Optical Observations of Gamma-Ray Bursts, the Discovery of Supernovae 2005bv, 2005ee, and 2006ak, and Searches for Transients Using the “MASTER” Robotic Telescope

V.M. Lipunov, V.G. Kornilov, A.V. Krylov, N.V. Tyurina, A.A. Belinski, E.S. Gorbovskoy, D.A. Kuvshinov, P.A. Gritsyk, G.A. Antipov, G.V. Borisov, A.V. Sankovich, V.V. Vladimirov, V.I. Vybornov, & A.S. Kuznetsov

February 2, 2008

Abstract

We present the results of observations obtained using the MASTER robotic telescope in 2005—2006, including the earliest observations of the optical emission of the gamma-ray bursts GRB 050824 and GRB 060926. Together with later observations, these data yield the brightness-variation law $t^{-0.55\pm0.05}$ for GRB 050824. An optical flare was detected in GRB 060926—a brightness enhancement that repeated the behavior observed in the X-ray variations. The spectrum of GRB 060926 is found to be $F_E \approx E^{-\beta}$, where $\beta = 1.0 \pm 0.2$. Limits on the optical brightnesses of 26 gamma-ray bursts have been derived, 9 of these for the first time. Data for more than 90% of the accessible sky down to $19^\text{m}$ were taken and reduced in real time during the survey. A database has been composed based on these data. Limits have been placed on the rate of optical flares that are not associated with detected gamma-ray bursts, and on the opening angle for the beams of gamma-ray bursts. Three new supernovae have been discovered: SN 2005bv (type Ia)—the first to be discovered on Russian territory, SN 2005ee—a one of the most powerful type II supernovae known, and SN 2006ak (type Ia). We have obtained an image of SN 2006X during the growth stage and a light curve that fully describes the brightness maximum and exponential decay. A new method for searching for optical transients of gamma-ray bursts detected using triangulation from various spacecraft is proposed and tested.

INTRODUCTION

The construction of robotic telescopes, which not only automatically acquire but also automatically process images and choose observing strategies, is a new and vigorously developing area in modern astronomy.

MASTER (Mobile Astronomy System of Telescope Robots), the first robotic telescope in Russia, began to be created through the efforts of scientists at the Sternberg Astronomical Institute of Moscow State University and the Moscow “Optika” Association in 2002, and continues to be developed to the present [1, 2]. In its current form, the system has four parallel telescopes on an automated equatorial mount, capable of slewing at a rate of up to $6^\circ/s$ (located near Domodedovo, Moscow region), and two very-wide-field cameras with separate mounts and domes, with one located on the Mountain Solar Station of the Pulkovo Observatory (near Kislovodsk), roughly 1500 km from the other (which is also near Domodedovo). The parameters of the telescopes and CCD arrays are given in Table [1]

The system whose characteristics are closest to the MASTER system ([http://observ.pereplet.ru](http://observ.pereplet.ru)) is the American ROTSE-III system [3] ([http://www.rotse.net](http://www.rotse.net)). MASTER (Fig. [1]) differs in its larger...
field of view and the presence of several telescopes on a single axis, which makes it possible to obtain images at several different wavelengths simultaneously. The main telescope, Telescope 1 (355 mm diameter, a modified Richter-Slevogt system initially invented by V. Yu. Terebizh) takes images in white light, and is the main search element of the system. An Apogee Alta U16 (4096 × 4096 pixels) is installed on this telescope, making it possible to obtain images in a six square degree field. A Sony video recorder is mounted on Telescope 2 (200 mm diameter, a Richter-Slevogt system constructed by G. V. Borisov), providing images to $13 \div 14''$ with a time resolution of 0.05 s. A prism is mounted at the focus of Telescope 3 (280 mm diameter, a Flugge system), providing spectra of objects to $13''$ in a $30' \times 40'$ field of view with a resolution of 50 Å (with a Pictor-416 camera). Telescope 4 (200 mm diameter, a Wright system constructed by A. V. Sankovich) is equipped with a filter cassette and SBIG ST-10XME camera. In addition, MASTER has a very-wide-field camera ($50^\circ \times 60^\circ$), that covers the field of view of the HETE orbiting gamma-ray telescope, making it possible to obtain simultaneous observations with HETE to $9''$ using a separate automated scheme. This widefield equipment enables searches for bright, transient objects.

In the Summer of 2006, we installed a widefield camera (MASTER-VWF-Kislovodsk) on the Mountain Solar Station of the Main Astronomical Observatory in Pulkovo, making it possible to continuously monitor a 420-square-degree field of sky to $13''$ in a five second exposure.

Thus, we currently have three automated mini-observatories with the following equipment:

- Six telescopes and CCD arrays
- Three automated equatorial mounts.
- Three automated domes
- Two cloud-cover and temperature sensors
- One GPS receiver
- Six control and reduction computers

The Kislovodsk and Domodedovo systems are connected via the Internet, and are able to respond to the detection of uncataloged objects (optical transients) within several tens of seconds (including processing time). The results of observations using the MASTER network will be reported separately.

MASTER is able to operate in a fully automated regime: automatically, based on the ephemerides (sunset) and the presence of satisfactory weather conditions (the control computer is continuously attached to a weather sensor), the roof (above the main mount and wide-field camera) is opened, the telescope is pointed at bright stars and pointing corrections introduced, and, depending on the seeing, it then either goes into a standby regime or begins a survey of the sky using a specialized, fully automated program.

Thus, observations are conducted in two regimes: survey and “alert” (e.g. observation of the locations) of gamma-ray bursts based on coordinates obtained). In the former case, the telescope automatically takes three frames of an arbitrary region in succession, with exposures from 30 to 60 s, moves to a neighboring region $2^\circ$ away and carries out the same procedure, and so on, repeating a given set of three frames every 40-50 min. This makes it possible to avoid artefacts in the data processing, and to locate moving objects. The alert regime is supported by a continuous connection between the control computer and the GCN international gamma-ray burst (GRB) network [4] (http://gcn.gsfc.nasa.gov). After detection of a GRB by a space gamma-ray observatory (SWIFT, HETE, Konus-Wind, INTEGRAL etc.), the telescope obtains the coordinates of the burst region (the so called coordinate error box), automatically points to this direction, obtains an image of this region, reduces this image, and identifies all objects not present in the computer catalogs. If a GRB is detected during the day, its coordinates are included in the observing program for the next night.
Table 1: Telescopes and receivers of the MASTER system in Domodedovo.

| Optical system | Diameter, mm | Relative aperture | CCD camera       | Field of view | Format, Mpxixels |
|----------------|-------------|------------------|-----------------|--------------|-----------------|
| 1 Richter-Slevogt | 355         | F/2.6            | Apogee U16E     | 2.4° × 2.4°  | 16              |
| 2 Richter-Slevogt | 200         | F/2.6            | Sony LCL 902K   | 1° × 0.7°    | 0.4             |
| 3 Flugge         | 280         | F/2.5            | Pictor-416      | 1° × 0.7°    | 0.4             |
| 4 Wright         | 200         | F/4              | SBIG ST-10XME   | 1° × 0.7°    | 3.2             |
| 5 Wide-field camera | 25         | F/1.2            | Foreman Electr. FE-285, Sony ICX285AL | 30° × 40° | 1.4             |

A special program package for image reduction in real time has been created, making it possible not only to carry out astrometry and photometry of a frame, but to recognize objects not contained in astronomical catalogs: supernovae, new asteroids, optical transients, and so forth.

