Search for optical counterparts of Gamma Ray Burst*

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Observing prompt optical emission from Gamma Ray Bursts (GRB) sources is crucial to understand the processes involved. After brief review of the status of this domain we present "Pi of the Sky" project proposing new aproach to the problem. Algorithm for detection of optical flashes is described and the first results from the prototype apparatus are given.

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1. Introduction

Gamma Ray Bursts (GRB) are violent cosmic processes caused most probably by collapsing massive stars and/or merging of two neutron stars [1]. The name refers to the most characteristic signature of the phenomena, namely short and strong gamma ray pulses. The pulses last 0.01 - 100 s and the total enegy released is typicaly 10^{51} erg. This is usually followed by emission of all sort of radiation from radio waves to TeV photons.

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The sources are randomly distributed over the whole sky. Observing all sky one could detect as much as 2-3 bursts per day. Typical observing scheme begin with a triger issued by a satellite based gamma detector and giving approximate ($\sim 1^\circ$) position of the source. X-ray cameras on satellites can then determine the position with the precision of arcminutes. Information from satellites is distributed to ground based detectors via GRB Coordinate Network (GCN) [2].

So far over 3000 GRB's have been observed, most of them triggered by BATSE detector on CGRO satellite. Currently GRB triggered are issued by satellites HETE, Integral and Swift. The newest one, Swift, has 3 instruments dedicated for GRB study: BAT – γ-ray detector covering 2 steradians, XRT – X-ray detector with resolution of 4 arcmin, and UVOT – optical and ultraviolet telescope with limiting magnitude of 17.

2. GRB optical observations

Optical observations are especially important for two reasons. Firstly, optical telescopes give the best spatial precition which enables to identify GRB sources. Secondly, optical spectrum can bring a lot of information about the physical processes in GRB sources. Redshift measurement is the only method to evaluate the distance to the source. Till the end of October 2005, in total 63 redshifts have been measured. The closest GRB happened at $z = 0.0085$ (GRB 980425) and the farest one at $z = 6.29$ (GRB 050904).

Most of the optical afterglows have been observed only many hours or even days after the GRB. The delay was caused by big inertia and small field of view of large telescopes. With the advent of small and fast robotic telescopes it became possible to catch the prompt optical emission. The first discovery of this kind has been made by ROTSE detector equipped with four 10 cm telephoto lenses [3]. Images taken from 20 s after the BATSE GRB 99123 trigger have shown an optical transient reaching 8.6^m in the peak! Other opticaly bright GRB's are collected in Tab. 1. It is worth to note, that GRB 050904 with z=6.29 observed by 25 cm TAROT telescope is the most distant source ever observed with such a small device [4].

3. Project "π of the Sky"

Observing prompt optical emission is crucial to understand the GRB central engine. Unfortunately, trigger decision and signal propagation from a satellite to the ground plus the telescope slewing time take usually 20-100 s. Therefore, this method is not suitable to detect the optical emission before or during the gamma burst. Different approach has been proposed by "π of the Sky" collaboration based on experience in particle physics

Table 1. Bright GRB optical counterparts: two brightest ever observed and brighter than 15^m observed last year. Δt - time after the GRB.

GRB	m	Δt	telescope
990123	8.6^m	20 s	ROTSE
030329	13.0^m	1 h	Riken (25 cm) and Kyoto (30 cm)
041219	14.9^m	0.8 h	Palomar 200-inch Hale Telescope (infrared)
050502	14.3^m	23 s	ROTSE
050525	14.7^m	6 min	ROTSE
050801	15.0^m	22 s	ROTSE
050820	14.7^m	7 min	Palomar 60-inch telescope
050922C	14.6^m	2 min	Swift UVOT
051111	13.0^m	27 s	ROTSE

experiments. The observation is performed continuously and the images are being analysed on-line, almost in real time. Optical transients can be detected automaticaly and GCN alerts can be used as a confirmation.

Because no one knows where the next burst will occur, one has to observe large part of the sky simultanuously. Therefore, we have designed the system covering 2 steradians. It consists of two sets of 16 CCD cameras, each camera having $20° \times 20°$ field of view (FoV). The two sets observe the same part of the sky from distant ($\sim$100 km) locations to enable rejection of near-Earth objects by parallax. Each camera has a CCD of 2000×2000 pixels of $15 \times 15\,\mu\mathrm{m}^2$. Cameras are equipped with CANON EF $f = 85$ mm, $f/d = 1.2$ photo lenses. This gives the pixel scale of 0.6 arcmin/pixel. The expected limiting magnitude for 10 s exposures is 12^m and for 20 exposures added together it is 14^m. The apparatus is currently under construction.

A prototype consisting of two cameras has been built and installed at Las Campanas Observatory (Chile) in June 2004. Each camera has a CCD of 2000×2000 pixels of $15 \times 15\,\mu\mathrm{m}^2$. Cameras are equipped with Carl Zeiss Planar T* photo lenses of $f = 50$ mm, $f/d = 1.4$, giving $33° \times 33°$ field of view and the scale of 1 arcmin/pixel. The limiting magnitude for 10 s exposures is $10^m - 11^m$ and for 20 exposures added together it is $12^m - 13^m$ depending on environmental conditions.

