MASTER: The Mobile Astronomical System of Telescope-Robots.

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Abstract. We present the first Russian robot-telescope designed to make prompt observations of gamma-ray bursts (http://observ.pereplet.ru). The telescopes are near Moscow. The system of telescopes with prompt pointing rates connects to the internet. The main parameters are the following: Richter-Slefoogt system telescope (355 mm, f/d=2.4); Richter-Slefoogt system telescope (200mm, f/d=2.4); Flugge system telescope (280mm, f/d=2.5); TV-camera with 20x40 degree objective; Two CCD cameras (Pictor 416); One CCD Apogee Camera AP16E. The type of mount is German with 8 grad/sec slew rate. MASTER images stars down to 19 magnitude in a 1 min exposure covering 6 square degrees.

Key words: telecopes:robots gamma-ray bursts

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1. Introduction

The creation of robotic observatories is a leap forward for modern astronomy. These complexes are especially indispensable in survey work, being devoted to the discovery of new and known transient phenomena, like gamma-ray bursts, supernova and nova bursts, microlens events, comets, asteroids, etc. The position and time of these phenomena can’t be predicted. So observations from several tens of longitudes (which Russia has) can increase the effectiveness of new astronomical object detections.

The MASTER system is located 30km from Moscow. It is the first robotic telescope of its type and unique in Russia. It was built to provide the rapid response necessary in the follow-up observations of gamma-ray bursts (GRBs). Multicolor photometry of GRB optical emission in the first minutes after their detection gives us an opportunity to study the physical processes taking place at the beginning stage of these most powerful radiation events in the Universe. We should point out that up to now optical afterglows have only been observed after delays of tens of seconds. There are no light curves (LC), taken in the first seconds and extending to several hours, taken by one instrument and in one photometric system. The shape of the LC will permit us to study the dynamics of relativistic sphere expansion and to draw conclusions about the nature of GRBs.

The second goal of the MASTER project relies on the fact that the optical GRB afterglow can be more isotropic than gamma-ray one and consequently can be detected more often, since the polar pattern in such different wavelengths can not concur. Optical emission can have more isotropic distribution. MASTER allows us to make a constant sky survey in order to discover optical bursts without gamma-ray radiation, but produced by the same physical process. We can survey 50 square degrees per hour to a 19.5″ limiting magnitude.

Our third goal is to make wide-field observations synchronously with gamma-ray telescopes (for example, HETE).

In summary, MASTER can carry out early afterglow research into GRB, triggered by alert from gamma-ray telescopes, make synchronous observations of the region of a GRB and make sky surveys.

Let’s consider the main principles of the work of such robotic systems.

2. Robot telescopes

A robotic telescope is an autonomous instrument, that can both point to, and make observations of a sky region by itself, then automatically reduce the images, perform image quality checks, and point to discovered objects. Such telescope,
designed to detect the optical radiation from a gamma-ray burst’s source, works by the following scheme:

\[
\begin{array}{|c|c|c|}
\hline
\text{Gamma-ray bursts} & \text{Robot-telescope} & \text{GRB observations} \\
\text{Center Network (GCN) sends an Alert} & \text{points to received} & \Rightarrow \text{GCN circular publication} \\
\hline
\Rightarrow \text{Image reduction} & \text{coordinates} & \\
\hline
\end{array}
\]

The publication in GCN circulars is the next step in minimising the error-box boundaries for the newly-discovered object 1, that makes them observable by large telescopes.

There are about 20 autonomous observatories, MASTER included, directed to GRB observations in optical wavelengths, registered in GCN.

The ROTSE-III (Ackerlof, 2000) instruments are the most similar to MASTER. ROTSE-III has made follow-up observations of about 5 bursts (from 60 up to 500 sec) since the first observations of synchronous optical afterglow of a GRB in 1998. We should point out a feature of MASTER and ROTSE-III. These systems are able to make a rapid response to GRB alerts in addition to an ongoing survey of the whole available sky. The major feature is the depth of the surveys: MASTER can measure 19\textit{m} objects with a 1.5 min exposure. Furthermore MASTER has a wide-field camera, that allows us to make observations synchronously with gamma-ray telescopes in the magnitude range 9\textit{m}.

3. The MASTER main parameters

The MASTER system includes 3 wide-aperture telescopes. These are mounted on a robotic German parallax mount, which can slew at a rate of 8\textdegree/sec. The main MASTER Richter-Slefogt telescope (diameter = 355mm, D:F = 1:2.4) can obtain unfiltered images of 19m objects over 6 square degrees in a 1.5 min co-added exposition (3 exp. of 30sec). Additionally, there is a modified Richter-Slefogt telescope (200mm, D:F = 1:2.5) and a Flugge system telescope (280mm, D:F = 1:2.8). All three telescopes are mounted parallel to one another on the same mount, which allows us to make a simultaneous observations in R and V filters. There are 2 CCD cameras: an AP16E camera with Kodak KAF-16801E CCD (4096 x 4096 pixels, front illuminated, 30 sec download time) on the 355mm telescope, and a Pictor-416 (700 x 500 pixels) on the 200mm one.

There is also a wide field video camera (fov = 30x40 deg). This camera allows us to work synchronously with space-based gamma-ray telescopes (being pointed to the region of the GRB), giving a magnitude limit of 8\textit{m}. This was used for making a film of an aurora 2, which was observed over Moscow on 2003/10/30.

MASTER is permanently connected to the internet and receives alerts from GCN.

