IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10145-x

Optical camera with high temporal resolution to search for transients in the wide field(*)

S. Karpov(1), G. Beskin(1), A. Biryukov(2), S. Bondar(3), K. Hurley(4)
E. Ivanov(3), E. Katkova(3), A. Pozanenko(5) and I. Zolotukhin(2)

(1) *SAO RAS, Nizhnij Arkhyz - Karachai-Cherkessia, Russia, 369167*
(2) *Sternberg Astronomical Institute of Moscow State University*
Universitetskij pr. 13, Moscow, Russia, 117415
(3) *Research Institute for Precision Instrumentation - Moscow, Russia*
(4) *Space Science Laboratory, University of California - Berkeley, USA*
(5) *Space Research Institute - Profsojuznaja 84/32, Moscow, Russia, 117997*

(ricevuto il 23 Maggio 2005; pubblicato online il 12 Ottobre 2005)

Summary. — The wide-field optical camera with high temporal resolution for the continuous monitoring of the sky in order to catch the initial stages of GRBs is described.

PACS `95.55.Cs` – Ground-based ultraviolet, optical and infrared telescopes.
PACS `98.70.Rz` – γ-ray sources; γ-ray bursts.
PACS `01.30.Cc` – Conference proceedings.

Gamma-ray bursts (GRBs) are one of the most powerful transient events in the Universe which are probably related to the compact relativistic objects. The fine time structure of the GRB emission is defined by the properties of their central engine.

At the same time a number of models predict generation of considerable optical flux synchronous with GRB event which can achieve 10–12^m for 0.2 s [1] or even 8–9^m for 0.1–10 s [2]. In the model of early afterglow in the wind shell the optical flash is expected to be as bright as 9–10^m in 0.2–0.5 s with 0.5–60 s lag from proper GRB event [3].

Thus, search and study with high temporal resolution of optical transients (OTs) accompanying GRBs, can provide statistically reliable information about the nature of these phenomena. To be successful such observations have to be carried out independently of alerts receiving from space-borne gamma-ray telescopes and use optical instruments with a wide field of view. As a side effect such observations also give the possibility to detect and investigate short stochastic flares of different variable objects—SNs, flare stars, CVs, X-ray binaries and NEOs, natural and artificial.

(*) Paper presented at the “4th Workshop on Gamma-Ray Burst in the Afterglow Era”, Rome, October 18-22, 2004.

TABLE I. – *Main parameters of the camera.*

Main objective		Intensifier		CCD	
Diameter	150 mm	Photocathode	S 25	Dimensions	1280 × 1024 pix
Focus	180 mm	Photocathode diameter	90 mm	Image scale	56″ / pix
D/F	1/1.2	Gain	150	Exposures	0.13–10 s
Field of view	21 × 16 deg	Scaling coefficient	7.6 / 1	Pixel size	6.45 micron
		Quantum efficiency	10%	Data stream	400 Gb / night

Simple analysis of the technical parameters of a camera for such a task may be performed as follows.

It is well known that the detection limit in the observations with CCD is to determine noise of the detector and the sky background.

For wide-field instruments the last case is realized. In the V band, for the atmospheric and optics transparencies of 0.5 and 0.7 correspondingly, and for the sky background of 20 mag/$\square''$ the detection limit is $S = 4.9\frac{aKl}{DF\sqrt{et}}$ photons/cm^2/s, or, in magnitudes, $m = 13 - 2.5\lg\left[\frac{aKl}{DF\sqrt{et}}\right]$. We used flux calibration from [4] and the following notation: a—detection threshold in 3σ, l—pixel size in 6.45 microns, D—telescope diameter in 10 cm, F—focal length in 20 cm, e—detector quantum efficiency in 0.6, t—exposure time in 0.13 s. K is the scaling coefficient in units of 4, which characterizes the reduction of the focal image linear size by the special unit—the taper, or the image intensifier, to use the single CCD to cover the whole original telescope field of view. For example, in our camera the reduction of the FOV of 80 mm size by the image intensifer and special objective by 7.6 times gives the possibility to use standard 2/3 inch TV-CCD. Certainly, in any case the spatial resolution of the main objective, reduction unit and the CCD have to be in agreement.