Over the entire time observations have been obtained on the MASTER system (see the results for 2002–2004 in [1,2]), images have been obtained for 52 GRB error boxes. In 23 cases, these observations were the first in the world. In three cases, optical emission was detected (this was the earliest detection in Europe for GRB 030329, and the earliest in the world for the two cases reported here).

Note that, from February through August 2006, the main matrix of the search telescope was being repaired, so that the sky survey essentially was not conducted during this time.

**OBSERVATIONS OF GRBS IN 2005–2006**

Starting at the beginning of 2005 through October 2006, the Domodedovo MASTER station carried out observations of 31 GRBs (see Table 2). In 16 cases, we obtained the first upper limits on the optical fluxes of the GRBs, i.e., fluxes brighter than which no optical candidate for the GRB was detected.

Note that, before 2005, only a few alerts for GRBs in the Moscow night-time sky in regions of sky accessible to MASTER were received from the SWIFT orbiting observatory, which provided more than 90% of all detected GRBs in 2005, with one of these occurring during rainy weather. Nevertheless, we were able to report the first optical detections in the world for two of these GRBs.

Unless otherwise indicated, we present instrumental magnitudes in white light. Our photometry was carried out in an automated regime using objects in the frame identified with stars in the USNO–A2.0 catalog [51] (there were usually about 2000 stars in a frame) and the combined USNO-A2.0. $R$ and $B$ magnitudes:

\[ m = 0.89R + 0.11B \]  

We chose this combination so that our instrumental magnitude was close to the $R$ magnitudes of minor planets, i.e., objects with solar spectra. As our observations show, these magnitudes are in poor agreement with the $R$ magnitudes of GRBs, due to the enhanced red sensitivity of the Apogee Alta U16 array.

The processing of a frame begins immediately after it is taken, and requires less than one minute. As a result, the robotic system can attempt to find unidentified objects within the error box and compose the text of a GCN telegram with the indicated brightness limit for an optical transient. In parallel, our full frame with the error box and an enlarged error box (usually 6 ÷ 8 with an image of
the same region in the Palomar Sky Survey are sent to a database over the Internet, together with our frames obtained during the previous survey observations. Thus, an on-duty observer can visually inspect the region to search for objects with low signal-to-noise ratios (two to three).

If no object is found in the individual frames, the images are summed. On a good, Moonless night, the sum of 10–15 images lowers the limiting magnitude to \(20^m\). The results of our observations are summarized in Table 2.
Table 2: Observation GRB-error boxes in 2005-2006yy.

| GRB       | Publication in GCN circular | Time from detection of the GRB | Limiting magnitude | First observation? | Comments                                                                 |
|-----------|-----------------------------|--------------------------------|--------------------|-------------------|------------------------------------------------------------------------|
| GRB060926 | 5632 [5], 5619 [6], 5613 [7]| 76 c                           | 17"m5              | 1                 | Optical transient detected, decay law obtained.                        |
| GRB060712 | 5303 [8]                    | 212 s                           | 14"m               | 1                 | Pointing 72 s after the burst. No optical candidate detected.           |
| GRB060502B| 5056 [9]                    | 69 s, 82 m                      | 16"m               | 2                 | SWIFT GRB. Evening sky. Main observations were 82 min later (after sunset) with all MASTER instruments: simultaneous BVR, spectral, and high-time-resolution images of the GRB region obtained. No optical candidate detected. |
| GRB060427B| 5032 [10]                   | 18.5 h                          |                    | 1                 | Konus-Wind GRB. Observations began 18.5 hr after the GRB in the survey regime (the delay was due to processing of the signals from the IPN triangulation equipment; the IPN error box is a region tens of square degrees in size). The region is located near the Galactic plane. We obtained roughly 20 six-square-degree images. |
| GRB060427 | 5020 [11]                   | 9 h 13 m                        | 17"m5              | 4                 | SWIFT GRB. First image obtained on 04.27.2006 at 18:18:07 UT. No new objects brighter than 17.5"m detected. |
| GRB       | Time [sec], [day] | Duration | MAG | Notes                                                                 |
|-----------|------------------|----------|-----|-----------------------------------------------------------------------|
| GRB060425 | 5026 [12], 5008 [13], 5080 [14] | 26 h 53 min | 17"5 | IPN triangulation GCN5005. MASTER observed in the survey regime on two nights: 04.26.2006 from 18 : 17 : 03 to 19 : 53 : 07 UT (1.05-1.12 days after the event [13]) and 04.27.2006 from 18:57:51 to 19 : 21 : 20 UT. A total of 72 images were obtained. No new objects brighter than 15.5" were detected. |
| GRB060421 | 4988 [15]        | 562 s    | 16"8 | Two minutes before the alert, the roof was closed due to strong cloud-cover. No new objects within the SWIFT-XRT error box brighter than 16"8 (S/N = 3) were detected. |
| GRB060319 | 4892 [16], 4888 [17] | 162 s    | 19"5 | Spectral and integrated images of the burst region were obtained. No new objects brighter than 19"5 were found in the SWIFT error box. |
| GRB060213 | 4767 [18], 4765 [19] | 55 h 17 m | 17"5 | GRB 060213 was detected by the IPN. No optical candidate brighter than 17"5 was found. |
| GRB060211B| 4741 [20]        | 282 s    | 14"5 | Snow, gaps in the clouds.                                             |
| GRB060209A| 4718 [21]        | 235 s    | 15"8 | No optical candidate found.                                           |
| GRB060124 | 4572 [22]        | 96 m     | 14"4 | SWIFT GRB 060124. Information about the GRB did not arrive through the alert system. The weather was hazy and cloudy. |
| GRB060118 | 4549 [23]        | Synchronous | 8"0 | HETE alert 4006 without coordinates. Observations before and after the alert with the wide-field camera. All exposures were 3 s. No object brighter than 8"0 detected. |
| GRB060111A| 4485 [24]        | 130 s    | 16"0 | Observations began half an hour before dawn. No optical candidate detected. |
| GRB051103   | 4198 [25], 4206 [26] | 58 h 30 m | 18''5 | 1 | IPN triangulation GRB 051103 [27]. Observations began several minutes after receiving the alert. A total of 36 images with a total exposure of 1080 s were obtained. No optical candidate brighter than 18.5m found (the weather was hazy). Four galaxies (M81,M82, PGC 2719634, PGC 028505) are located near or in the triangulation region; it is possible the GRB arrived from a source in PGC 028505. |
| GRB051028   | 4171 [28] 4173 [29] 4182 [30] | 3 h 23 m | 17''—19''4 | 2 | HETE alert GRB 051028. No objects brighter than 17''9 (sum of nine frames taken between 17:32:40 and 18:03:03 UT) and 19''4 (8 h 26 m after the alert, total exposure of 1200 s) detected. |
| Swift trigger 160640 | 4119 [31] | 1 h 11 m | 16''3 | 1 | Technical alert. Sunset, haze. No new object found based on comparison with USNO-A2. |
| GRB051021.6 | 4118 [32] | 1 h 29 m | 14'' | 4 | HETE alert 3947. Sunset, haze. No new object found based on comparison with USNO-A2. |
| GRB051011   | 4082 [33], 4083 [34] | 45 s | 17''0 | 1 | First image with exposure 5 s obtained 45 s after detection of the GRB. A second image with exposure 30 s obtained 87 s after the GRB. No new objects detected in the error box.. |
| GRB050824   | 3886 [35], 3883 [36], 3869 [37], 3870 [38] | 764 s | 19''4 | 1 | Optical candidate detected. |
| GRB050825   | 3882 [39] | 94 s | 18''9 | 1 | SWIFT alert, no new objects found.. |
| GRB050805b  | 3769 [01] | 74 s | 17''1 | 2 | SWIFT trigger 149131. No new objects found (MilkyWay region). |
GRB050805a | 3767 [41] | 113 s | 14°5 | 1 | Weak object detected at the noise level. Subsequently not confirmed..
GRB050803 | 3755 [42] | 198 s | 18°6 | 2 | SWIFT alert. No new objects found..
GRB050410 | 3221 [43] | 5 h | 18°5 | 3 | SWIFT alert. No new objects found..
GRB050408 | 3188 [44] | 1 h 09 m | 14°7 | 7 | Sunset, cloudy; no new objects found..
GRB050316 | 3108 [45] | 103 s | synchronous | 19°5 | 1 | No object was found on the summed frame(19°5) or the image obtained from the survey observations coincident with the GRB. This event was later classified by the HETE group as unconfirmed.
GRB050316 | 3106 [46] | 103 s | 18° | 1 | Preliminary result; 50 frames with an exposure of 30 s. No new object detected based on a comparison with USNO-B. A total of 50 spectra (50Å) of a 40' × 30' region obtained.
GRB050126 | 2988 [47] | 2 h 48 m | 17° | 1 | Object from GCN 2986 not detected..
GRB050126 | 2986 [48] | 2 h 48 m | 15° | 1 | Optical transient at the noise level. Not confirmed.
GRB050117 | 2954 [49], 2953 [50] | 2 h | 19° | 1 | First observations of the region of this SWIFT GRB..

