

HIGH-PRECISION PHOTOMETRY OF THE GAMMA-RAY BURST GRB 020813: THE SMOOTHEST AFTERGLOW YET

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ABSTRACT

We report results of our precise reduction of the high signal-to-noise ratio *VRI* observations of the optical afterglow of the gamma-ray burst GRB 020813 obtained by Gladders & Hall with the Magellan 6.5 m telescope 3.9–4.9 hr after the burst. These observations are very well fitted locally by a power-law curve, providing the tightest constraints yet on how smooth the afterglows can be in some cases: the rms deviations range from 0.005 mag (0.5%) for the *R* band to 0.007 mag for the *I* band, only marginally larger than the rms scatter for nearby nonvariable stars. This scatter is a factor of several smaller than the smallest reported rms of 0.02 mag for GRB 990510 (Stanek et al.). These observations are in strong contrast to those of afterglows of GRB 011211 and GRB 021004, for which large, greater than 10% variability has been observed on timescales from ~20 minutes to several hours. If interstellar medium (ISM) density fluctuations near the GRB are indeed causing the bumps and wiggles observed in some bursts, very uniform regions of ISM near some bursts must be present as well. This result also constrains the intrinsic smoothness of the afterglow itself.

Subject heading: gamma rays: bursts

1. INTRODUCTION

Short-timescale variability in the optical afterglow of gamma-ray bursts (GRBs) can be a tool for understanding the details of GRB origins. The optical afterglow of a GRB stems from a relativistic blast wave as it slows down in the interstellar medium (ISM)/stellar wind surrounding a source hypernova (e.g., Stanek et al. 2003; Matheson et al. 2003). Understanding variations in intensity of the optical afterglow, or lack thereof, can yield insights into the details of the interaction between GRBs and their surroundings (e.g., Wang & Loeb 1999). Such greater than 10% variability has been observed by Holland et al. (2002) in GRB 011211 and by Bersier et al. (2003) in GRB 021004.

GRB 020813 was detected by the *High Energy Transient Explorer 2* at 2:44:19 UT on 2002 August 13 (Villasenor et al. 2002). Its optical afterglow was localized by Fox, Blake, & Price (2002) at $\alpha_{2000} = 19^{\text{h}}46^{\text{m}}41^{\text{s}}.88$, $\delta_{2000} = -19^{\circ}36'05''$. The properties of the burst and the afterglow have been described so far by Barth et al. (2003), Covino et al. (2003), Li et al. (2003), and Urata et al. (2003). Gladders & Hall (2002a, 2002b) began taking optical data 3.0 hr after the event with the Baade 6.5 m telescope. These data had exceptionally good seeing and high signal-to-noise ratio and were made public by Gladders & Hall via an anonymous ftp. We decided to use these high-quality data to investigate the possible presence of short-timescale variability in the afterglow. In this Letter, we find that between 3.9 and 4.9 hr after the burst, the afterglow of GRB 020813 has been the smoothest yet, with rms deviations ranging from 0.005 mag for the *R* band to 0.007 mag for the *I* band, only marginally larger than the photometric scatter for nearby nonvariable stars.

2. OBSERVATIONS AND DATA REDUCTION

The *VRI* data were obtained with the Las Campanas Observatory Magellan Baade 6.5 m telescope equipped with the Tek5 camera by M. Gladders and P. Hall over two nights (Gladders & Hall 2003c). Thirty-seven 60 s exposures were taken of the afterglow the first night (11 in *V*, 10 in *R*, and 16 in *I*) and 15 of the same length the second night (two in *V*, four each in *BR*, and five in *I*). Since we were interested in

the short-term variability, we decided not to reduce the second night's data. According to the ftp posting,¹ they were overscan-corrected, trimmed, debiased, and flat-fielded using calibration frames from the first night (August 13 UT). Also, a fringe frame was produced from other science observations on August 13 UT and was used to defringe the *I*-band data.

We used the DAOPHOT point-spread function fitting package (Stetson 1987, 1992) and the ISIS image subtraction package (Alard & Lupton 1998; Alard 2000) to reduce the data. We found excellent agreement between the two packages. For consistency, we used the photometry obtained with DAOPHOT throughout this Letter. Images from the first night were brought to a common zero point using approximately 50 stars per image, providing very stable differential photometry. Our reduction of the Gladders & Hall data is listed in Table 1.

While this is not important for the current Letter, for consistency we have calibrated our photometry to that of Covino et al. (2003). We note that the reductions of Gladders & Hall's *R*-band data by Covino et al. (2003) and by Li et al. (2003) differ by about 0.09 mag, with the Li et al. photometry being brighter.