The rate N of GRBs to be detected by the wide-field camera may be easily estimated for standard slope of $-3/2$ of the "$\log N_S$- $\log S$" relation. The number of events N is then proportional to $N_S \propto S^{-3/2}$, where S is the detection limit, and the camera field of view $\Omega = 4.2 \cdot 10^4 P^2 l^2 K^2/F^2$ arcsec^2, where P is the CCD size in pixels. So, $N \propto N_S\Omega \propto S^{-3/2}P^2l^2K^2/F^2 \propto a^{-3/2}e^{3/4}t^{3/4}A^{1/2}K^{1/2}DP^2l^{1/2}$.

Here $A = D/F$ is the aperture of the system, which should be as high as possible, but can hardly exceed 1 for the acceptable aberrations in the wide field.

The important consequence of these formulae is that the GRB rate depends on D linearly and quadratically on P (thus, the field of view size). It means that for higher GRB count rate the wider field of view is more important than the larger objective diameter. Also it is clear that the wide field may be achieved only by means of special methods of focal scale reduction (tapers, image intensifiers) which enlarges K (for the fixed maximal A). Certainly, the main objective has to give good quality FOV Ω corresponding to the detector size P. That condition is much easier to achieve for smaller D.

The camera (see fig. 1) has been created as a realization of ideas formulated above. Its parameters are given in table I. The camera has $A = D/F = 1/1.2 = 0.83$ and uses the image intensifier to lower the focal scale ($K = 1.9$, $e = 0.17$), so the theoretical estimation of limiting magnitude for it is determined by the sky background noise and is equal to 11.6^m for the 0.13 s exposure. The TV-CCD used (VS-CTT285-2001) is able to operate in 7.5 Hz frame rate mode with such an exposure.

The observational data from the TV-CCD are transmitted (see fig. 2) to the local PC which brodcasts it through the LAN to the storage—RAID array with 480 Gb capacity—

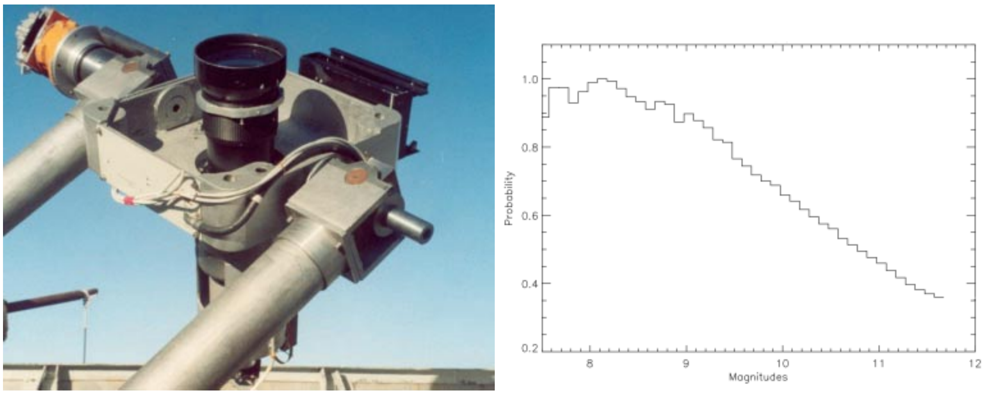

Fig. 1. – Left panel: photo of a camera installed in Northern Caucasus near the 6-m telescope. Right panel: typical detection efficiency (the probability for the object of a given magnitude to be detected) for the objects in dependence on magnitude.

and to the real-time processing box. The data flow rate for the system is about 13 Mb/s. In order to process such a data stream in real time, no standard reduction routines applied usually for field photometry and source extraction may be used. For this reason special software complex for detection and investigation of OTs has been created.

The software is installed at the three PCs and operated by WINDOWS and LINUX OSes. Incoming information is a sample of 1280×1024 pixels CCD frames with exposure time of 0.13 s. The software performs the data reduction in real time—detection and classification of OTs, determination of their equatorial coordinates and magnitudes, their possible identification with known objects and transfer of information about OTs (alerts) to the local and global networks.