Table 3: Observations of GRB 050824.

| Time (UT) | Time from GRB | Magnitude | Exposure | Comments |
|-----------|---------------|-----------|----------|----------|
| 23:25:00  | 788 s         | > 17.8 m  | 45 s     | Upper limit |
| 23:25:00 – 23:47:55 | 24 m | 18°6 ± 0°3 | 15 × 30 s |
| 23:49:00 – 00:09:03 | 47 m | 19°4 ± 0°3 | 15 × 30 s |

**GRB 050824: EARLIEST IMAGE**

Information about the coordinates of GRB 050824 arrived at the MASTER observatory on August 24, 2005 after some delay due to the processing of the signal in the SWIFT data center [52]. The first
Table 4: Bright galaxies near and inside the large error box for GRB 051103.

| Name          | Type | Coordinates (2000) | Magnitude | Redshift | Diameter  |
|---------------|------|--------------------|-----------|----------|-----------|
|               |      |                    | $B$ MASTER|          | $25^m$ isophote |
| M81 Sab       |      | 09h55m33.2 +69d03'55'' | 7.8       | 0.000376 | large     |
| M82 Sb        |      | 09h55m52.2 +69d40'47'' | 9.3       | 0.000677 | large     |
| PGC2719634    |      | 09h51m32.3 +68d31'24'' | 17.8 16''7 |          | 16''9     |
| PGC028505 E   |      | 09h53m10.2 +69d00'02'' | 17.0 14''8 |          | 6''0      |

Figure 2: Upper limit and brightness estimate for the optical counterpart of GRB 050824 obtained in the first minutes after the burst. The hollow circles are ROTSEstimates [54], the dark circles MASTER estimates [36], the diamonds the $R$ magnitudes from [53], and the triangles the SWIFT estimates in various photometric bands [55].

The earliest available optical image of this object, obtained on our MASTER system, can be found at the address [http://observ.pereplet.ru/images/GRB050824/1.jpg](http://observ.pereplet.ru/images/GRB050824/1.jpg)

Fig. 2 presents the upper limits and magnitudes obtained in the first minutes of observations. Fig. 3 shows our data together with the $R$ data of the MDM Observatory [56]. The MDM $R$ observations obtained from 5.6 to 12.6 h after the GRB are consistent with a power-law decay in the flux (with index $-0.55 \pm 0.05$), and also with our data obtained 24 min and 47 min after the burst.
THE SHORT BURST GRB 051103 — A SOFT GAMMA-RAY REPEATER IN THE GALAXY M81?

GRB 051103 may be the first soft gamma-ray repeater (SGR) detected outside our Galaxy; the first image of the error-box region was obtained on the MASTER telescope.

The bright, short (0.17 s) burst GRB 051103 was detected by Konus-Wind, as well as HETE-Fregate, Mars Odyssey (GRS and HEND), RHESSI, and SWIFT-BAT [27]. The MASTER telescope started to observe the error-box region for GRB 051103 [25] several minutes after receiving the alert telegram [27]. The first image was obtained at 19:55:47 UT on November 5, 2005, 2 d, 10 hr, and 30 min after the GRB. We obtained 36 images with a total exposure time of 1080 s between 19:55:47 and 21:45:17 UT. No optical transient was found in the error box to 18.5\textsuperscript{m} (in the presence of a full Moon and light haze).

Analysis of the frame showed the presence of four bright galaxies near or in the large error box (see Fig. 8 and Table 4).

The most likely candidate host galaxy is M81 [27], and the burst itself has been interpreted as a SGR. The error box lies outside any spiral arms, where strongly magnetized neutron stars (magnetars, which are thought to be the sources of SGRs) would be likely to form. However, the structure of M81 is distorted by tidal interaction, and part of a disrupted spiral may fall in the error box. For example, the ultra-luminous X-ray source (ULX) M81 X-9 [57] is located at a similar distance from the center of M81 (on the side opposite to the error box), and belongs to that galaxy's population of massive stars. It would be interesting to search for supernova remnants within the error box (unfortunately, the supernova-remnant survey [58] does not encompass the error box of the GRB).

In our telegram [25], we also noted the elliptical galaxy PGC 028505, which is close to the center of the triangulation error box. Its distance is estimated to be 80 Mpc. If the GRB occurred in PGC 028505, the isotropic energy of the burst can be estimated to be $\sim 2 \times 10^{49}$ erg. This exceeds the energy of the short burst GRB 050509b, which is associated with an elliptical galaxy [59], by an order of magnitude, but remains fairly characteristic of long GRB energies. Based on our data, Holland et al. [60] carried out photometry of PGC 028505 the following night, without finding any optical transient brighter than 21\textsuperscript{m} although this work excluded the region of the galactic bulge.

Nevertheless, the absence of an optical object represents an additional argument that GRB 051103 is the first SGR observed beyond our Galaxy, in the galaxy M81 [61]. Our full image of the error box region can be found at the address http://observ.pereplet.ru/images/GRB051103.4/sum36.jpg.

