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# A Search for Gamma-Ray Burst Optical Emission with the Automated Patrol Telescope

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**Abstract.** The Automated Patrol Telescope (APT) is a wide-field ( $5^\circ \times 5^\circ$ ), modified Schmidt capable of covering large gamma-ray burst (GRB) localization regions to produce a high rate of GRB optical emission measurements. Accounting for factors such as bad weather and incomplete overlap of our field and large GRB localization regions, we estimate our search will image the actual location of 20-41 BATSE GRB sources each year. Long exposures will be made for these images, repeated for several nights, to detect delayed optical transients (OTs) with light curves similar to those already discovered. The APT can also respond within about 20 sec. to GRB alerts from BATSE to search for prompt emission from GRBs. We expect to image more than 2.4 GRBs  $\text{yr}^{-1}$  during  $\gamma$ -ray emission. More than 5.1 will be imaged  $\text{yr}^{-1}$  within  $\sim 20$  sec. of emission. The APT's 50 cm aperture is much larger than other currently operating experiments used to search for prompt emission, and the APT is the only GRB dedicated telescope in the Southern Hemisphere. Given the current rate of  $\sim 25\%$  OTs per X/ $\gamma$  localization, we expect to produce a sample of  $\sim 10$  OTs for detailed follow-up observations in 1-2 years of operation.

## INTRODUCTION

This meeting featured observations of the two optical transients (OTs) associated with gamma-ray bursts (GRBs) so far. These important observations have produced some controversial results (see presentations by Caraveo, Lamb, and Fruchter), and they have not yet yielded either explanations of the physics of the bursts or an identification of the bursting object(s). An obvious next step is to find and study a *sample* of OTs, not just two examples as we have now. Observations of  $\sim 10$  or more OTs are needed to address the controversies and give a statistical basis to host galaxy incidence and other properties.

We have begun to use the wide-field ( $5^\circ \times 5^\circ$ ) Automated Patrol Telescope (APT) to image GRB positions for the identification of GRB-associated OTs. The telescope, located at Siding Spring Observatory in Australia, is fully dedicated to this

project. The wide field is essential to search the large GRB localizations from BATSE, the majority of all GRB localizations. In one mode of operation, we will study delayed emission similar to the OTs already discovered. In a second mode of operation, we will search for prompt optical emission, actually during or shortly after gamma-ray emission.

## PROJECT DESCRIPTION

Our telescope performs a regular observing program unless a GRB alert is received. The Gamma-Ray Coordinates Network (GCN) sends out alerts 1-3 sec. after a BATSE GRB reaches threshold; these alerts reach our site via the Internet in 200-400 msec. The APT then interrupts its observations, slews to the GRB position, and begins integration.

**1) Prompt Emission Search:** Because the APT can make long slews in  $< 20$  sec., we can make optical observations during the tail end of  $\gamma$ -ray emission for many GRBs. Figure 1 shows that more than 47% of all bursts are longer than our 20 sec. slew time. Shorter bursts would still be observed less than 20 sec. after  $\gamma$  emission.

After the initial slew, a series of exposures of 10, 20, 40, ... sec. are taken to sample different time scales up to  $\sim 2$  hrs. Our CCD can be read in 6-10 sec. We expect to reach a sensitivity of  $V > 17.7$  mag at  $5\sigma$  in 10 sec. exposures.

**2) Delayed Emission Search:** For up to 4 nights after the GRB (double the time-to-peak for OT970508), 1 hr. of exposures are acquired every other hour the source position can be observed. In this way, we will sample light curves at good time resolution and build up long total exposure times, but still do some scheduled observing. The APT will reach a sensitivity of  $V > 20.9$  at  $5\sigma$  in 1 hr. of co-added exposures. Fig. 2 shows that OT970508 would be detectable by the APT at better than  $5\sigma$  in less than 1/2 hr. of exposure.

We will search for OTs by subtracting images taken just after the alert, and those taken later at the same position. Automated software will then examine the subtractions for transients, measure their position and brightness, and eliminate false candidates. To facilitate follow-up, our positions (better than  $\sim 5''$ ) will be rapidly publicized using the GCN e-mail list.

