Abstract. We present an analysis of the unusual optical light curve of the gamma-ray burst GRB 081029, which occurred at a redshift of $z = 3.8479$. We combine X-ray and optical observations from the Swift X-Ray Telescope and the Swift UltraViolet Optical Telescope with optical and infrared data obtained using the REM and ROTSE telescopes to construct a detailed data set extending from 86 s to $\sim 100000$ s after the BAT trigger. Our data also cover a wide energy range, from 10 keV to 0.77 eV (1.24 Å to 16 000 Å). The X-ray afterglow shows a shallow initial decay followed by a rapid decay starting at about 18 000 s. The optical and infrared afterglow, however, shows an uncharacteristic rise at about 5000 s that does not correspond to any feature in the X-ray light curve. Our data are not consistent with synchrotron radiation from a single-component jet interacting with an external medium. We do, however, find that the observed light curve can be explained using multi-component model for the jet.

Keywords: gamma-ray burst: individual: GRB 081029

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INTRODUCTION

There is growing evidence that the classical picture of a single uniform jet cannot explain the spectral energy distributions and light curves of some gamma-ray burst (GRB) afterglows. For example, the unusually bright optical afterglow of the “naked-eye” burst GRB 080319B was best explained using a two-component jet [6] while GRB 030329 [1] appears to require a narrow, ultra-relativistic inner jet and a wide, mildly relativistic outer jet to explain its light curves. This is in agreement with results from magneto-hydrodynamic modelling that show complex structure in GRB jets [e.g., 9]. GRB afterglows appear to be more complex than originally thought.

An example of a GRB afterglow that appears to require a multi-component jet is GRB 081029. This burst was detected by Swift/BAT at 01:43:56 UT on 2008 Oct 29 [8]. ROTSE-IIIc identified the optical afterglow at 86 s [7], and the REM telescope started observing the optical afterglow at 154 s [2], so there is a well-sampled $R$-band light curve starting less than 90 s after the BAT trigger. Due to an observing constraining Swift was unable to slew to this burst as soon as it was detected. XRT and UVOT observations began about 45 minute after the BAT trigger and continued for approximately 10 days.

The VLT/UVES and Gemini-South measured a redshift of $z = 3.8479$ [4, 3], which corresponds to a look back time of 11.9 Gyr. The Gemini-South GMOS spectrum shows evidence for a damped Lyman-alpha system as well as several metal absorption features in the host galaxy of GRB 081029.
OBSERVATIONS

BAT: Prompt Emission

The Swift/BAT discovered and observed GRB 081029. The burst duration was $T_{90} = 280 \pm 50$ s, the peak flux was $(2.8 \pm 1.3) \times 10^{-8}$ erg cm$^{-2}$ s$^{-1}$, and the spectrum was best fit by a simple power law with a photon index of $\Gamma = 1.5 \pm 0.2$. The BAT light curve was somewhat smoother and weaker than a typical BAT-detected GRB. Figure 1 shows the BAT light curve for the prompt emission from GRB 081029.

XRT: X-Ray Light Curve and Spectrum

The Swift/XRT observed GRB 081029 from 41.4 minutes to approximately 10 days after the BAT trigger. The X-ray light curve (see Figure 2) is well fit by a broken power law with indices ($f_\nu \propto t^{-\alpha}$) of $\alpha_1 = 0.56 \pm 0.03$ until $18230 \pm 346$ s, and $\alpha_2 = 2.56 \pm 0.09$ after that. There is some evidence for flaring between approximately 2500 s and 5000 s. The time scales of these flares are consistent with $\Delta t/t < 1$. The X-ray data are not unusual, and are consistent with the canonical X-ray light curve for GRB afterglows described by [5] and [10].

The Swift/XRT spectrum can be fit by a single power law ($f_\nu \propto \nu^{-\beta}$) with an index of $\beta_X = 0.98 \pm 0.08$. There is no evidence for any evolution in the power law index at X-ray energies. The estimated Galactic column density in the direction of the burst is $N_H = 2.8 \times 10^{-20}$ cm$^{-2}$, and the absorption in the host is $N_H = 4.9 \times 10^{-21}$ cm$^{-2}$.
FIGURE 3. A two-component jet model provides a reasonable fit to the optical, infrared, and X-ray light curves of the afterglow of GRB 081029.

