Rapid Optical Follow-up Observations of SGR Events with ROTSE-I

R. Balsano[1], C. Akerlof[2], S. Barthelmy[3], J. Bloch[1], P. Butterworth[3], D. Casperson[1], T. Cline[3], S. Fletcher[1], G. Gisler[1], J. Hills[1], R. Kehoe[2], B. Lee[4], S. Marshall[5], T. McKay[2], A. Pawl[2], W. Priedhorsky[1], N. Seldomridge[1], J. Szymanski[1], and J. Wren[1]

[1] *Los Alamos National Laboratory, Los Alamos, New Mexico 87545*
[2] *University of Michigan, Ann Arbor, Michigan 48109*
[3] *NASA/Goddard Space Flight Center, Greenbelt, MD 20771*
[4] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[5] *Lawrence Livermore National Laboratory, Livermore, California 94550*

Abstract. The primary mission of the Robotic Optical Transient Search Experiment (ROTSE) is to search for contemporaneous optical emission from GRBs. Among the triggers ROTSE receives via the GRB Coordinates Network (GCN), there are a number from Soft-Gamma Repeater (SGR) events. Since beginning operations in March 1998, ROTSE-I has triggered on 16 observable SGR events. Ten of these events had useful data, eight events from SGR 1900+14 and two events from SGR 1806−20.

The error regions for these SGRs are a small fraction of the ROTSE $16° \times 16°$ field of view and have been searched for new or variable objects. Limits on optical transient counterparts are in the range $m_{\rm ROTSE} \approx 12.5 - 15.5$ during the period 10 seconds to 1 hour after the observed SGR events.

INTRODUCTION

There is currently nothing known about the emission of Soft Gamma-ray Repeater (SGR) bursts at energies below a few keV. In this paper we present the first known attempts to detect optical emission from SGRs in the period just following SGR bursts. The Robotic Optical Transient Search Experiment (ROTSE) [1] is configured to respond to transient events from the Gamma-Ray Burst Coordinates Network (GCN) and is capable of rapidly slewing to the coordinates of a transient event such as an SGR burst. Since beginning operations in March 1998, the first generation system, ROTSE-I, has triggered on 16 SGR events, ten of which had useful data.

CP526, *Gamma-Ray Bursts: 5th Huntsville Symposium,* edited by R. M. Kippen, et al.

TABLE 1. Summary of ROTSE-I SGR Observations

SGR	Date	BATSE trigger	Delay before first usable exposure (s)	Number of usable images	Comments[a]
1900+14[b]	980530	6798	168	4	tiles
	980607	6809	19	13	direct
			1023	4	tiles
	980719	6932	226	1	tiles
			669	4	tiles
	980720	6934	316	23	direct
	980921	7107	682	22	direct
	980927	7124	153	4	tiles
			617	16[c]	direct
	990429	7536	933	2	tile
	990429	7537	831	4	tile
1806−20	980908	7073	425	6	direct, first images cloudy
	980922	7109	174	4	tiles

[a] "Direct" means the SGR was in direct exposures, "tiles" that it was only in tiles.
[b] For three triggers, a second GCN trigger was received at a new location.
[c] This does not include 6 frames in which only half of the SGR error region was covered.

OBSERVATIONS

A typical ROTSE-I response to a GCN trigger consists of a series of *direct* exposures centered at the trigger coordinates followed by a series of *tiled* exposures with the mount shifted by $\pm 8^\circ$ (half the total FOV) in both right ascension and declination to extend the ROTSE-I coverage of the GCN error box. ROTSE-I SGR responses are summarized in Table 1. The durations of the SGR bursts were all < 1 s with the exception of BATSE trigger 6798 which was a series of bursts lasting 350 s. ROTSE generally begins observations ~ 10 s after receiving a GCN trigger. However, the first useful image may be taken up to several minutes later if the SGR position is only in tiled images. Six of the 16 SGR responses have no useful data, either because they occured during twilight or in cloudy conditions (3 of 6), because the GCN trigger positions differed from the SGR location by more than 16 degrees (2 of 6) or because a software failure occurred (1 of 6).

Data reduction

All images have been dark-corrected and flat-fielded. Examples of corrected images are shown in Figure 1. Parameters for all objects in an image are measured using SExtractor [2]. The object lists are photometrically and astrometrically calibrated against the Tycho Reference Catalogue [3]. Since ROTSE-I uses an unfiltered CCD, the photometry is color-corrected using Tycho $B - V$ to produce a ROTSE-I equivalent V-band magnitude, m_{ROTSE}.