GRB 060926: EARLIEST IMAGE AND DETECTION OF AN OPTICAL FLARE

Our observations of GRB 060926, detected by the SWIFT gamma-ray observatory [62], were carried out in an automated regime under good weather conditions [63]. The earliest image was obtained on September 26, 2006 at 16:49:57 UT, 76 s after the detection of the burst. We found an optical transient in our first and subsequent summed frames, at the position $R.A. = 17\h 35\m 43\s 66 \pm 0\s 05, Dec. = 13\d 02\arc 18\arc 3 \pm 0\arc 7$, which coincides within the errors with the coordinates of the optical transient reported in [62]. Our photometry of the object provided the earliest points on the light curve (Table 5).

Our preliminary reduction indicated a more gradual brightness decrease than the OPTIMA-Burst observations [64] (the power-law index for the brightness decrease in the first 10 min was 0.69). However, subjecting the data to finer time binning revealed an optical burst: after its initial decrease, the brightness began to increase beginning 300 s after the GRB, reaching a maximum 500–700 s after the GRB (Fig 4). Synchronous SWIFT-XRT measurements of the X-ray flux show similar behavior (see Fig 4).

Such an event had already been observed in at least two other cases: GRB 060218A ($z = 0.03$) 1000 s after the GRB [66], and GRB 060729 ($z = 0.54$) 450 s after the GRB [67, 68]. Note that the
GRB considered here has a redshift of 3.208 [69].

The absorption indicated by the X-ray data corresponds to \( n_H = 2.2 \cdot 10^{21}\text{cm}^{-2} \) of which \( n_H = 7 \cdot 10^{20}\text{cm}^{-2} \) occurs in the Galaxy [65]. Taking into account the redshift, the total absorption in our band should be \( \approx 3\text{m} \). Naturally, we assume here that the dust-to-hydrogen ratio is the same as it is in our Galaxy.

Comparison of our optical data with the SWIFT XRT X-ray fluxes [65] can be used to determine the slope \( \beta \) of the electromagnetic spectrum \( (F_E \sim E^{-\beta}) \), which turned out to be constant within the errors and equal to \( 1.0 \pm 0.2 \) [5], which coincides with the corresponding value for the X-ray spectrum.

The earliest image of the optical transient can be found at [http://observ.pereplet.ru/images/GRB060926/GRB060926_1.jpg](http://observ.pereplet.ru/images/GRB060926/GRB060926_1.jpg), the sum of the five following frames at [http://observ.pereplet.ru/images/GRB060926/GRB060926_5.jpg](http://observ.pereplet.ru/images/GRB060926/GRB060926_5.jpg), and the sum of the ten following frames at [http://observ.pereplet.ru/images/GRB060926/GRB060926_10.jpg](http://observ.pereplet.ru/images/GRB060926/GRB060926_10.jpg).

Images of this same region obtained during the previous set of survey observations can be found at [http://observ.pereplet.ru/images/GRB060926/GRB060926_2005.jpg](http://observ.pereplet.ru/images/GRB060926/GRB060926_2005.jpg).

**OPTICAL EMISSION OF GRBS IN THE FIRST HOUR AFTER THE BURST.**

In this section, we consider the question of how universal the behavior of the optical emission of GRBs is with regard to their absolute luminosity and time behavior. We collected observations of the following GRBs with known redshifts in the first hour after their onset (Fig. 5).
Figure 4: Comparison of the light curve of GRB 060926 obtained using the MASTER telescope [63] (points) with the (a) OPTIMA Burst [64] (circles) and (b) SWIFT XRT (0.3-10 keV; diamonds) [65] light curves.

We then normalized the magnitudes to a single redshift (to take into account their different distances; Fig. 6) and gamma-ray flux (to take into account their directional beaming, assuming the beaming for the optical and gamma-ray emission is similar Fig. 7).

Since the largest number of afterglows have power-law light curves, we chose as boundaries in the synthetic light curves straight lines (in logarithmic coordinates) of the form

\[ f(t) = 2.5 \cdot 0.8 \cdot \log t + c = 2 \cdot \log t + c. \]  \hspace{1cm} (2)
Table 5: Photometry of GRB 060926 obtained on the MASTER telescope.

| Beginning of exposure, s | Middle of exposure, s | Exposure, s | Magnitude | Flux, erg/(sm$^2$·c·eV) after correction for absorption, erg/(sm$^2$·c·eV) |
|-------------------------|-----------------------|-------------|-----------|-------------------------------------------------|
| 76                      | 91                    | 1 × 30      | 17$^{m}3$ ± 0$^{m}3$ | (1.4 ± 0.3) · 10$^{-13}$ (4.3 ± 1.0) · 10$^{-12}$ |
| 150                     | 165                   | 1 × 30      | 18$^{m}5$ ± 0$^{m}3$ | (4.6 ± 1.1) · 10$^{-14}$ (1.4 ± 0.4) · 10$^{-12}$ |
| 165                     | 343                   | 5 × 30      | 19$^{m}3$ ± 0$^{m}3$ | (2.2 ± 0.5) · 10$^{-14}$ (6.9 ± 1.7) · 10$^{-13}$ |
| 255                     | 432                   | 5 × 30      | 18$^{m}9$ ± 0$^{m}3$ | (3.2 ± 0.8) · 10$^{-14}$ (9.9 ± 2.4) · 10$^{-13}$ |
| 343                     | 519                   | 5 × 30      | 18$^{m}5$ ± 0$^{m}3$ | (4.6 ± 1.1) · 10$^{-14}$ (1.4 ± 0.3) · 10$^{-12}$ |
| 432                     | 608                   | 5 × 30      | 18$^{m}3$ ± 0$^{m}3$ | (5.8 ± 1.3) · 10$^{-14}$ (1.7 ± 0.4) · 10$^{-12}$ |
| 519                     | 707                   | 5 × 30      | 18$^{m}4$ ± 0$^{m}3$ | (5.1 ± 1.2) · 10$^{-14}$ (1.6 ± 0.4) · 10$^{-12}$ |
| 608                     | 804                   | 5 × 30      | 18$^{m}7$ ± 0$^{m}3$ | (3.9 ± 0.9) · 10$^{-14}$ (1.2 ± 0.3) · 10$^{-12}$ |
| 707                     | 1001                  | 5 × 30      | 20$^{m}0$ ± 0$^{m}3$ | (1.2 ± 0.3) · 10$^{-14}$ (3.6 ± 0.9) · 10$^{-13}$ |
| 804                     | 1200                  | 5 × 30      | 20$^{m}1$ ± 0$^{m}3$ | (1.1 ± 0.3) · 10$^{-14}$ (3.3 ± 0.8) · 10$^{-13}$ |
| 901                     | 1298                  | 5 × 30      | > 20$^{m}1$ ± 0$^{m}3$ | < (1.1 ± 0.3) · 10$^{-14}$ < (3.3 ± 0.8) · 10$^{-13}$ |

where \( c = \text{const} \). The width of the band bounding the synthetic light curve is then

\[
\Delta m = c_{\text{max}} - c_{\text{min}} \tag{3}
\]

It’s obvious that, the smaller \( \Delta m \) the better the model used to construct the synthetic light curve describes the real physical situation.