## Status

During March - April of 1997, a short pilot search was undertaken to demonstrate and test our system. While the APT was performing unrelated observations, and while no operator was present, the system responded to GRBs 970326b and 970329. The system worked as planned, producing a series of images at the alert locations for both bursts; one of them is shown in Figure 3. (The BACODINE original positions for these two "test" events were of very poor accuracy, and the GRB position was unlikely to be on our single-pointing fields.) During another run, GRB 970616 was

observed for  $>1$  hr. At this time, the APT requires an operator to open and close the telescope each night. Also, our CCD covers only a  $3^\circ \times 2^\circ$  field at a quantum efficiency of only 28% in V. To implement our full search, we plan to upgrade the camera with a 79% quantum efficiency (at V)  $2048 \times 2048$  detector to cover our  $5^\circ$  square field. We will also automate the telescope open/closing procedure and weather monitoring to enable unsupervised searching every clear night.

## Event Rate

Important improvements are expected in the GCN which will provide LOCBURST quality positions ( $4^\circ$ - $11^\circ$  68% error diameter, see Kippen et al. and Briggs et al., this volume) as soon as most of the photons in a burst are received. These “updated positions” are expected to be in place by early 1998. Our “prompt emission search” event rate was calculated by taking into account time lost due to weather (35% for our site), and time lost due to the moon increasing our background by more than a mag per square arc sec ( $\sim 5\%$  of the time not already counted), and the fraction (48%) of GRBs longer than 20 sec. (our estimated average time before pointing). Of the 27 updated positions per year for our site, we calculate that our system will slew to about 18 bursts per year, more than 8 longer than 20 sec. Taking into account the overlap of our field with the updated position errors, **our prompt emission search will image more than 2.4 GRBs yr.<sup>-1</sup> during  $\gamma$ -ray emission, and more than 5.1 yr.<sup>-1</sup> within  $\sim 20$  sec. of emission.** (We use “image a GRB” here to mean that the actual position of the GRB is on the detector, resulting in either a measurement or an upper limit.)

Our “delayed emission search” event rate was calculated by taking into account weather and moon as above, but considering GRBs of all durations, and all of the sky accessible any time during the night ( $\sim 64\%$ ). From 52-104 BATSE LOCBURST positions yr.<sup>-1</sup>, **we estimate our delayed emission search will image 20-41 LOCBURST sources yr.<sup>-1</sup>** by covering the larger error boxes with  $2 \times 2$  mosaics. We will also acquire 4.7 images from RXTE ASM alerts, and 3.5 images from SAX alerts each year.

## Comparison To Other Efforts

The LOTIS and ROTSE are currently operating, rapid-slewing, wide-field 11 cm aperture instruments custom built to search for prompt emission. They have faster response and a higher event rate, however, the APT’s 50 cm aperture yields much greater sensitivity. LONEOS (see Wagner & Shrader, this work) has a comparable aperture to the APT, but has a limited commitment to GRB observations, and lacks automated response. The APT is complementary to these projects, however, as they are located in the Northern Hemisphere, and the APT is located in the Southern Hemisphere for access to the far southern sky.

Conventional telescopes have been used to search for OTs, however, the APT program has many advantages over these searches. Most telescopes suffer from scheduling problems and can therefore miss bursts, they have a low event rate (mostly Sax alerts), and they lack the installed and maintained software required to identify OTs on the same night as their discovery. The latter capability is very important, in order that follow-up spectroscopy and other measurements may be made while the OT is near peak brightness. The rapid, dedicated APT program avoids these problems, and has an event rate more than six times that for typical telescopes (due to its BATSE follow-up capability). In addition, the APT is immune to Sax malfunctions. The most recent Sax problems include gyro failure, which means delays in producing sub-arc minute imager positions. Without the sub-arc minute positions, searches by typical telescopes are much more time consuming.

## CONCLUSION

A significant-sized sample of OT light curves and more detailed follow-up observations (e.g. spectroscopy) would be likely to yield significant, rapid progress in this field. The data would clarify controversies in the existing observations, such as host galaxy frequency and possible variable extended emission. A frequent lack of hosts would cause modifications to the neutron star - neutron star event scenario; confirmation of variable extended emission would locate some GRBs near our own galaxy. If the current trend continues, and  $\sim 25\%$  of localized bursts yield OTs, our project's high event rate will produce a sample of observations of 10 OTs after only 1-2 years of operation.

## Figure Captions

Figure 1. Duration ( $T_{90}$  = time to measure 90% fluence) of GRBs in the 4B BATSE catalog; many are longer than 20 sec. Figure 2. The  $5\sigma$  sensitivity of the APT with increasing delay (and integration) time after a GRB trigger. The sensitivity of the APT is shown both truncated at 1 and 6 hours of co-added exposures; final verification of the sensitivity of our longest co-added exposures is now in progress. Figure 3. A 320 sec. image taken with the APT at the position of GRB970326b. The sensitivity is better than  $V= 19.6$  at  $5\sigma$ . Many sources are present in the wide field.

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