The OT detection algorithm is based on the comparison of the current frame with the one averaged over 100 previous frames and is able to detect and classify any transient

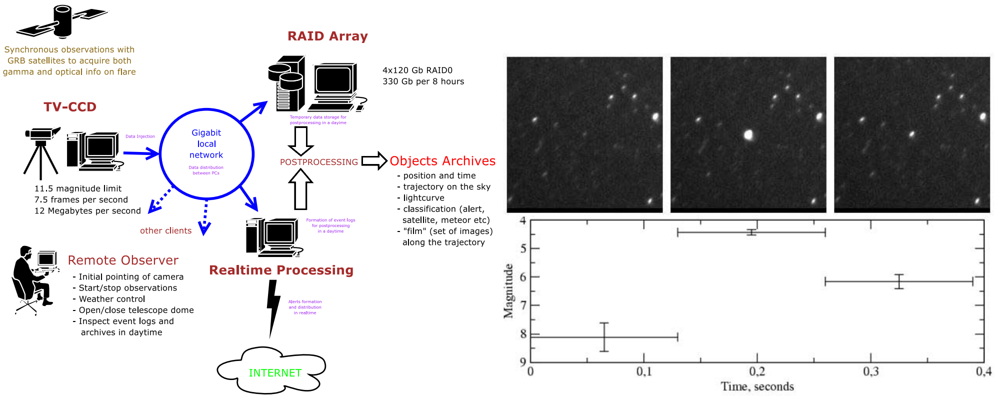

Fig. 2. – Left panel: global scheme of the camera hardware and software complex and data flow. Right panel: example of a short flare detected by the camera. Total length of the event is 0.4 s (seen on 3 successive frames).

that is seen on three successive frames (*i.e.* with duration of 0.4 s), determine its shape, trajectory and light curve and cross-correlate it with catalogues of known transient objects such as stars and satellites. When transient does not match the catalogues and does not look like a meteor the system is able to send its information to robotic telescopes and/or global networks.

The example of a short (0.4 s) transient detected by the system is shown on fig. 2. The transient shown is due to geostationary satellite.

As has been noted above, the faintest detectable object has 11.5^{m} in a band close to V. This limit may be increased up to 12.5–14^{m} by simultaneous analysis of sums of large number of frames (10–100) by the cost of temporal resolution loss.

Nearly all instruments for gamma-ray bursts related OTs (prompt emission and afterglow) search currently in operation are divided into two classes—the trigger based relatively large (25–100 cm) telescopes with up to 10 deg^2 FOV and the monitoring cameras, consisting of 1–4 small objectives (5–10 cm) with 200-1500 deg^2 FOV. Both classes are equipped with standart CCDs with exposures larger than 10 s (in rare cases—ROTSE III—5 s). The instruments of the first class need 30–60 s for the pointing and thus cannot begin the observations until the GRB fade off, but they are essential for the detection and study of early afterglows (1–10 min after the trigger) due to ability to perform accurate photometry of 17–20^m objects on the 5–60 s timescale [5, 6]. At the same time the monitoring systems are able to detect 10-12^m OTs only for the 10–60 s one [7, 8]. The camera described has the 2^{m} better sensitivity on the same time scale and even with 3–5 smaller FOV is able to detect 3–5 times larger amount of OTs with similar duration (for $-3/2$ distribution law), but also it is able to detect the flares with 0.13–5 s time scale, undetectable by the all other systems.

The camera is placed in the Northern Caucasus (near the 6-m optical telescope BTA) at the height of 2030 m above the sea level (see fig. 1). Since 2003 it has been monitoring on the regular basis the part of HETE-2 gamma-ray satellite field of view. For the whole period of observations (approximately 150 good nights) no GRB triggers hit the monitored field. The camera detects the large number of meteors (approximately 300) and satellites (approximately 150) each night. The work is in progress.

* * *

This work was supported by grants of CRDF (No. RP1-2394-MO-02), RFBR (No. 04-02-17555), and INTAS (04-78-7366). SK thanks Russian Science Support Foundation for support. GB thanks Cariplo Foundation for the scholarship and Merate Observatory for hospitality.

REFERENCES

[1] Eichler D. and Beskin G., *Phys. Rev. Lett.*, **85** (2000) 13.
[2] Liang *et al.*, *ApJL*, **519** (1999) L21.
[3] Wu *et al.*, *MNRAS*, **342** (2003) 1131.
[4] Fukujita M. *et al.*, *PASP*, **107** (1995) 945.
[5] Rykoff E. S. *et al.*, *AAS*, **199** (2001) 1205.
[6] Boër M. *et al.*, *AAS*, **138** (1999) 579.
[7] Burd A. *et al.*, astro-ph/0411456.
[8] Vestrand W. T. *et al.*, *SPIE*, **4845** (2002) 126.