Simultaneous optical/γ-ray observations of GRBs

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We report on the on-going project to search for serendipitous time-correlated optical photographic observations of γ-ray bursts (GRBs). The regular photography at twelve observatories is used to look for plates which have been exposed simultaneously with a GRB detected by BATSE and contain the burst position. The results of this search for GRBs detected during the previous four years of BATSE operation are presented.

INTRODUCTION

The importance of GRB counterpart searches in as many wavelength bands as possible and the far-reaching consequences of a possible counterpart identification for the understanding of the GRB enigma are beyond discussion. Counterpart searches are hampered by many unknowns. It is not known whether a GRB will cause a permanent change in the emission in one or several wavelength bands, or will cause a multiwavelength transient event. If there is a transient event at other energies correlated with a GRB, it is not known whether it occurs before, during or after the γ-ray event and how long it might last.

The search for simultaneous or near-simultaneous observations of GRBs at other wavelengths can be attacked with two different strategies: (1) either correlating independently conducted monitoring observations which happen to overlap in time or (2) aiming in quick follow-up observations after the onset of a GRB. While the rapid follow-up observations have now set the most stringent limits for emission from GRBs at times greater than 1 day after the burst event (McNamara *et al.* 1995, Hudec *et al.* 1995a), most of the simultaneous and near-simultaneous (within a day) limits so far arose from the correlation of BATSE burst locations and times with monitoring observations in various other bands (Greiner 1995, Hudec 1995, Vrba 1995).

STRATEGY

We are correlating two independent surveys, namely the photographic plates in the optical region exposed regularly at several observatories for a variaty of purposes not related to GRBs. and the BATSE γ-ray burst data (time and location). The photographic sky patrols of the observatories Sonneberg (FRG), Ondřejov (CR), Odessa, Crimea (Ukraine), and Dushanbe (Tadshikistan) as well as the regularly taken Schmidt plates of Tautenburg (FRG) and Hamburg observatory (on Calar Alto, Spain), Mt. Palomar (USA) and Kiso (Japan) are presently used for the northern hemisphere, and the Australian UK and ESO (La Silla, Chile) Schmidt plates for the southern hemisphere GRBs. The instruments which are used for this search are described in Greiner *et al.* (1992).

With BATSE detecting and localizing $\approx$ 1 GRB per day and a spatial and temporal optical coverage with the observatories involved of about 80%, we are presently checking 280–300 GRBs per year. In average, we may expect

- $\approx$15 simultaneous plates per year with $150°\times150°$ field of view (FOV) and limiting magnitude of $1–3^{m}$.
- $\approx$1 simultaneous plate per year with $20°\times20°$ FOV and limiting magnitude of $6–8^{m}$.
- $\approx$10–15 near-simultaneous plates ($\pm$12 hours) per year with $6°\times6°$ FOV and limiting magnitude of $8–14^{m}$.

All limiting magnitudes given above refer to the sensitivity for a 1 sec duration flash within the exposure time of the plates which typically is 0.5–4 hours.

RESULTS

Location comparison between common GRBs in 2B and 3B: Any counterpart search relies on accurate coordinates. The GRB coordinates for the 3B catalog have been calculated using an improved algorithm (Meegan *et al.* 1996). In order to evaluate the impact of the corresponding changes on our search programme we have compared the coordinate shifts of the bursts in the 2B catalog as compared to the improved 3B positions. We have excluded all 100 GRBs from the 2B catalog which have locations computed only from MAXBC rates (with an error label of 999). From the remaining 485 GRBs

- 171 (35%) have a coordinate shift larger than 2B error (including a 4° systematic error)

TABLE 1. Number of plates correlated with GRBs

Observatory	No. of GRBs	No. of plates	Time interval
Calar Alto Schmidt	1229	217	4/91 - 9/95
Crimea astrograph	585 (2B)	240	4/91 - 8/93[1]
Dushanbe patrol	480 (2B)	100	4/91 - 2/93[1]
ESO Schmidt	480 (2B)	889	4/91 - 2/93
Hamburg Quasar Survey[2]	1229	983	4/91 - 9/95
Kiso Schmidt	1229	276	4/91 - 5/95[1]
Odessa patrol	480 (2B)	500	4/91 - 2/93[1]
Ondřejov patrol	1229	2500??	4/91 - 9/95
Palomar Schmidt	1175	1308	4/91 - 2/95
Sonneberg patrol	1229	7751[3]	4/91 - 9/95
Sonneberg astrograph	1229	1379	4/91 - 9/95
Tautenburg Schmidt	1229	1443	4/91 - 9/95
UK Schmidt	1122	1922	4/91 - 9/94

[1)] Regular exposures of photographic plates have ceased.
[2)] Using the Calar Alto Schmidt telescope, formerly at Hamburg Observatory.
[3)] Only blue sensitive plates are counted. For about 90% of these plates, also simultaneously taken red sensitive exposures are available.

- 132 (27%) have a coordinate shift larger than 10°
- 52 (11%) have a coordinate shift larger than 20°
- 30 (6%) have a coordinate shift larger than 30°

This means that nearly 30% of the previous 43 near-simultaneous plates as reported in Greiner *et al.* (1994) do not cover the new GRB error box any more. Therefore, we have restarted the whole search procedure at all observatories with the new burst locations from the 3B catalog. In Tab. 1 we give a break-down of the number of plates correlated against the number of GRBs including the corresponding time intervals. In few cases, the search with the 3B locations has not yet been completed, and the numbers refer to the 2B catalog (indicated in the second column).

