RESULTS FROM GROCSE, A REAL-TIME SEARCH FOR THE OPTICAL COUNTERPARTS OF GAMMA-RAY BURSTS

CARL AKERLOF[1], ELDEN ABLES[2], SCOTT BARTHELMY[3], RICHARD BIONTA[2], THOMAS CLINE[3], DONALD FERGUSON[4], GERALD FISHMAN[5], NEIL GEHRELS[3], CHRYSSA KOUVELIOTOU[5], BRIAN LEE[1], CHARLES MEEGAN[5], LINDA OTT[2], HYE-SOOK PARK[2], ERIC PARKER[2]

[1] *University of Michigan, Department of Physics, Ann Arbor, MI 48109 USA*
[2] *Lawrence Livermore National Laboratory, Livermore, CA 94550 USA*
[3] *NASA/Goddard Space Flight Center, Greenbelt, MD 20771 USA*
[4] *EarthWatch, Inc., Livermore, CA 94550 USA*
[5] *NASA/Marshall Space Flight Center, Huntsville, AL 35812 USA*

Abstract. The GROCSE Collaboration (Gamma-Ray Optical Counterpart Search Experiment) has been operating a rapid response camera since January 1994 in an attempt to capture optical images of GRB events. This detector has a response time of 15 seconds and a limiting magnitude of 8. A second generation detector is now under construction which is expected to eventually reach $m_v \simeq 15$ with a 5 second exposure.

1. Introduction

The Gamma-Ray Optical Counterpart Search Experiment (GROCSE) was initiated in 1993 to take advantage of the efforts of Scott Barthelmy (Barthelmy *et al* 1995) to disseminate the BATSE GRB coordinates via the BACODINE software system. Up until that time, any effort to search the night sky for transient optical flashes from GRBs was limited by the need to cover a field of view spanning at least π steradians. Fortunately, the median GRB duration is about 8 seconds for τ_{50} and 20 seconds for τ_{90} so that the 5 second response time of BACODINE allows a fast slewing camera to reach designated sky coordinates while bursts are still in progress. Previous talks at this symposium have already motivated why the detection of such optical images would considerably aid our understanding of the GRB phenomenon.

Band and Ford (Band *et al* 1995) have described an effort to estimate the optical flux from GRBs by extrapolating from the high energy spectra measured by BATSE. These results suggest an upper limit of $m_v \simeq 10$. Such an estimate is liable to large uncertainties since the photon flux must be extrapolated over four or five decades in energy with no underlying theoretical model for guidance. A second approach, based on a simple physical model, assumes (optimistically) that the low energy part of GRB spectra

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is governed by bremsstrahlung processes with $\frac{dN}{dE} \propto \frac{1}{E}$. This implies a constant logarithmic spectral distribution so the upper limit of GRB fluxes of 100 photons/cm^2-sec would correspond to an optical flux of $m_v \simeq 10$. A "typical" GRB flux of 1 photon/cm^2-sec would have an optical flux of $m_v \simeq 15$, setting the required sensitivity scale for any realistic optical counterpart search.

TABLE I

Livermore WFOV Camera

focal length	250 mm	
aperture	89 mm (*f* 2.8)	
imaged FoV	0.621 steradians	
image reduction	3.8 : 1	
23 image intensifier - CCD sensors		
CCDs	384 × 576 Thomson	
pixel size	23 $\mu\times$ 23 μ	
pixel coverage	1.2 arc-min	
exposure time	0.50 sec	
data transfer	5 $\times 10^6$ pixels/second	
camera mount	Contraves inertial guidance test system	
slew rate	100°/sec; 200°/sec	
limiting magnitude	8 (3 σ)	
response time	BATSE→GFSC	4.5 secs
	GFSC→LLNL	0.4 secs
	Camera slewing	~8.0 secs

2. Observations with GROCSE I

The GROCSE Collaboration is attempting to reach such a sensitivity level in a series of stages. The first effort, GROCSE I, began in earnest in January 1994 with routine systematic observations of GRB events using a wide field of view camera (Park *et al* 1989); (Akerlof *et al* 1994) at the Lawrence Livermore National Laboratory. This device had originally been developed for the SDI program but was inherited by our group after several years of disuse. The optical system consists of an 89 mm aperture wide angle lens focussing to a mosaic of 23 sets of coherent fiber optic bundles coupled to image intensifiers and, ultimately, CCDs. The combination of the limited acceptance of the optic fibers and poor quantum efficiency of the image intensifiers limits the sensitivity of the instrument to stellar magnitudes of about 8 under optimal conditions. The characteristics of the system are shown in Table I.