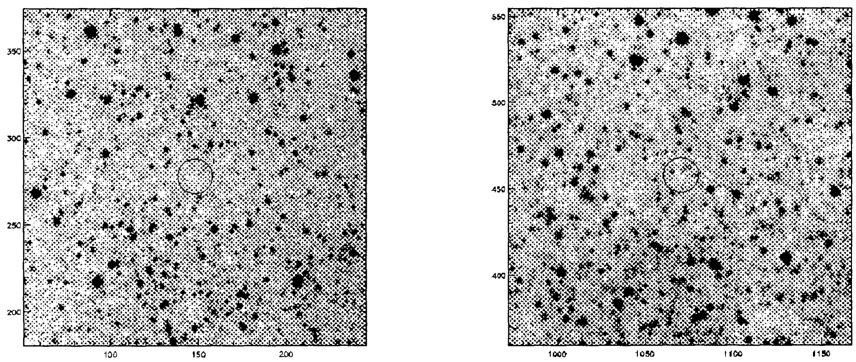

FIGURE 1. Sample images for SGR 1900+14 (left) and SGR 1806−20 (right). Each image is $\approx 50'$ wide. The adopted search region, which is $5'$ in diameter, is circled.

DISCUSSION

No new or variable objects were detected in any images for either SGR. Limits, shown in Figure 2, were obtained by determining the magnitude at which the efficiency for detecting artificial objects falls to 50%. For SGR1806−20, we have used objects found with SExtractor. For SGR1900+14, we performed this estimate visually, although a cross-check performed with SExtractor on a subset of the data indicates the limits agree to within 0.25 mag for the two methods.

Extinction

Since both SGR 1900+14 and SGR 1806−20 are at low galactic latitudes, extinction is highly uncertain. Unfortunately, no direct measurements of the extinction to either SGR exist. However, infrared observations covering the IPN localization for SGR 1900+14 provide estimates of $A_V = 15.4 \pm 1.2$ mag at $2.2 - 6.6$ kpc and $A_V = 19.1 \pm 1.2$ mag at $12 - 15$ kpc [4]. To get an alternate estimate for the extinction to these SGRs, we turn to the X-ray data.

Both SGR 1900+14 and SGR 1806−20 have been detected as X-ray pulsars so the hydrogen column density measured from the X-ray spectra may be related to optical extinctions. SGR 1900+14 was detected as a pulsar by ASCA and spectral fits gave a hydrogen column density of $n_h = (2.16 \pm 0.07) \times 10^{22}$ cm^{-2} and an estimated distance to the SGR of ~ 5 kpc [5] which agrees with the distance estimate to the supernova remnant G42.8+0.6 in which the SGR appears to be embedded [6]. The value of n_h can be converted to extinction via: $A_V = R_V \times n_h/E(B-V)$ where $R_V \equiv A_V/E(B-V) = 3.1$ (see e.g. [8]) and $n_h/E(B-V) = 5 \times 10^{21}$ cm^{-2} mag^{-1} [7]. Since ROTSE-I uses an unfiltered CCD which is sensitive out to $\sim 1\ \mu$m, A_V can be used as only a rough guide to the expected extinction. Using these values gives an estimate of the total visual band extinction

