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LOTIS: GRB follow-up observations at early times

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Abstract. LOTIS is an automated wide field-of-view telescope system capable of responding to GRB events as early as 10 s after a trigger from the GCN which rapidly distributes coordinates from the Beppo/SAX, BATSE and RXTE instruments. Measurements of optical activity at these early times will provide important clues to the GRB production mechanism. In over two year's of operation, LOTIS has responded to 40 GCN triggers including GRB971217 within 10 s and GRB980703 within 5 hours. We report results from these events and constraints on simultaneous optical signals during these GRBs.

Key words: gamma rays – bursts

1. Introduction

The origin and nature of gamma-ray bursts (GRBs) remains an important unresolved problem in astrophysics. Much of the difficulty in studying gamma-ray bursts is due to the poor directional precision of GRB detectors ($1 \sim 10^\circ$ $1\ \sigma$ statistical error) and their short duration ($1 \sim 100$ s). Recently an Italian-Dutch satellite (BeppoSAX) provided GRB coordinates with arcmin accuracy leading to the observation of fading X-ray, optical and radio afterglows (Costa 1997, Heise 1997, Djorgovski 1997, van Paradijs 1997). These events provided information on their distance scale (Metzger 1997) and external environment. However, these observations were made many hours after the GRB event and the signals may be due to processes different from the GRB production mechanism. An observation of optical activity occuring at the same time as the gamma-ray emission may provide clues to understanding GRB physics (Sari 1998).

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To search for simultaneous optical counterparts of GRBs, we are operating an automated wide field-of-view telescope at Lawrence Livermore National Laboratory (LLNL) to rapidly image GRB coordinate error boxes distributed by the Gamma-ray burst Coordinate distribution Network (GCN) (Barthelmy 1998). This system is called LOTIS for Livermore Optical Transient Imaging System.

Currently, the real-time trigger derived from BATSE telemetry in ~5 s has large angular error ($1\ \sigma$ error of $2 \sim 10^\circ$.) This requires wide field-of-view optics to obtain significant coverage of an event. LOTIS utilizes commercially available Canon f/1.8 telephoto lenses of 200 mm focal length and 110 mm diameter effective aperture. The electronic focal plane sensors are 2048×2048 pixel Loral 442A CCDs with 15×15 μm pixels driven by custom read-out electronics. Each lens/camera assembly has a field-of-view of $8.8 \times 8.8^\circ$ with a pixel scale of 15 arcsec. Four cameras are arranged in a 2×2 array to cover a total field-of-view of $17.4 \times 17.4^\circ$ overlapping 0.2° in each dimension. We are running these cameras without filters to enhance our detection sensitvity to dim objects. While we are waiting for GRB triggers which occur ~once per 20 days, we systematically monitor the entire available night sky 4 times a night.

LOTIS started operating in October 1996 at LLNL's remote test facility, 25 miles east of Livermore, California. We recorded ~40 GCN triggers as of Nov. 1998 including GRB970223 (Park 1997), GRB971227 and GRB980703. In this paper we report on 2 events: GRB971227 and GRB980703. Many follow-up observations were made for these events because BeppoSAX detected fading hard X-ray counterparts and was able to localize the GRB coordinate to ~ 1 arcmin. The ealiest observations were made by LOTIS responding to the BATSE triggers.

2. LOTIS observation of GRB971227

LOTIS received GCN coordinates derived from BATSE telemetry approximately 4 s after the start of the burst and obtained its first 10 s exposure, centered on the GCN coordinates 6 s later (10 s after the burst began: 27.3495 UT) LOTIS continued taking 10 s exposures at the rate of 1 image every 20 s for the next 20 minutes, then at the rate of once per minute for the rest of the night. Because of LOTIS's large, field-of-view, the recorded images fully contain the error box of the location of the associated X-ray transient detected by BeppoSAX's NFI despite the 6.7° difference between the location of the BeppoSAX NFI position and the GCN BATSE-Original coordinates. We scanned the area of our images within the BeppoSAX error circle (8 arcmin radius) and found 10 objects brighter than an R equivalent magnitude of R_{eq}=12.3±0.3; all of which were identified with known objects in the Guide Star Catalog and the Digital Sky Survey, and none showing variations in brightness in the other images.