We normalized the observed curves using the mean weighted gamma-ray flux for the entire sample:

\[
F_{\gamma 0} = \frac{\sum f_i n_i}{\sum n_i}, \quad n_i = 2.13 \cdot 10^{-5} \text{erg/cm}^2, \tag{4}
\]

where \( f_i \) are the individual fluxes and, \( n_i \) is the number of GRBs with fluxes in the interval:

\[
i \times 10^{-6} \leq f_i \leq (i + 1) \times 10^{-6} \tag{5}
\]

The normalization in redshift \( (z_0 = 1) \) was carried out using the formula

\[
m_{\text{opt}}^z = m_{\text{opt}}^{z_0} - 5 \log \frac{d_l(z)}{d_l(z_0)} = m_{\text{opt}}^{z_0} - 5 \log \frac{(1 + z)I(z)}{(1 + z_0)I(z_0)}, \tag{6}
\]

where

\[
I(z) = \int_1^{(1+z)d^{-1/3}} \frac{dq}{\sqrt{q^3 + 1}}, \quad d = 0.3/0.7 \tag{7}
\]

We obtained synthetic curves in the optical and gamma-ray normalized to the same redshift and gamma-ray flux using the formula:

\[
m_+ = m_{\gamma}^z - 2.5 \log \frac{1 + z}{1 + z_0} + 2.5 \log \frac{F_{\gamma}^z}{F_{\gamma 0}} \tag{8}
\]

Correcting for interstellar absorption does not appreciably affect the distribution.
Figure 5: Light curve for the GRB afterglows observed within an hour after the burst. The width of the band, shown by dashed lines, corresponds to $\Delta m = 8^m.5$

Applying the above normalization substantial narrowed the width of the synthetic light curve, although $\Delta m$ remained fairly large. We assumed that the synchrotron mechanism operates in GRB sources, suggesting that the spectrum should have the form: $\lambda^\beta$.

Let us try to predict the value of $\beta$ based on the tendency for the width of the synthetic curve normalized in this way to narrow. We must take into account the so-called $K$ correction:

$$K_z = 2.5 \log(1 + z) + 2.5 \log \left( \frac{\int I(\lambda)s(\lambda)d\lambda}{\int I\left(\frac{\lambda}{1 + z}\right)s(\lambda)d\lambda} \right)$$  \hspace{1cm} (9)

Formula (8) then takes the form:

$$m_* = m_\gamma^* - 2.5\beta \log \frac{1 + z}{1 + z_0} + 2.5 \log \frac{F_z^*}{F_{70}^*}$$  \hspace{1cm} (10)

Fig. 9 shows the dependence of the width of the synthetic curve on the spectral index. We can see a weak minimum for $\beta = -1$, with the corresponding value of $\Delta m$ equal to the width of the synthetic curve when we do not include the $K$ correction. Consequently, the $K$ corrections are too small to appreciably influence the width of the curve.

Thus, by normalizing the light curves using an appropriate set of parameters, we have been able to appreciably decrease the width of the synthetic light curve. However, while the dependence of the optical flux on the gamma-ray flux is as unique as was thought initially, there must be some reason for the width of the synthetic GRB light curve. In addition to internal absorption in the host galaxy, another possible origin is the directional beaming of the GRB jets, which most likely has different opening angles in the optical and gamma-ray, and, thereby, different intensity distributions as a function of the viewing angle.
NEW METHOD FOR SEARCHING FOR OPTICAL TRANSIENTS ASSOCIATED WITH GRBS DETECTED BY TRIANGULATION

All attempts to detect optical emission from GRBs before 1997 were unsuccessful for various reasons. First, the main method for deriving coordinates was triangulation using data from several different spacecraft. As a rule, this method gave very large error boxes (from several to hundreds of square degrees). Second, even these coordinates became available, at best, only several days after the GRB itself. With the launch of gamma-ray observatories equipped with X-ray telescopes, the size of the error boxes and reduction time decreased sharply, and interest in searching for optical emission for triangulated GRBs fell.

Nevertheless, we suggest that the situation with triangulated GRBs has now changed, due, first and foremost, to the appearance of robotic search telescopes that are able to inspect large regions of sky in relatively short times. For example, there exist a number of specialized projects aimed at searches for supernovae, minor planets, comets, and dangerous asteroids. Our idea is that these telescopes could carry out specialized searches within large error boxes provided by triangulation [14]. This is especially important for three reasons. First, it has recently become clear that at least long GRBs are associated with supernovae. Second, optical emission has been detected days after some short GRBs. Third, as a rule, anomalous bright GRBs are not detected by SWIFT, which is the main provider of information about the coordinates of GRBs with accuracies up to several arc minutes.

In 2005 and 2006, in cooperation with the Konus-Wind project, we carried out several surveys at an early stage (from several hours to several days), when the error boxes reached several tens of square degrees. The MASTER telescope is able to obtain frames of up to 360 square degrees to $18^m-19^m$ in an hour. For reliable transient searches, we usually use our standard three-frame scheme, taking three frames in a six-square-degree field of view sequentially over several minutes, and returning to the same area an hour or more later. This appreciably enhances the depth and reliability of the search and
Figure 7: Synthetic light curve for GRBs in the optical and gamma-ray normalized to the same redshift $z$ and gamma-ray flux, taking into account interstellar absorption. The width of the band has narrowed to $\Delta m = 6''3$ makes it possible to identify asteroids, including previously unknown ones, but decreases the survey speed to 60 square degrees per hour.

The MASTER robotic telescope uses two automated search algorithms: a search for optical transients not associated with known galaxies, and a search for supernovae, as unidentified objects in a frame near known galaxies from the HyperLeda catalog [123]. We will illustrate this method using our search for an optical transient from GRB 060425 [14] as an example.

| Date       | Time from GRB, days | Ref | Frame limit |
|------------|---------------------|-----|-------------|
| 26.04.2006 | 1.1                 | [13]| 17''5       |
| 27.04.2006 | 2.1                 | [12]| 17''5       |
| 30.04.2006 | 5.2                 |     | 17''8       |
| 03.05.2006 | 8.1                 |     | 17''6       |

The short, hard burst GRB 060425 was detected on April 25, 2006 at 16:57:40 UT by SWIFT BAT, Konus-Wind, Suzaku-WAM, RHESSI, and INTEGRAL-SPI-ACS [124]. A telegram with a refined error box 2.53 square degrees in size arrived on April 26, 2006 at 23:50:41 UT. The Konus-Wind group provided preliminary information on April 25 with a large error box having the form of a narrow area with a length of 7° (Fig. 10). This enabled a search of the error-box region to begin at 19:53:00 UT on April 26, 2006, 1.12 days after the GRB at twilight. We then repeated the error-box
Figure 8: Image of the region of the short burst GRB 051103 (the error box is shown) obtained from a sum of 30 MASTER frames. The limiting optical magnitude in a frame is $18.5^m$. An image of the error box can be found at [http://observ.pereplet.ru/images/GRB051103.4/sum36.jpg](http://observ.pereplet.ru/images/GRB051103.4/sum36.jpg).

survey on April 27 and 30 and May 3, 2006. The results of these searches are listed in Table 6.

Our reduction of these images provided an upper limit of $17^m$0 for the optical emission from GRB 060425 at the indicated times. In other words, no new objects were found in the GRB 060425 error box, in either the field or near known galaxies. However, in spite of this lack of success, we believe that this method is capable of yielding fruit in the near future.

