A Search for Prompt Optical Emission from GRBs

A. Pozanenko, V. Loznikov
IKI RAS, Moscow, Russia
G. Beskin, S. Karpov
SAO RAS, Karachai-Cherkessia, Russia
S. Bondar, E. Ivanov, E. Katkova
Kosmoten Observatory, Karachai-Cherkessia, Russia
A. Biryukov, I. Zolotukhin
SAI MSU, Moscow, Russia
K. Hurley
UC Berkeley Space Sciences Laboratory, Berkeley, CA
V. Rumyantsev
CrAO, Crimea, Ukraine

An automatic, rapid, wide-field optical camera for the search for optical transients (OT) and GRB prompt emission has recently been deployed in the North Caucasus (longitude 41 25 57, latitude +43 39 26). The main parameters of the camera are the following: the FOV is 17x20 degrees, the angular resolution is 1 arcminute, and the frame frequency is 7.5 Hz. The limiting magnitude in the band close to V is 11.5 mag (for single frame exposure, 0.13 s). The camera can automatically detect optical transients and generate alerts in real time, and calculate their brightness and coordinates. The camera operated in test mode from May to November, 2003; since November 2003 it has been working in commissioning phase, observing synchronously a portion of the HETE-2 WXM FOV. The camera will observe the FOV of BAT/Swift, when BAT pointing data become available. Because of the large volume of data we do not plan free access to the data; however, we encourage the community to request raw data to support projects as needed. After extensive tests of the automatic identification and filtering system we plan to distribute OT alerts in real time.

Even though GRBs were discovered in gamma-rays, they are now truly all waveband events: from radio up to high energies (GeV) emission has been detected. However GRB identifications start with γ-rays (i.e. omni-directional γ-ray detectors report them first), and practically nothing is known about prompt emission in other wavebands. Discovering and investigating this prompt emission may give clues to the physics of the GRB central engine. The mystery of optical prompt emission seems to be ready for resolution after the observation of GRB990123 [1]. However, in the 5 years following this discovery no synchronous (during the GRB onset) and onlly one case of prompt emission (during active phase of GRB in γ-rays) has been observed: GRB990123 ($= 8^{\mathrm{m}}.9$), GRB030329 (upper limit $> 5^{\mathrm{m}}.1$), GRB040825 ($> 10^{\mathrm{m}}$), GRB041016 ($> 13^{\mathrm{m}}.1$), GRB041219 ($= 19^{\mathrm{m}}.4$), GRB050215b ($> 10^{\mathrm{m}}$), GRB050309 ($> 3.8^{\mathrm{m}}$). The problem is that the astronomical telescopes and their methods of observation are not fully suited to the problem.

To register prompt emission we need to look for celestial optical transients (OT) independent of the alert system. Although the time delay between a GRB trigger and an optical observation has been drastically reduced with the new generation of space observatories (HETE-2 and Swift), it will never vanish completely. Hence an alert-based observation cannot register either early prompt emission or possible optical precursors [2], or afterglow or prompt emission from short duration bursts [4]. In any case several models predict prompt optical emission (e.g. [3]) and the early observations are the most likely way to find optical counterparts.

To ensure that an OT is a counterpart to a GRB one needs to confirm the event in γ-rays. Simultaneous observations with space-borne GRB missions are therefore necessary. However it is not necessary to correlate the optical and γ-ray data in real time; we need only assure that both telescopes observe the same field of view (FOV) of the sky simultaneously. The joint correlative analysis may be done later. Observation of only a specific part of the sky decreases the amount of data to be stored in comparison with all sky surveys [5, 6] and allows the time resolution of the survey to be improved.

The FOVs of the telescopes and the time resolutions of the detectors are crucial points in the search strategy. Astronomical telescopes have small FOVs compared to space-borne X- and γ-ray telescopes. Specialized telescopes may have a wide FOV ($19.^{\circ}5 \times 19.^{\circ}5$ with 30 s time resolution, such as RAPTOR [7]) but do not posses a sufficient sensitivity with the appropriate time resolution or vice versa ($1.^{\circ}85 \times 1.^{\circ}85$ at 4 s, ROTSE-III [8]). To detect prompt emission efficiently the time resolution should be better than or nearly equal to the duration of the event. If the prompt emission consists of short duration optical flashes (e.g. [9, 10]) then a high time resolution detector should be used. Moreover, if the nature of the prompt optical emission is similar to that of the γ-ray emission, fast variability may be expected down to the millisecond range. Fast optical variability or a low on-off time ratio may explain the non-detection of optical prompt emission from GRB030329 and GRB050309. For example the upper limit for prompt emission of $V = 5.^{m}1$ (32 s accumulation time) [11] may be converted to an upper limit of $V = 1.^{m}4$ if the prompt emission consists of only one flash with duration about 1 s. The non-detection of prompt emission cannot exclude the model of a rapidly fading ($f \sim t^{-2}$) flare found in GRB990123 and GRB021211 [1, 12].

Obviously, the larger the FOV of the telescope, the larger the fraction of the GRB error-box that can be observed simultaneously, and a more sensitive detector has a greater chance of detecting a faint OT from a GRB. On the other hand, for a fixed detector size (e.g. a CCD-matrix), increasing the FOV decreases sensitivity. One can show that the number of detected GRB optical events per fixed amount of time and fixed size of the detector follows the formula $N_{Detected} \sim \left(\frac{D}{\alpha}\right)^{3/2} \cdot FOV$, where D is the diameter of the telescope aperture, α is the angular resolution and the FOV is expressed in steradians; here we assume 3-D Euclidian space and a uniform distribution of GRB sources $N(> S) \sim S^{-3/2}$. One can see that the telescope with the larger FOV can detect more OTs, and the OT detection probability can be maximized while observing simultaneously with a given space-born telescope.