Results for simultaneous plates: For the GRBs of the 3B catalog (April 1991 – September 1994) plus 107 selected GRBs in the interval September 1994 – September 1995 we have identified simultaneous photographic observations for 80?? GRBs. For most of these hits, several simultaneously exposed plates from different observational stations (3–4 plates per GRB) are available. The majority of these plates are from the Czech meteor patrol which uses a predominantly red sensitive combination of objective and panchromatic emulsion (almost no sensitivity below 400 nm). The plates covering the 2B bursts (but with new coordinates) have been investigated by blink comparison. Except for very few bursts for which the 3B location is now outside the 150°×150° FOV of these plates and which thus have to be checked again, no optical flash or any brightening of an object was found which could be undoubtedly attributed to a GRB. The newly identified plates for the 3B bursts have not yet been investigated by blink comparison. Thus our upper limits have not improved, i.e. any optical emission accompanying a GRB must have been less than the minimum detectable optical flux (erg/cm^2/s) of the corresponding plate. Using the peak γ-ray flux in the 50–300 keV range reached on the 1024 ms timescale we derive a lower limit of typically $F_\gamma/F_{opt} > 0.5$–40.

Results for near-simultaneous plates: Furthermore, near-simultaneous exposures (24 hours before or after GRB) of the Schmidt cameras and Astrographs are also registered. Since these plates have smaller FOV, the large GRB error boxes are not always covered fully. In addition to the partial coverage, some of these plates are taken under programmes which are not related to variability studies; i.e. there is no plate of the same area (and same filter/emulsion combination) which could be used for blink comparison. Thus, only part of the near-simultaneous plates could be investigated for optical activity.

The blink comparison of those deep plates having suitable comparison plates revealed a number of known as well as new variable stars (Wenzel 1993a, b). However, this optical activity is presumably not related to the GRB phenomenon. We have found no optical flash event. Counting only plates which contain 100% of the error box (mostly astrographic plates of Sonneberg Observatory) and which have been checked by blink comparison, we constrain the optical brightness within 1–3 hours before or after the GRB to be less than 5–7th mag for a 1 sec flash. The figure shows the upper limits achieved by these plates for a time interval of $\pm$12 hours of the corresponding GRB. It is interesting to note that there are a couple of cases where more than one plate per GRB falls in this interval, i.e. where the optical emission can be constrained for some time before and also after a GRB (for instance plates at –8.9 hrs and +12.4 hrs for GRB 920227, or 7.1 hrs and 7.7 hrs for GRB 940415).

DISCUSSION

Due to the relative short time of availability of the 3B catalog and the necessity to redo the whole correlation process and the time-consuming checks (blink comparison) of the identified plates for optical activity the correlation is not yet complete and the results are only preliminary. With the present sample of simultaneous optical observations of 80 GRB locations we can conclude with rather high confidence that the optical emission of typical GRBs is (1) at a level below $(F_\gamma/F_{opt})^{-1} \approx 2$ at the time of the burst and (2) below $(F_\gamma/F_{opt})^{-1} \approx 20$–400 a few hours after the burst.

In addition, the latter upper limit also holds for optical emission a few hours prior to the GRB event, thus excluding optically bright precursor emission. In the future (with improving statistics) we expect to find more simultaneous plates with deeper limiting magnitudes and possibly also for brighter GRBs.

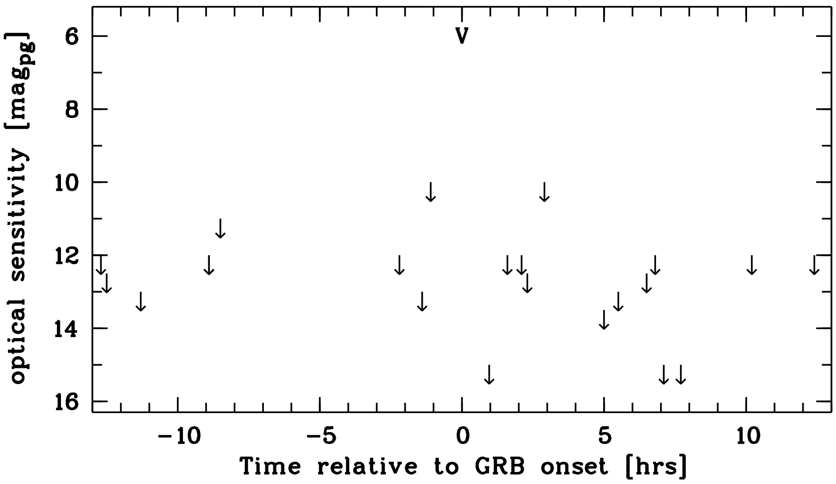

FIG. 1. Upper limits for optical emission within 12 hours of a GRB. Each arrow marks a plate which covers at least 95% of the BATSE error box. The limiting magnitude is given for the full exposure time of the corresponding plate, in accordance with the assumption of a (slowly with respect to the exposure time of typically 20–40 min.) fading counterpart. The large arrow at the top indicates the mean of the simultaneous limits (again for the full exposure time for comparison purposes).

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