MASTER works in the following way:

\[
\begin{array}{|c|c|}
\hline
\text{manager server} & \text{programm block (PB) of telescope management} \\
\hline
\Rightarrow \text{PB to get} & \text{initial image reduction PB } \Rightarrow \text{the database} \\
\hline
\end{array}
\]

To obtained a fast and precise telescopes pointing, two identical drives were mounted on the mount, one on the declination axis, and one on the polar axes. Each drive consists of a step-motor and intelligent controller, connected to manager computer through the RS485 interface.

The managing program (run on a Linux operating system) executes telescope pointing commands from the managing server. The program converts from astronomical object coordinates to the instrumental coordinate system. It also calculates the optimal route of telescope displacement (if the object is available at the current time) keeping within the limits accessible to the telescope.

The rough calibration of the instrumental coordinates system is supplied by zero-points sensors. This approximate correction is applied to objects with known coordinates. This simple system supplies a pointing with a precision of 5", which is adequate given the instruments field of view.

4. MASTER optical observations of GRB

MASTER began surveying for GRB optical afterglows at the end of 2002. Our main results are summarized in Table 1. We should note that no GRB with an optical afterglow occurred during local nighttime from Dec 2002 to May 2004.

We publish only the first observation of the GRB error-box (if anyone observes the alert error-box before us and there was no optical afterglow, we do not observe it again). GRB030329 excludes, we present only upper limits on the magnitude (i.e. there is no afterglow to these mag). The main time delay is the time required for data reduction and transmission by the gamma-ray telescope (HETE in our case). The MASTER telescopes can slew into position in 10-15sec.

The scientific mean of the limits on found optical flux can be estimated in the following way. All the published GCN observations of GRB optical afterglows (unfiltered and R) are in the Figure 1. Stellar magnitudes limits of the observed error-boxes were reduced to the gamma wavelength fluence of GRB030329: \( m = m_{\text{obs}} + 2.5 \log (F_\gamma/F_{030329}) \). The dashed-lines at the Figure 1 are the bounds of normal fluences. If the light of the optical afterglow is less than low limit, we’ll be able to detect "dark"-GRB.

5. GRB030329 observation.

Images of optical transient GRB030329 (Peterson,Price,2003) were taken by MASTER (Lipunov et al.,GCN2002, GCN2035) on the 2003/03/29. We note that MASTER was the first instrument in Europe to start observations of this event. Figure 2 presents the optical light curve for this GRB event 3, consisting of more than 200 frames. To increase the signal/noise ratio and to reduce instrumental errors we averaged \( t \) times of exposure span, resulting in 64 data points. The magnitude calibration was performed in accordance with GCN2023 (Henden,2003) using 4 stars. The large errors on some of the magnitudes are due to weather conditions; the first data points

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1 http://gcn.gsfc.nasa.gov/gcn3_archive.html
2 http://observ.pereplet.ru/index.shtml
3 http://observ.pereplet.ru/lightcurve.txt
### Table 1. Observations of GRB error-boxes.

| GRB       | Number of GCN circular publication | Time $t - t_0$ from GRB alert | Optical mag image limits | Comments to observations                                                                 |
|-----------|-----------------------------------|-------------------------------|--------------------------|--------------------------------------------------------------------------------------------|
| GRB040308 | GCN 2262                          | 48h                           | 21.2                     | Unfiltered                                                                                 |
| GRB030913 | GCN 2394, GCN 2385                 | 43 min                        | 17.5                     | Clouds present for 120 seconds after GRB alert.                                             |
| GRB030601 | GCN 2262                          | 55 min                        | 12.0                     | The first image was taken only 43 minutes after GRB alert.                                  |
| GRB030414 | GCN 2157                          | 8h                            | 13.3 − 14.5              | First observations. Almost full Moon, clouds.                                                |
| GRB040308 | GCN 2543                          | 48h                           | 21.2                     | First observations                                                                        |
| GRB030416 | GCN 2158                          | 11h                           | 16.5                     | First observations                                                                        |
| GRB030329 | GCN 2091, GCN 2035, GCN 2002      | 5.2h                          | Full Moon. First observations | R-filter brightness curve for 8.8h                                                          |
| GRB021219 | GCN 1770                          | 7.5h                          | 13.7                     | First observations of first INTEGRAL GRB, clouds.                                           |

**Fig. 1.** "Synthetic" brightness curve. Y-axis is R or unfiltered magnitude, X-axis is the time from the burst moment in hours. Triangles are the optical limits, found by MASTER. The dashed-line inclination corresponds to the law of light afterglow of GRB030329, $t^{-1.2}$. The circular are the observational data of almost all GCN circulars.

The power index of our light curve corresponds to the observations made by Burenin et al., 2003 within error-limits.

**Fig. 2.** Brightness curve of GRB030329 measured by MASTER. Y-axis is R-magnitude, X-axis is the time from the burst moment in days.

6. Conclusions

The MASTER system of robotic telescopes was designed to make follow up and synchronous observations of gamma-ray burst events. Such systems allow us to study the earliest stages of GRB optical emission and also allow us to find supernova and new transient optical phenomena in the Universe. At the same time, we can discover minor planets, comets and space garbage. It’s especially important to address this problem using small telescopes since observations can only be made by large telescopes some hours after the alert.

We present our light curve of GRB030329 taken in the R-filter.

Synthetic light curve of GRB observations is introduced. One can estimate received optical limits on observed error-boxes of GRBs. There are regions for normal GRB and for "dark” GRB.

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