughly corresponds to the time at which the fireball starts decelerating significantly. At this time, the afterglow luminosity reaches a maximum. Unluckily, the early light curves are very complex, and the observed emission is a mixture of several components, which easily hide the afterglow peak: residual prompt activity, reverse shocks, late internal shocks, reverberation of the main GRB. A clear peak could be observed in very few cases, most noticeably GRB 030418 and GRB 050820A (Rykoﬀ et al., 2004; Vestrand et al., 2006).

The *Swift* satellite triggered on the long-duration GRB 060418 and GRB 060607A, promptly located them, and for both discovered an X-ray and optical afterglow (Falcone et al. 2006; Ziaepour et al. 2006). Their redshifts are $z = 1.489$ and 3.082 , respectively, thus implying an isotropic-equivalent energy $E_{\text{iso}} = 9 \times 10^{52}$ and $\sim 1.1 \times 10^{53}$ erg (Dupree et al., 2006; Vreeswijk & Jaunsen, 2006). The X-ray telescope followed their light curve for a few days, revealing intense flares for both. The REM (Rapid Eye Mount) robotic telescope (Zerbi et al., 2001; Chincarini et al.,

2003) promptly reacted to the triggers, and started observing the GRB fields about one minute after the GRB, locating in both cases a near-infrared (NIR) counterpart (Covino et al., 2006a,b). In the case of GRB 060418, multifilter observations were secured to study the afterglow spectrum, while for GRB 060607A a single, densely sampled light curve was recorded. We refer to Molinari et al. (2007) for a full description of these data.

2 The fireball Lorentz factor

Figure 1 shows the light curves of GRB 060418 and GRB 060607A. In the NIR, a clear peak is observed ≈ 150 s after the trigger. Following the maximum, the curves evolve gradually into a power-law decay. This is different from what observed in the X rays, where the flares are observed superimposed to an underlying component with power-law behaviour. For GRB 060418, the decay goes on interrupted for more than three decades in time, directly linking the peak to the forward shock emission. These properties suggest that the observed maximum corresponds to the afterglow onset. The peak times were quantitatively determined by fitting a smoothly-broken power law to the light curve.

The observed peak times t_{peak} (150 and 180 s for GRB 060418 and GRB 060607A, respectively) are longer than the burst durations, and this corresponds to the so-called thin-shell case. In this scenario, the

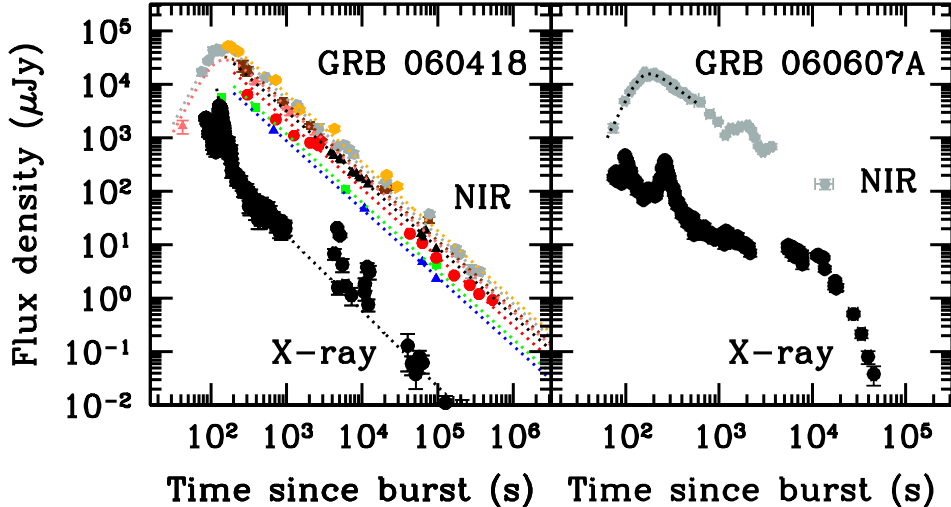


Fig. 1. X-ray and NIR/optical light curves of GRB 060418 and GRB 060607A. The REM data have been complemented by GCN and VLT data.

afterglow peak time roughly marks the epoch at which the expanding fireball has swept up enough mass to be significantly decelerated. Using the formulation by Sari & Piran (1999), we have

$$\Gamma_0 = 320 \left[\frac{E_{\gamma,53}(1+z)^3}{\eta_{0.2} n_0 t_{\text{peak},2}^3} \right]^{1/8}, \quad (1)$$

where $E_\gamma = 10^{53} E_{\gamma,53}$ erg is the fireball (isotropic-equivalent) energy, $n = n_0 \text{ cm}^{-3}$ is the particle density of the surrounding medium (supposed homogeneous), $\eta = 0.2\eta_{0.2}$ is the radiative efficiency, and $t_{\text{peak},2} = t_{\text{peak}}/(100 \text{ s})$. We infer $\Gamma_0 \approx 400$ for both bursts, weakly dependent on the unknown efficiency and external medium density.