**SEARCH FOR OPTICAL TRANSIENTS NOT ASSOCIATED WITH DETECTED GRBS (ORPHANED BURST).**

Searches for “orphaned” bursts is one of the most important tasks of modern astronomy. Bursts from such objects could be associated with GRBs that are “hurting past the Earth” or could be the result of other, completely new astrophysical processes.

Up to October 2006, we obtained roughly 80 000 images covering more than 90% of the accessible sky no fewer than six times (Fig. 11). In the reduced MASTER images (and also those obtained at other observatories), we encounter objects that have disappeared 40–50 min later, in the next series of frames. They are clearly not asteroids, comets, spacecraft, or other moving objects, and are not
associated with artefacts.

We have created a special section for the detection of short-lived optical objects in the MASTER database. The character of the sky survey (two series of three frames, separated by 40–50 min), enabled starting in June 2005 a continuous search for optical transients. With the aim of automating the process of distinguishing such objects and conducting more trustworthy analyses, we adopted information about the optical afterglows of GRBs as the basis for the expected behavior of such objects, which will enable us to place limits on the rate at which they appear.

According to the data [125], about 50% of GRBs are brighter than 18\textsuperscript{m} for the first 30 min after the burst onset. This suggests the following transient search criterion: a transient should be reliably detected in all frames in the first series of images (three frames with exposures of 30–60s), but not in any frame in the second series. This strategy will avoid classifying various types of artefacts (“hot” pixels, cosmic rays, etc.) as transients. The use of a continuously updated database on asteroids and other minor planets enables us to also exclude these objects from consideration as transients.

Unfortunately, we have thus far not been able to demonstrate a trustworthy detection of an orphan GRB. However, even this negative result can be used to place limits on the frequency of GRBs. Following [126], we will assume that a flash down to 17\textsuperscript{m} would be visible for 30 min. Since the surveys occur at different times with different seeing, the observations cannot all be considered to have equal weights. Therefore, we determined the limiting magnitude for each frame. The essence of the algorithm for estimating the limiting magnitude is to determine the magnitude for which there arises an appreciable difference in the number of stars in the frame and in the USNO–B catalog [127]. Objects that have the limiting magnitude found in this way have signal-to-noise ratios of seven and higher. To ensure trustworthiness in the results, the lowest of the limits in the frames was adopted outside a given area.

We can estimate the minimum solid angle in which we would expect not to observe a single flash brighter than 17\textsuperscript{m} during a year using the formula

\[
\omega = S \times 30\text{min} \times \sum_i e^{m_i - 17.5}
\]  

where \(\omega\) is the GRB frequency in (sq. deg.)year, \(S\) is the size of the field of view, and \(m_i\) the limiting magnitude in area \(i\). The field of view of the MASTER telescope after cutting off strips near the edge to filter out false objects at the frame edge is \(S = 6\) square degrees. The summation is carried out
Figure 10: Preliminary large error box for GRB 060425 (kindly presented by the Konus-Wind group) together with areas corresponding to the MASTER field of view (gray rectangles).

over all survey areas.

Fig. 12a and 12b illustrates the distribution of limiting magnitudes $m_i$ for our survey. The limit on the GRB frequency derived in this way using our data from the MASTER telescope is 1.21 (sq. deg.) year to $(1^\circ) \cdot \text{year to } 17^{m}.5$ Together with analogous results published by the ROTSE group in [126], the joint limit is 2.95 (sq.deg.) year.

SEARCH FOR SUPERNOVAE

In [128], the rate of cosmological supernovae was calculated based on a population-synthesis analysis (the “Scenario Machine”) for the first time. It was shown that the rates of formation and detection of distant supernovae depend directly on the fraction of baryonic matter in the Universe present in stars and the contribution of dark energy to the density of the Universe. For example, based on data already currently available, the most probable value for the dark-energy contribution can be estimated as $\Omega_\lambda = 0.7$.

It can be shown using the results of these calculations that, on average, in a six-square-degree field of view, the number of supernovae at any given time $N$ will be

\begin{equation}
N = 2 \cdot 10^{3(m-20)/5},
\end{equation}

where $m$ is the limiting magnitude for a frame in that part of the sky.

We emphasize that this estimate was obtained assuming an isotropic distribution of galaxies, and so is applicable for supernovae located at distances of more than 100 Mpc, i.e., for supernovae with maximum brightnesses fainter than $15^{m} - 16^{m}$. Note, for example, that the apparent magnitudes
of Type Ia supernovae located at redshifts $z \sim 1$ will be of the order of $20^m$ (without including absorption). This shows that even a random survey of the sky using a wide-field telescope such as MASTER can lead to the discovery of a substantial number of supernovae.

This is especially important in connection with the study of distant Type Ia supernovae carried out in [129]. It was shown that the distances to distant galaxies determined from the estimated maximum brightnesses of Type Ia supernovae occurring in them were larger than the distances obtained from the redshifts of lines in their spectra (the Hubble law). This can be interpreted as evidence for the presence of a vacuum energy (dark energy) that leads to an acceleration of the expansion of the Universe. It is striking that the contribution of the vacuum energy increases with time, becoming substantial at redshifts $z < 1$, so that any observations of supernovae with magnitudes brighter than $20^m$, are important for verifying this important discovery.

This last circumstance gave birth to a boom in supernova searches. Currently, several hundred supernovae are discovered at various observatories around the world each year. However, as a rule, these searches are conducted using telescopes with small fields of view (less than one square degree) and lists of galaxies that lead to certain selection effects. For example, as a rule, the observations concentrate on bright, giant galaxies, while the much more numerous dwarf galaxies are largely omitted from the search. Therefore, it is of considerable interest to carry out a random search for supernovae using a wide-field system such as MASTER.

We wrote a specialized program package for the reduction of images to search for supernovae. Searching for unidentified objects in a frame containing more than 10,000 stars that are observed against a non-uniform Galactic background is a complex algorithmic task, which we have been able to solve successfully.

When searching for new objects during a sky survey with the MASTER system, all known and unknown objects are distinguished automatically using the program package we have devised. Searching for supernovae in an automated fashion essentially translates to identifying new objects near known galaxies. The situation is greatly complicated by the incompleteness of existing catalogs and the presence of false objects in these catalogs. The general scheme for finding supernovae in images that
Figure 12: Distribution of limiting magnitudes $m_i$ for the (a) first and (b) second pass of a sky survey by the MASTER telescope.

have passed through the preliminary data processing is as follows: (1) distinguish the signals of stellar objects above the Galactic background, (2) compare the coordinates and magnitudes of these objects with those for objects in catalogs, (3) if this area of sky has already been observed by the MASTER telescope, compare any new objects with those distinguished in the previous survey — if there is no known object at the coordinates of a new object, it is taken to be a possible supernova. The most complex part of this search procedure is distinguishing the object against the Galactic background and distinguishing between regions of star formation and of supernovae.

Our survey of clusters of galaxies proved to be efficient: we detected many supernovae in our fields that had been discovered several days earlier. Due to the deterioration of seeing in the area surrounding Moscow in recent years, our rate of discovery of supernovae is not very high; nevertheless, the MASTER telescope has already discovered three supernovae, two of them of Type Ia. These are the first supernovae discovered on Russian territory.

We will now consider the supernovae discovered by the MASTER telescope in more detail.