Taking into account this strategy we have developed a low cost optical camera for a wide field survey and an autonomous search for OTs [13]. We use an image intensifier both to reduce the size of the image in the main objective focal plane to the small size of the TV-class CCD matrix, and also to amplify the light to compensate for the light lost in transmission through the optical system. The details of the camera are the following. The main objective (15 cm diameter, F/1.2) of the camera projects a 17x20 degree area onto an image intensifier photocathode 90 mm in diameter (quantum efficiency - 10%, gain - 150, scaling factor - 0.22). Special optics transfer the image from the intensifier to the VS-CTT285-2001 TV-CCD camera (1280x1024 pixels with size 6.5 microns) with a frame frequency of 7.5 Hz (0.13 sec exposure time).

The practical parameters of the instrument are a $17° \times 20°$ FOV with spatial resolution $\sim 1'$ and a limiting magnitude (3 σ level) of $11.^{m}5$ for a 0.13 s exposure. A limiting magnitude of 13^{m} is reached for a 5.2 s exposure (co-added in PC memory). The spectral sensitivity is close to V. The system is mounted on a proprietary equatorial mount with a pointing and tracking accuracy of a few arc minutes and less than 1' per 2 hours, respectively.

The relatively poor spatial resolution is the result of a compromise between cost and a wide field of view. Indeed precise spatial resolution in fast observations is less important than the early detection: the precise localization can be done later by large aperture telescopes. Because of the high readout noise of the TV-CCD the sensitivity of the camera is restricted by the noise at minimum exposure time, and by sky background at maximum exposures.

The Wide Field Optical Camera (WFOC) is located in the Northern Caucasus (close to the 6-m optical telescope BTA) at a height of 2030 m above sea level.

In order to process the 13 Mb per second real time data stream coming from the camera a special software suite for data storage, detection and investigation of OTs has been created.

The software is installed on three PCs running Windows (frame grabber and data storage) and LINUX (real time data analysis) operating systems. One additional PC is used for automatic pointing control. The incoming information is a sample of 1280x1024 pixel CCD frames with exposure time of 0.13 sec. The software performs the following tasks: real time data transfer to the LAN; accumulation of raw data (up to 0.5 Tb per night) at the RAID; data reduction in real time - detection of OTs, determination of their equatorial coordinates and magnitudes, and identification of OTs with known objects; distribution of information about newly discovered OTs to the local and global networks (alerts distribution).

The OT detection algorithm is based on the comparison of the current frame with a frame averaged over 10-100 preceding ones and consists of the following steps: extraction from the current frame of all pixels with intensity deviating from the averaged frame by a given fraction of the RMS noise; location of continuous regions of such pixels on the current frame and determination of its parameters - coordinates and fluxes. All these regions are considered to be optical transients (OTs) if they exist on at least 3 successive frames; analysis of the OT's shape (on a single frame) and proper motion of the region center; classification of OTs as meteors, satellites or stationary transients, and parameter estimation (trajectory, light curve etc); for the two last cases - comparison of object parameters with known objects from star and satellite catalogues (note however, that available satellite catalogues are not complete); for stationary transients with no known (catalogued) events, information on their parameters can be sent locally and into alert distribution networks (such as the GCN [14]).

The primary purpose of this WFOC is to perform continuous, alert- independent observations of optical transients and variable astrophysical sources simultaneously with space-borne X- and γ-ray telescopes. The high time resolution raw data are stored in a data base for a limited amount of time (usually 2 days) and within the 2 days can be used for detailed analysis. The long term data base consists of stacked images (by 100 original frames $\sim$ 13 s exposure) and may be used for long term variable source search/analysis. Every raw data set for a night is also transformed into a $\sim$ 3 minute film for a visual post check of observation parameters and the film is stored in the long term data base too. Finally for an event identified as an optical transient (of any nature) the equatorial coordinates, brightness, and UT are stored in a long term data base and can be used for correlative analysis with data at different wavelengths.

The camera has been operated in test mode since the end of May 2003. During the operation periods up to December, 2004 the total number of good nights, i.e. during which the WFOC observed the part of HETE-2 WXM FOV is 162. The average number of meteors brighter than $9^{\rm m}$ is between 8 and 20 per hour. No synchronous GRB observation with HETE-2 was recorded, which, compared with the HETE-2 GRB rate in 2004, is well within statistical expectations. Most autonomously generated alerts were due to active spacecraft and space debris. The average number of moving objects, which are associated with satellites is about 300 per night. A few objects per night are still unclassified, i.e. no correlation has been found either with satellite catalogues or with gamma- ray/X-ray triggers. Examples of the unclassified events are available at website (http://rokos.sao.ru/favor/selected.html). However one needs more statistics (or confirmation by other telescopes) to establish the astrophysical nature of such types of events. Henceforth the events should be considered as artificial ones generated from un- catalogued space debris. Based on the non-detection of astrophysical events one can estimate the rate of GRB orphans: the all sky rate is less than 0.48 per day for event durations between 0.25 - 20 seconds and up to a limiting magnitude $V = 10^{\rm m}$.

This fully autonomous camera can detect and perform early photometry of prompt optical emission from both long and short duration GRBs, optical flashes preceding gamma-ray emission in GRBs, GRB afterglows not identified in γ-rays (orphan afterglows), optical outbursts related to Soft Gamma Repeaters, possible fast optical supernova precursors, optical flashes from LMXBs, and other compact X-ray transients, such as cataclysmic variables and related stars.

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