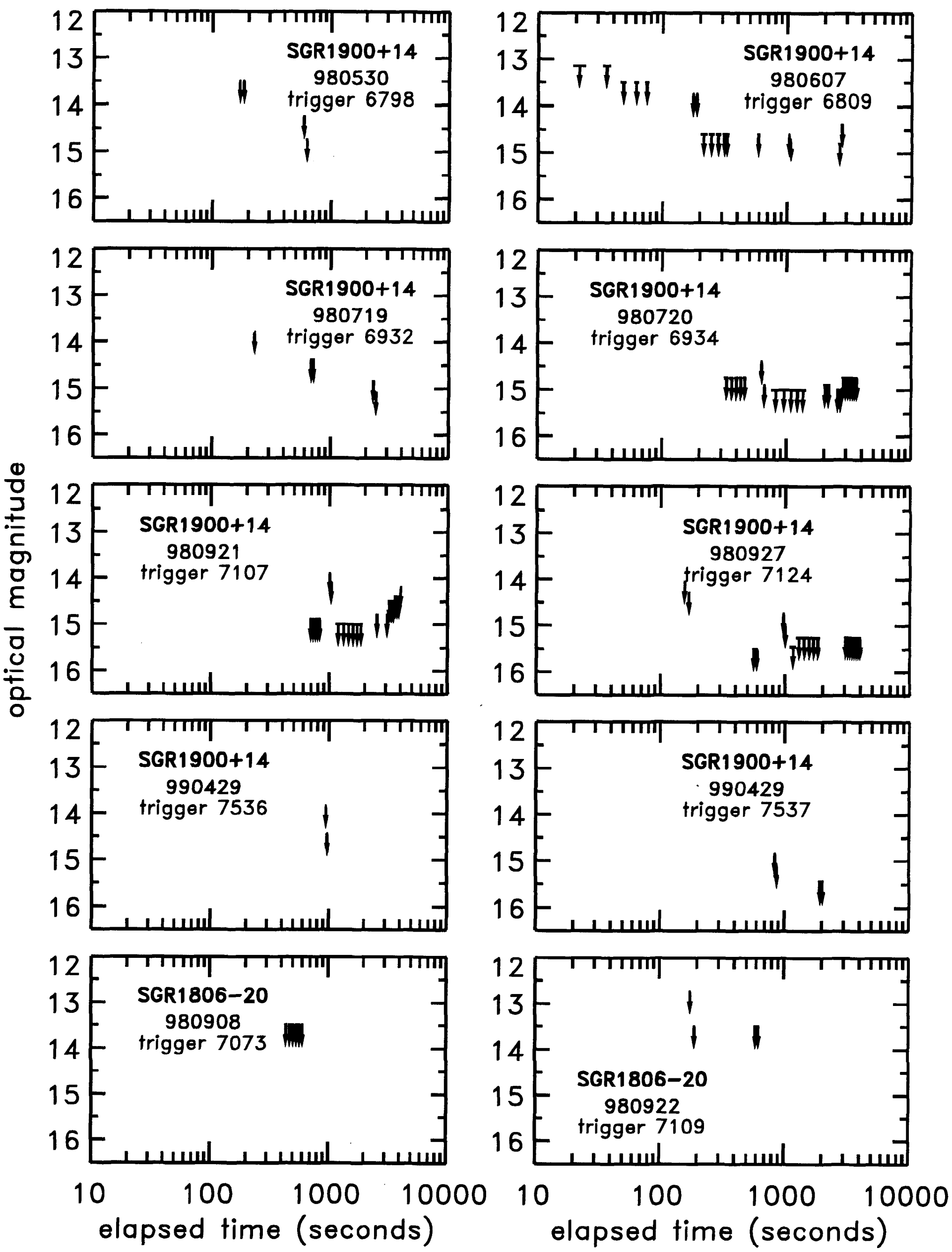

FIGURE 2. Limits for the 10 triggers with useful data. Each plot gives the limits, m_{ROTSE}, as a function of delay since the SGR trigger.

to SGR 1900+14 of $A_V \approx 13$ mag. This agrees well with the extinction value found above for a distance of $2.2-6.6$ kpc, so we adopt $A_V \approx 13$ mag. For SGR 1806−20, $n_h \approx 6 \times 10^{22}$ cm^{-2} [9,10] gives $A_V \approx 30$. This large value, if indicative of the true extinction to SGR 1806−20, would make it impossible to see this source in the optical.

With the calculated extinction to SGR 1900+14, we can now address how bright an optical transient would have to be for ROTSE-I to detect it. Accepting the distance of 5 kpc for SGR1900+14, the ROTSE-I limits of $m_{\mathrm{ROTSE}} \approx 14$ mag give absolute magnitude limits of $M_{\mathrm{ROTSE}} \approx -1$. The extinction of $A_V \approx 13$ mag reduces this to $M_V \approx -14$, roughly between a nova and supernova in brightness.

With the large extinction in the direction of the known SGRs, a campaign specifically designed to detect SGRs would utilize a rapid-response detector sensitive in the $1-10$ μm region of the spectrum. However, ROTSE-I will continue to observe SGR triggers since doing so is a simple extension of ROTSE's main GRB response program. To improve the chances that ROTSE-I observes an SGR event in the future, we may point to the coordinates of a particular SGR based on classification information in the GCN trigger and the position of the event as given by GCN. Furthermore, the ROTSE collaboration is developing several 45 cm aperture telescopes which should reach several magnitudes deeper than ROTSE-I. It is possible that this increased sensitivity will be enough to overcome the very large extinction in the direction of SGR 1900+14.

CONCLUSION

We have presented limits on optical emission in the period immediately following SGR bursts for a total of ten events. Limits on optical transient counterparts are in the range $m_{\mathrm{ROTSE}} \approx 12.5-15.5$ during the period 10 seconds to 1 hour after the bursts.

REFERENCES

1. Kehoe, R., et al., in *Proc. of the 1999 STSci May Symposium*, astro-ph 9909219 (1999).
2. Bertin, E. & Arnouts, S., *Astr. Astrophys. Suppl. Ser.* **117**, 393–404 (1996).
3. Høg, E., et al., *Astr. Astrophys.* **335**, L65–L68 (1998).
4. Vrba, F. J., et al., *Astrophys. J.* **468**, 225 (1996).
5. Hurley, K., et al., *Astrophys. J.* **510**, L111–L114 (1999).
6. Vasisht, G., et al., *Astrophys. J.* **431**, L35 (1994).
7. Bohlin, R. C., Savage, B. D., & Drake, J. F., *Astrophys. J.* **224**, 132–142 (1978).
8. Savage, B. D. & Mathis, J. S., *Ann. Rev. Astr. Ap.* **17**, 73–111 (1979).
9. Murakami, T., et al., *Nature* **368**, 127–129 (1994).
10. Sonobe, T., et al., *Astrophys. J.* **436**, L23–25 (1994).