**2005bv** This was the first supernova discovered in Russia [130]. Fig. 14 shows the discovery frame for SN 2005bv. It was discovered on April 28, 2005 as a result of the first survey by the MASTER telescope, carried out over clusters of galaxies. SN 2005bv is a Type Ia supernova with the coordinates: $R.A.(2000) = 14^h24^m07^s44$, $Dec.(2000) = +26^\circ17'50''.3$, The supernova magnitude on the day it was discovered was 16.8$m$ (in a band close to $R$). The supernova is located 11'' East and 9'' South of the galaxy PGC 1770866. The distance to SN 2005bv was measured in [131] based on galactic HII regions; its redshift corresponds to a recessional velocity of 10 400 km/s.

**2005ee** This supernova was discovered on August 26, 2005; its magnitude on the day it was discovered was 16.0$m$ (in a band close to $R$). It is a Type II supernova [132] that exploded in the galaxy PGC 73054 [133]. Its coordinates are $R.A.(2000) = 23^h57^m55^s83$, $Dec.(2000) = +32^\circ38'08''.9$, SN 2005ee is located 3'' West and 5'' North of the center of PGC 73054 (its redshift corresponds to 9730 km/s). The first estimates of its absolute magnitude indicated that SN 2005ee is among the most powerful of Type II supernovae that have been studied in detail. Our long series of observations testifies to the anomalously powerful plateau of this supernovae. More detailed data and our theoretical interpretation will be published separately Fig. 14 presents the discovery frame for SN 2005ee.
measured magnitudes and light curve are shown in Table. 7 and on Fig. 15.

2006ak This supernova was discovered on August 26, 2005; its magnitude on the day it was discovered was 16.0$^m$ (in a band close to R). It is a Type II supernova [132] that exploded in the galaxy PGC 73054 [133]. Its coordinates are $R.A.(2000) = 11^h 09^m 32.83^s$, $Dec.(2000) = +28.3750.3'$, North of the galaxy PGC 083454 (the redshift corresponds to 11150 km/s [135]). The MASTER telescope obtained four images of SN 2006ak (Table. 8).

2006X In addition to the three supernovae listed above, we obtained an image of the very bright supernova SN 2006X in the galaxy M100 during our survey, before the publication of its discovery [136]. Its magnitude at epoch 06.06162 in February 2006 was 16$^m$.2 ± 0$^m$.3. Our data point was the second to be obtained on the rising branch of the Type Ia supernova SN 2006X. Fig. 17 presents the photometric light curve, and Table 9. On Fig. 18 presents an image of SN 2006X near maximum brightness.

The discovery of supernovae using the MASTER telescope enables us to estimate the efficiency of random searches for supernovae using wide-field systems. According to our estimates, a telescope
Figure 15: Decrease in brightness of SN 2005ee. The scale to the left shows the instrumental magnitude, and the scale to the right the absolute magnitude.

Table 7: Brightness of SN 2005ee.

| Date (JD)   | Magnitude | Uncertainty |
|------------|-----------|-------------|
| 2453608.43819 | 16\text{''}53 | 0\text{''}04 |
| 2453615.43489 | 16\text{''}80 | 0\text{''}03 |
| 2453672.31788 | 17\text{''}01 | 0\text{''}06 |
| 2453675.15890 | 16\text{''}98 | 0\text{''}02 |
| 2453693.27430 | 17\text{''}05 | 0\text{''}02 |
| 2453704.13819 | 17\text{''}44 | 0\text{''}07 |

with a diameter of 40–50 sm and a field of view of six square degrees located under favorable seeing conditions (for example at a height of 2000 m near Kislovodsk) should be able to discover up to 100 supernovae per year. The MASTER-IV system (four telescopes of the same type with an overall field of view of 24 square degrees) would be able to discover up to 500 supernovae per year, making it possible to determine the contribution of dark energy to the total mass of the Universe after two to three years of observations.

CONCLUSION

We have presented the results of observations obtained on the MASTER robotic telescope in 2005–2006, which is the only telescope of its kind in Russia. These results include the first observations of optical emission from the gamma-ray bursts GRB 050824 and GRB 060926. Our data together with observations made later yield a brightness-variation law for GRB 050824 of $t^{-0.55\pm0.05}$. During a survey, more than 90% of the accessible sky to 19" is observed and reduced, and a database created. We have been able to place limits on the rate of optical flashes that are not associated with GRBs, as well as on the beaming angle for GRBs. We can place a limit on the rate of detection of GRBs to 17\text{''}5, which corresponds to 1.2 (sq. deg.) year. We have also discovered three supernovae: SN 2005bv.
Figure 16: Discovery frame for the supernova SN 2006ak

Table 8: Brightness of SN 2006ak.

| Date (day in February 2006) | Magnitude | Uncertainty | Limiting magnitude in frame | Comments |
|-----------------------------|-----------|-------------|-----------------------------|----------|
| 08d990                      | 17.0      | 0.3         | 17.2                        | before discovery |
| 17d970                      | 15.8      | 0.1         | 17.5                        | discovery  |
| 17d996                      | 15.8      | 0.1         | 17.5                        |          |
| 17d951                      | 15.8      | 0.1         | 17.5                        |          |

(Type Ia), which is the first supernova discovered on Russian territory, the powerful Type II supernova SN 2005ee, and SN 2006ak (Type Ia).

Our experience of two years of operation of the MASTER wide-field robotic telescope has demonstrated its unique capabilities. If such systems could be installed at suitable sites at various hour angles across Russia, they would provide unique information via continuous monitoring of both the near and distant cosmos.

The authors thank the General Director of the “OPTIKA” Association S.M. Bodrov for providing the MASTER project with necessary expensive equipment. This work was partially supported by the Russian Foundation for Basic Research (project code 04-02-16411-a). The authors are grateful to Dr. V.L. Afanasiev for useful discussions of the idea behind the experiment and for kindly presenting us with a prism, and also to the Konus-Wind group, and, in particular, V. D. Palshin, for collaborative work. We also wish to thank the INET Internet provider (http://inetcomm.ru/) for free access to the Internet for the MASTER system in the Vostryakovo village in Domodedovo, Moscow region.
Figure 17: Light curve of SN 2006X.

Figure 18: Supernova SN 2006X (near maximum brightness) in the galaxy M100
Table 9: Brightness of SN 2006X.