Optical and Infrared Observations

The Swift UVOT began observing the afterglow of GRB 081029 at 2689 s after the BAT trigger. The afterglow was detected in the UVOT $v$, $b$, and white bands, consistent with the reported redshift of $z = 3.8479$. Ground-based data was obtained using REM and ROTSE. ROTSE began observations 86 s after the burst in the $R$ band. REM began observing GRB 081029 156 s after the BAT trigger in the $R$, $J$, and $H$ bands. The resulting light curves are complex, in stark contrast to the simple X-ray light curve. The combined optical and infrared observations are shown in Figure 2 along with the Swift/XRT light curve. The optical and infrared data show a jump in the flux density of approximately a factor of ten at approximately 5000 s. There is no corresponding increase in the X-ray flux density at that time.

DISCUSSION

The X-ray light curve is consistent with energy injection from ongoing central engine activity until about 15 000 s followed by a jet break at 18 230 s. However, this scenario cannot explain the jump in the flux seen at optical and infrared wavelengths at about 5000 s. Therefore, we do not think that a change in the energy injection is capable of explaining the light curves for this afterglow. Similarly, the jump cannot be modelled by invoking the passage of the synchrotron peak frequency through the optical regime, or as the rise of the forward shock due to interaction with the circumburst medium. We also examined the possibility that the jump is due to density structure in the surrounding environment, but this is unable to reproduce the speed or the magnitude of the increase in luminosity.

In general we find that a one-component jet cannot explain the observed light curves and spectral energy distribution of the X-ray, optical, and infrared afterglows of GRB 081029. However, a two-component jet model, similar to what is seen in some other GRB afterglows, does provide a reasonable fit to the data. Our two-component jet model is shown in Figure 3, and the parameters of each jet are listed in Table 1. The half-opening angle of the jet is denoted by $\theta_j$, $\Gamma_0$ is the Lorentz factor, $E_{K,iso}$ is the isotropic equivalent kinetic energy in the jet, $p$ is the electron index, $\varepsilon_e$ and $\varepsilon_B$ are the fractions of the energy in electrons and magnetic fields respectively, $n$ is the density of the circumburst medium, and $z$ is the redshift.

The narrow, inner jet has a half-opening angle of $\theta_{j,n} = 0.01$ rad and a Lorentz factor of 500. This component gives
Table 1. Model parameters for the best-fitting two-component jet model for GRB 081029.

| Parameter       | Narrow Jet | Wide Jet  |
|-----------------|------------|-----------|
| $\theta_j$ (rad) | 0.01       | 0.02      |
| $\Gamma_0$      | 500        | 60        |
| $E_{K,iso}$ (erg) | $2.5 \times 10^{54}$ | $2.0 \times 10^{54}$ |
| $p$             | 2.2        | 2.2       |
| $\varepsilon_e$ | 0.02       | 1/3       |
| $\varepsilon_B$ | 0.0002     | 0.0002    |
| $n$ (cm$^{-3}$) | 10         | 10        |
| $z$             | 3.8479     | 3.8479    |

rise to the X-ray flux and the pre-jump optical flux. The wider, outer jet has $\theta_{j,w} = 0.02$ rad and a Lorentz factor of 60. This component dominates the afterglow after about 10,000 s. The total electromagnetic energy in the afterglow is approximately equally divided between the two jets.

CONCLUSIONS

GRB 081029 was a long–soft GRB with a redshift of $z = 3.8479$. It had a smooth gamma-ray light curve and did not appear to have any unusual gamma-ray properties. Neither the gamma-ray nor the X-ray properties of this burst showed any sign of strange behaviour. The optical and infrared light curves, on the other hand, were not typical of GRB afterglows. There is a brightening in the optical and infrared light curves at about 5000 s that cannot be explained using a single-component jet model. However, we find that a two-component jet model fits the data reasonably well.

We conclude that the afterglow of GRB 081029 was probably powered by a two-component jet with the energy split approximately equally between a narrow ($\theta_{j,n} = 0.01$ rad) inner jet and a wider ($\theta_{j,w} = 0.02$ rad) outer jet. The inner jet has a Lorentz factor of $\Gamma_n = 500$ while the outer jet has $\Gamma_w = 60$. This result provides evidence that some (and perhaps all) GRB jets have complex internal structure.

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