As Scott Barthelmy described in his talk on the BACODINE system, any optical search from a single site is limited by environmental factors to about 1/15 to 1/20 of the total number of GRB trigger events. In our case, the Livermore WFOV camera is further constrained by the expense of moving the Contraves mount to remain situated between nearby buildings which restrict the field of view to elevation angles above 30°. To date, we have logged a total of 8 GRB events in response to BATSE triggers provided by BACODINE. Unfortunately, the results have provided an unedifying demonstration of the power of Murphy's Laws.

TABLE II

GROCSE Recorded GRB Triggers

BATSE Trig #	UTC Date (1994)	Weather	Moon	Cam 7 Δt (sec)	Burst τ_{90} (sec)	Burst Intensity (c/s)	Baco-Hunts error (deg)	IPN
2793	1/29	clear	~full	22	6	20500	4	y
2896	3/29	clear	~full	82	0.5	37000	5.3	n
2952	4/28	clear	~full	12	0.8	21000	63	n
3040	6/23	clear	full	15	37	6000	4.8	n
3139	8/27	patchy	none	14	8	7600	9.6	n
3141	8/28	clear	none	14	4	2100	8.4	n
3159	9/7	clear	new	16	25	4300	18.7	n
3241	10/14	fog	half	15	90	55000	12.7	y

Notes: The fifth column lists the delay time between trigger detection and first image; the eighth column lists the angular difference between the BACODINE coordinate estimate and the final Huntsville value. Exposure Summary: Jan. 5 to Nov. 3, 1994, Available observation time: 2937 hours, GROCSE online time: 1559 hours, BACODINE overlap time: 1367 hours.

Because the CCD readout system multiplexed each chip sequentially to the host computer, we reduced the time between successive frames to ~ 5 seconds by recording only the central six imaging systems out of the 23 available. In retrospect, this was something of a mistake because the BACODINE initial GRB coordinate estimates varied considerably from later determinations by the BATSE analysis team, even for some of the brighter bursts. Consequently, between GRB position errors and local ground fog, we have not yet obtained any observations that improve on the results reported $1\frac{1}{2}$

years ago by Krimm *et al.* from the ETC (Krimm *et al* 1994). A summary of the 8 GRB observations to date is shown in Table II.

The best events so far were recorded on 23-Jun-94 and 14-Oct-94. In the first case, the ultimate Huntsville coordinate lay right on the boundary circumscribed by the 6 imaging subsystems and, in the second case, both local fog and bad coordinate estimates completely prevented the camera from imaging the appropriate region of the sky. Recently we have compensated for these problems by including all 23 image detectors for all future GRB triggers. We anticipate that within six months we will have at least one or two events which might at least set better upper limits to GRB optical fluxes.

3. Development of GROCSE II

The limitations of the Livermore WFOV camera quickly taught us that radical improvements in sensitivity could be achieved by simplifying the optical detection system. The goal has been to extend the sensitivity from $m_v \simeq 8$ to $m_v = 15$, using commercial optics and large format CCDs. Our efforts have been constrained by tight financial limits but by the end of the summer of '95 we expect to operate a four-fold system of cameras using Nikon 200 mm focal length, $f/2.0$ lenses and Loral 2048 × 2048 15 μ CCDs. The four cameras will be mounted on a single rapid slewing 2-axis drive capable of reaching any part of the sky in 3 seconds from receipt of coordinates. Recent tests have shown that such a system can achieve detection limit of at least $m_v \simeq 12.5$ in 5 seconds while spanning a $17° \times 17°$ area on the sky. Tests have also shown that better optics with a slightly longer focal length will achieve $m_v \simeq 14.5$ with similar exposures. It is our goal to move to such a system next year if the money can be found for the additional CCD imagers that are required to match typical BATSE error boxes. This will finally give us an opportunity to explore the sky for optical transients with a range of sensitivity matched to the minimal requirements of GRB detection.

References

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