4. First results from "π of the Sky" prototype

Automatic detection of optical flashes is based on the multilevel trigger concept. The algorithm is divided into a number of steps. The first steps are simple and fast to deal with the large data stream. Consecutive steps can be more sophisticated, because they work on already reduced data stream. The effect of each step is shown in Fig. 1.

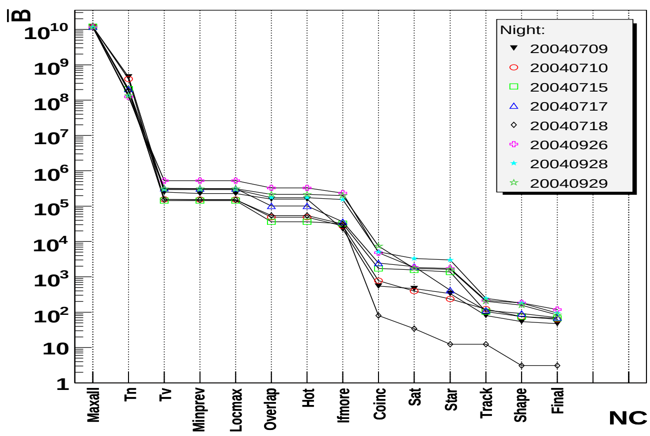

Fig. 1. Number of events $\bar{B}$ at specific stages of the triggering system, normalised for a single camera for 10-hours long night.

The number of pixels read-out during the night for a single camera is about 10^{10}. For each image a dark frame is subtracted and sharpening filter is applied. Flash candidate is defined as a pixel above threshold T_n preceded by a pixel below threshold T_p on a previous frame. Selected candidates are subject to a number of cuts eliminating detector and atmospheric effects. The most important step is the comparision of candidates from two cameras ("Coincidence"). It is followed by a number of more sophisticated steps. "Sat" and "Star" remove objects that are found in catalogues of satellites and constant stars. "Track" seeks a series of flashes forming a line on subsequent frames. It removes mainly blinking satellites and planes. "Shape" checks whether detected object is circular, because most of the fast moving objects, like meteors, planes and some satellites leave an elongated track. Remaining few events per night are subject to human inspection.

Between July 2004 and July 2005, 103 events have been finally accepted as real flashes, visible on a single frame. It is very likely that most of those flashes are sunlight reflexes from satellite, which have not been found in available databases or recognized by other means. Moreover, 6 flashes visible on two frames have been detected. These are unlikely to be satellite images, because staying on 2 frames in a single pixel requires very high orbit, which contradicts their high brightness. However, no coincidence with any satellite GRB trigger was detected. One flash was visible on more than 2 frames and turned out to be a CN *Leo* flare star outburst (Fig. 2). Example of a slower flare found off-line is shown in (Fig. 3).

From 2004.07.01 to 2005.08.07 satellites observed 89 gamma ray bursts with known positions. Most of them happened during the day or below the horizon. Only 2 occurred within "π of the Sky" FoV: GRB 040825A and 050412. In several other cases the system has slewed to the target shortly after the alert. No new optical sources have been found. Limits have been given and published through GCN for the cases, when "π of the Sky" was faster than others: GRB 040916B, 041217, 050123, 050326, and 050607. Most interesting limits are given in Table 2.

Table 2. Limits for optical counterparts of GRB set by "π of the Sky".

GRB	limit before	during	after the GRB
040825A	$> 10.0^m$ for $t < t_0 - 11\,\mathrm{s}$	$> 12^m$	$> 9.5^m$ for $t > t_0 + 7\,\mathrm{s}$
050412	$> 11.5^m$ for $t < t_0 - 11\,\mathrm{s}$	$> 11^m$	$> 11.5^m$ for $t > t_0 + 7\,\mathrm{s}$
050607			$> 12.5^m$ for $t > t_0 + 60\,\mathrm{s}$

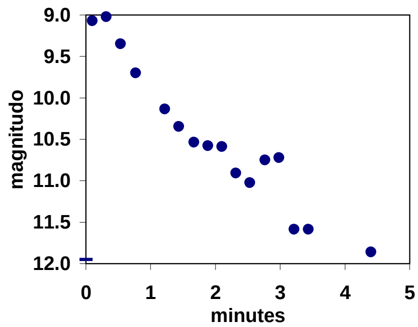

Fig. 2. Outburst of CN *Leo* flare star automaticaly detected 2005.04.02 1:13:42 UT = 3462.55620 HJD

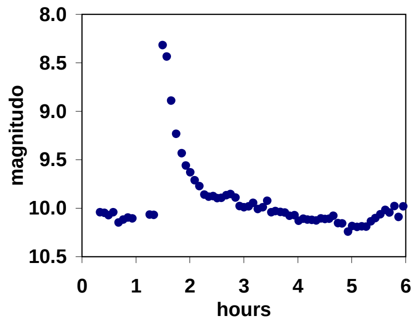

Fig. 3. Outburst of EQ *Peg* flare star 2004.09.19. Time in hours after 2453267.56 HJD. Peak at 2453267.6224

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