In our computation, we have assumed a homogeneous medium. The light curve before the peak indeed rises as $\sim t^3$, consistent with the expectations for a uniform ISM (Jin & Fan, 2007) and in contrast with a wind-shaped ($n \propto r^{-2}$) environment. Af-

ter the peak, however, the behaviour of GRB 060418 is inconsistent with both a homogeneous and a wind medium. This might be due, for example, to varying microphysical parameters, or presence of Compton emission, or radiative losses. Assuming a wind-shaped density profile, we find a somehow lower value for the Lorentz factor, $\Gamma_0 \approx 150$.

The measured values are in agreement with theoretical predictions and consistent with existing lower limits (Lithwick & Sari, 2001). Using $\Gamma_0 \approx 400$, we compute the emission radius $R = 2ct_{\text{peak}}[\Gamma(t_{\text{peak}})]^2/(1+z) \approx 10^{17}$ cm. This is much larger than the internal shocks scale (where the prompt emission is believed to arise), confirming the different origin of these two components. Albeit Γ_0 is similar for GRB 060418 and GRB 060607A, a universal value is unlikely. For example, no peak was observed for GRB 050401 (Rykoff et al., 2005), implying $\Gamma_0 > 900$.

3 Afterglow energetics

The detection of the peak allows the measurement of another important quantity, the afterglow bolometric fluence $\mathcal{F} = \int F_\nu(t, \nu) d\nu dt$. The integration over the frequency domain requires also the knowledge of the spectral shape. For GRB 060418, our multiwavelength coverage, coupled with the X-ray monitoring, allows to determine the peak frequency as a function of time, and the spectrum can be safely extrapolated. The host-galaxy extinction ($A_V = 0.1$ mag) was computed by imposing for the optical/NIR and X-ray spectral slopes $\beta_{\text{opt}} = \beta_X - 0.5$, and assuming an SMC extinction curve.

By computing the integral, we get $\mathcal{F} = 2.2 \times 10^{-6}$ erg cm $^{-2}$. To our knowledge, this is the first case for which such a measurement has been performed. For comparison, the prompt emission bolometric fluence (easily computed thanks to the broad-band *Wind*/Konus measurement; Golenetskii et al. 2006) is $\mathcal{F}_{\text{GRB}} = 1.6 \times 10^{-5}$ erg cm $^{-2}$. This implies an afterglow-to-prompt fluence ratio of 16%. In principle, external shocks are more efficient in dissipating the fireball energy than internal collisions (which have a low Lorentz factor contrast). Our result thus implies that external shocks are not much efficient in radiating the dissipated energy. This is consistent with the observed regime of slow cooling inferred by the SED modeling.

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References

- Blandford, R.D., & McKee, C.F. 1976, *Phys. Fluids*, 19, 1130
- Covino, S., Antonelli, L. A., Vergani, S.D., et al. 2006a, GCN 4967
- Covino, S., Distefano, E., Molinari, E., et al. 2006b, GCN 5234
- Chincarini, G., Zerbi, F. M., Antonelli, A., et al. 2003, *The Messenger*, 113, 40
- Dupree, A.K., Falco, E., Prochaska, J.X., et al. 2006, GCN 4969
- Falcone, A.D., Barthelmy, S.D., Burrows, D.N., et al. 2006, GCN 4966
- Golenetskii, S., Aptekar, R., Mazets, E., et al. 2006, GCN 4989
- Jin, Z.-P., & Fan, Y.-Z. 2007, *MNRAS*, in press (astro-ph/0701715)
- Lithwick, Y., & Sari, R. 2001, *ApJ*, 555, 540
- Molinari, E., Vergani, S., Malesani, D., et al. 2007, *A&A*, 469, L13
- Piran, T. 2000, *Phys. Rep.*, 333, 529
- Ruderman, M. 1975, *NYASA*, 262, 164
- Rykoff, E.S., Smith, D.A., Price, P.A., et al. 2004, *ApJ*, 601, 1013
- Rykoff, E.S., Yost, S.A., Krimm, H.A., et al. 2005, *ApJ*, 631, L121
- Sari, R., & Piran, T. 1999, *ApJ*, 520, 641
- Vestrand, W.T., Wren, J.A., Wozniak, P.R., et al. 2006, *Nat*, 442, 172
- Vreeswijk, P., & Jaunsen, A. 2006, GCN 4974
- Zerbi, F.M., Chincarini, G., Ghisellini, G., et al. 2001, *AN*, 322, 275
- Ziaepour, H.Z., Barthelmy, S.D., Gehrels, N., et al. 2006, GCN 5233