We can improve our limiting magnitude by co-adding frames which reduces the background noise and enhances the signal. We added 60 frames which were taken during the first 20 min after the GRB and searched for any objects not in the catalog. We did not see any such objects at R_{eq}=14.2±0.2. Details of our analysis method and comparisions of our limits with GRB models can be found in Williams et al. 1998.

3. LOTIS observation of GRB980703

LOTIS obtained images in the field of GRB980703 5.03 hours after the burst began (July 3.39 UTC). Even though LOTIS is capable of responding to GRB events as soon as 10 s after a burst, the GRB980703 trigger came at 9:20 PM local time while there was still day light at the LOTIS site. In fact, the reported optical transient location (Frail 1998) was below the horizon at the time. Therefore, LOTIS could not cover this event in real-time. However, our all-sky patrol program eventually imaged the GRB980703 field 5 hours after the burst. The GRB980703 field was imaged 2 times the first night after rising above the horizon. We also have sky patrol data from the previous and the following nights. The integration time used for these images was 30 s. We have analyzed the images taken at July 2.39, 2.47, 3.39, 3.47, 4.39, 4.47 and 6.47 UTC by comparing them to each other and with Digital Sky Survey images.

No flaring sources were observed at brighter than R_{eq}=15.0±0.3. Figure 1 shows the LOTIS limit with respect to H, I and R band follow-up observations made by other telescopes (Bloom 1998.) A linear extrapolation of the R band observation to earlier times predicts bright signals easily detectable by LOTIS within the first 10s of seconds after the start of the GRB.

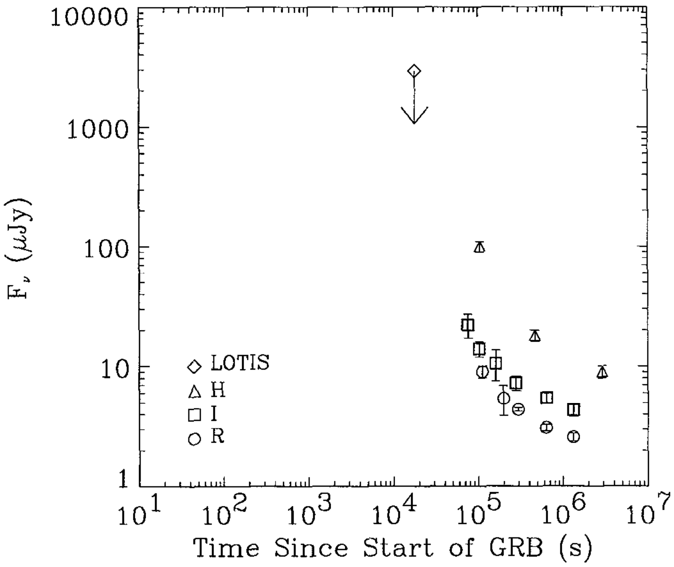

Fig. 1. Optical light curve of the H, I, and R band transients associated with GRB980703

4. Conclusions

LOTIS is capable of detecting optical signals associated with GRBs as easly as 10 s. No optical signals were detected at R_{eq}=12.3 after 10 s and at R_{eq}=14.2 after 20 min for GRB971227. No optical signals were detected at R_{eq}=15.0 after 5 hours for GRB970703. LOTIS run continuously as weather permits.

In addition, we are constructing a dedicated and automated 0.6 m telescope system for GRB afterglow searches. This system is called Super-LOTIS and will be installed at Kitt Peak National Observatory by summer of 1999. The expected senstivity is R∼19 with 30 s integration time; the response time will be < 30 s. Coverage of early optical activity at this sensitivity level will provide important understanding of the GRB production mechanism.

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