3. SHORT-TIMESCALE VARIATIONS

We fitted a power law to first night *VRI* data; this yielded a local decay slope of 0.77. This simple fit turns out to be a good description of the OT temporal behavior (Fig. 1). In the *R* band, the residuals from the power-law behavior are the smallest, with rms of 0.005 mag. The rms is slightly larger, 0.006 mag, for the *V* band, and is the largest for the *I* band, 0.007 mag. For comparison, nearby nonvariable stars show rms scatter of ~0.003 mag in the *R* band, ~0.005 mag in the *I* band, and ~0.007 mag in the *V* band. The observed deviations might be marginally significant for the *RI* bands. However, these deviations are a factor of several smaller than the smallest deviations reported so far: for GRB 990510, *R*-band rms scatter of ~0.021 mag was observed, with the largest deviation from the smooth decay being 0.08 mag (Stanek et al. 1999; see also Hjorth et al. 1999).

So far there have been two detections of short-timescale

¹ See ftp://ftp.ociw.edu/pub/gladders/GRB/GRB020813/README.

TABLE 1
MAGELLAN PHOTOMETRY

ΔT^a	Magnitude	σ_m	Filter
0.1641	18.903	0.005	V
0.1727	18.947	0.005	V
0.1765	18.973	0.005	V
0.1793	18.986	0.005	V
0.1803	18.985	0.005	V
0.1813	18.989	0.005	V
0.1824	18.990	0.005	V
0.1884	19.020	0.006	V
0.1925	19.047	0.006	V
0.1965	19.070	0.006	V
0.1975	19.066	0.007	V
0.1653	18.488	0.004	R
0.1739	18.518	0.004	R
0.1752	18.538	0.005	R
0.1837	18.568	0.004	R
0.1848	18.580	0.004	R
0.1858	18.574	0.004	R
0.1868	18.588	0.004	R
0.1910	18.603	0.004	R
0.1939	18.616	0.005	R
0.1987	18.640	0.004	R
0.1615	17.939	0.004	I
0.1670	17.970	0.004	I
0.1681	17.974	0.005	I
0.1692	17.972	0.005	I
0.1702	17.968	0.005	I
0.1713	17.976	0.005	I
0.1776	18.013	0.005	I
0.1898	18.070	0.005	I
0.1952	18.097	0.006	I
0.2001	18.122	0.005	I
0.2011	18.113	0.005	I
0.2021	18.118	0.006	I
0.2032	18.119	0.005	I
0.2042	18.141	0.005	I

^a Days after 2002 August 13.11411 UT.

variations in optical afterglows: GRB 011211 (Holland et al. 2002) and, especially clear, GRB 021004 (Bersier et al. 2003). Models have attempted to explain short-timescale bumps and wiggles in optical GRB light curves, but given the smoothness of the curve presented here, consideration should be given to explaining very smooth curves as well. If ISM density fluctuations near the GRB explain the bumps and wiggles, the models must also allow for very uniform regions of ISM.

The data reduced here cover only an hour very early after the event; hence, it cannot provide limits for later interaction with the ISM or other behavior. Longer term, equally dense,

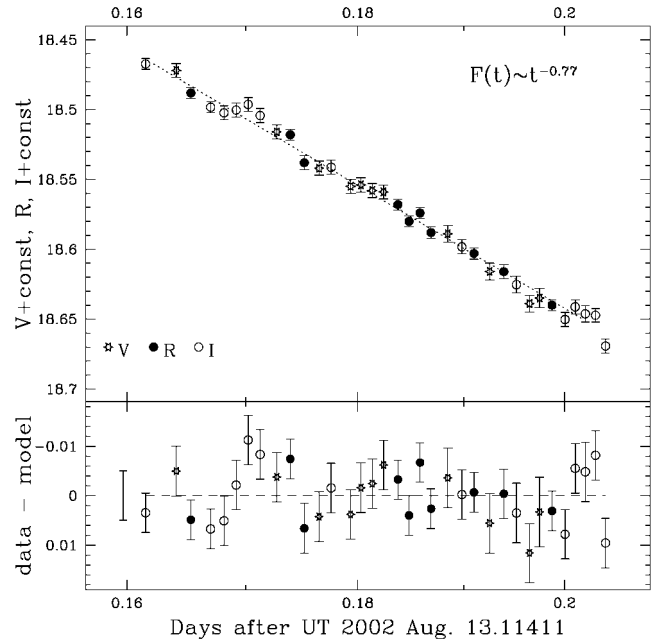


FIG. 1.—*Top*: VRI light curve of the optical afterglow of GRB 020813 during 3.9–4.9 hr after the burst. A power law has been fitted to the data. The V and I data have been shifted. *Bottom*: Residuals between the power-law model and the VRI-band data. The error bar on the left is typical for nonvariable stars with brightness similar to the afterglow (rms ~ 0.005 mag in I band).

and high-quality sampling would be appropriate for a better understanding of short-timescale variability over the course of the GRBs. Such data most likely already exist, for example for GRB 030329, which was very bright and observed intensively by numerous observers for many days. While the light curve of GRB 030329 was very bumpy on timescales of days, on timescales of hours the light curve was very smooth (e.g., Matheson et al. 2003).

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