| JD          | Date (JD) | JD          | Magnitude | JD          | Magnitude |
|-------------|-----------|-------------|-----------|-------------|-----------|
| 2453772.5618 | 15.974    | 2453803.5534 | 14.173    | 2453849.3443 | 15.914    |
| 2453772.5626 | 15.960    | 2453803.5541 | 14.192    | 2453849.3450 | 15.861    |
| 2453775.4587 | 14.668    | 2453803.5549 | 14.134    | 2453849.3653 | 15.820    |
| 2453775.4595 | 14.714    | 2453812.4202 | 14.245    | 2453849.3660 | 15.916    |
| 2453775.4620 | 14.869    | 2453812.4212 | 14.271    | 2453849.3667 | 15.892    |
| 2453775.4632 | 14.676    | 2453812.4222 | 14.189    | 2453850.2783 | 15.869    |
| 2453775.4640 | 14.565    | 2453812.4901 | 14.205    | 2453850.2789 | 15.784    |
| 2453775.4648 | 14.921    | 2453813.2289 | 14.363    | 2453850.2794 | 16.073    |
| 2453775.4657 | 14.740    | 2453813.2307 | 14.361    | 2453850.2826 | 16.001    |
| 2453775.4666 | 14.894    | 2453813.2346 | 14.326    | 2453850.2833 | 15.781    |
| 2453775.4674 | 14.895    | 2453813.2405 | 14.382    | 2453850.2848 | 15.900    |
| 2453777.4437 | 14.411    | 2453815.3852 | 14.396    | 2453850.2987 | 15.947    |
| 2453777.4445 | 14.298    | 2453815.3870 | 14.383    | 2453850.2994 | 16.041    |
| 2453777.4618 | 14.311    | 2453815.3880 | 14.370    | 2453851.3209 | 15.983    |
| 2453777.4625 | 14.326    | 2453817.3577 | 14.520    | 2453851.3216 | 16.010    |
| 2453777.4633 | 14.315    | 2453817.3607 | 14.519    | 2453851.3425 | 15.954    |
| 2453777.4640 | 14.322    | 2453820.4075 | 14.789    | 2453851.3431 | 16.062    |
| 2453784.4029 | 13.602    | 2453820.4085 | 14.735    | 2453851.3438 | 15.931    |
| 2453784.4039 | 13.690    | 2453820.4094 | 14.741    | 2453853.3701 | 16.059    |
| 2453795.3588 | 13.896    | 2453820.4271 | 14.770    | 2453853.3708 | 15.986    |
| 2453795.3717 | 13.909    | 2453820.4281 | 14.761    | 2453853.3717 | 16.231    |
| 2453795.3726 | 13.905    | 2453820.4299 | 14.745    | 2453853.3962 | 15.987    |
| 2453795.3734 | 13.948    | 2453822.4769 | 14.862    | 2453853.3976 | 15.835    |
| 2453795.3762 | 13.927    | 2453822.4778 | 14.847    | 2453854.3684 | 16.004    |
| 2453798.4338 | 14.105    | 2453822.4799 | 14.885    | 2453854.3690 | 16.116    |
| 2453798.4364 | 14.120    | 2453831.4717 | 15.285    | 2453854.3902 | 15.985    |
| 2453798.4391 | 14.099    | 2453831.4726 | 15.287    | 2453855.4066 | 15.833    |
| 2453801.4549 | 14.184    | 2453831.4736 | 15.247    | 2453856.3672 | 16.063    |
| 2453801.4586 | 14.195    | 2453831.5024 | 15.251    | 2453856.3679 | 15.857    |
| 2453801.4604 | 14.158    | 2453845.3354 | 15.764    | 2453856.3686 | 16.082    |
| 2453801.5072 | 14.182    | 2453845.3362 | 15.756    | 2453856.3867 | 16.133    |
| 2453801.5080 | 14.186    | 2453845.3561 | 15.750    | 2453856.3874 | 16.032    |
| 2453801.5089 | 14.157    | 2453845.3568 | 15.832    | 2453856.3881 | 16.150    |
| 2453802.3225 | 14.222    | 2453845.3576 | 15.823    | 2453857.3728 | 16.338    |
| 2453802.4249 | 14.192    | 2453846.3363 | 15.647    | 2453857.3735 | 16.200    |
| 2453802.4289 | 14.169    | 2453846.3377 | 15.811    | 2453857.3988 | 16.054    |
| 2453803.4530 | 14.166    | 2453846.3537 | 15.716    | 2453857.3998 | 16.219    |
| 2453803.4540 | 14.126    | 2453848.3293 | 15.864    | 2453857.4009 | 16.276    |
| 2453803.5519 | 14.125    | 2453848.3300 | 15.841    | 2453860.3159 | 16.518    |
| 2453803.5526 | 14.230    | 2453848.3503 | 15.792    | 2453860.3169 | 16.349    |
References

[1] V. Lipunov, V. Kornilov, A. Krylov et al., Astrophysics, 48, 389 (2005)
[2] V. Lipunov, A. Krylov, V. Kornilov et al., Astron. Nachr., 325, 580 (2004)
[3] S.A. Yost, F. Aharonian, C.W. Akerlof et al., Astron. Nachr., 327, 803 (2006)
[4] S.D. Barthelmy, P. Butterworth, T.L. Cline et al., Astrophys. Space Sci., 231, 235 (1995)
[5] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 5901, 1 (2006)
[6] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 5619, 1 (2006)
[7] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 5613, 1 (2006)
[8] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 5303, 1 (2006)
[9] V. Lipunov, V. Kornilov, N. Tyurina et al., GRB Coordinates Network, Circular Service, 5056, 1 (2006)
[10] V. Lipunov, V. Kornilov, N. Tyurina et al., GRB Coordinates Network, Circular Service, 5032, 1(2006)
[11] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 5020, 1 (2006)
[12] V. Lipunov, V. Kornilov, N. Tyurina et al., GRB Coordinates Network, Circular Service, 5026, 1 (2006)
[13] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 5008, 1 (2006)
[14] V. Lipunov, V. Kornilov, N. Tyurina et al., GRB Coordinates Network, Circular Service, 5080, 1 (2006)
[15] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4988, 1 (2006)
[16] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4892, 1 (2006)
[17] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4888, 1 (2006)
[18] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4767, 1 (2006)
[19] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4765, 1 (2006)
[20] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4741, 1 (2006)
[21] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4718, 1 (2006)
[22] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4572, 1 (2006)
[23] V. Lipunov, V. Kornilov, A. Krylov et al., GRB Coordinates Network, Circular Service, 4549, 1 (2005)
[24] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4485, 1 (2006)
[25] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4198, 1 (2005)
[26] V. Lipunov, V. Kornilov, D. Kuvshinov, et al., GRB Coordinates Network, Circular Service, 4206, 1 (2005)
[27] S. Golenetskii, R. Aptekar, E. Mazets et al., GRB Coordinates Network, Circular Service, 4197, 1 (2005)
[28] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4197, 1 (2005)
[29] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4171, 1 (2005)
[30] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4173, 1 (2005)
[31] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4182, 1 (2005)
[32] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4119, 1 (2005)
[33] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 4118, 1 (2005)
[34] V. Lipunov, V. Kornilov, N. Tyurina et al., GRB Coordinates Network, Circular Service, 4082, 1 (2005)
[35] V. Lipunov, V. Kornilov, N. Tyurina et al., GRB Coordinates Network, Circular Service, 4083, 1 (2005)
[36] V. Lipunov, V. Kornilov, N. Tyurina et al., GRB Coordinates Network, Circular Service, 4086, 1 (2005)
[37] V. Lipunov, V. Kornilov, A. Krylov et al., GRB Coordinates Network, Circular Service, 3886, 1 (2005)
[38] V. Lipunov, V. Kornilov, A. Krylov et al., GRB Coordinates Network, Circular Service, 3883, 1 (2005)
[39] V. Lipunov, V. Kornilov, A. Krylov et al., GRB Coordinates Network, Circular Service, 3870, 1 (2005)
[40] V. Lipunov, V. Kornilov, N. Tyurina et al., GRB Coordinates Network, Circular Service, 3869, 1 (2005)
[41] V. Lipunov, V. Kornilov, A. Krylov et al., GRB Coordinates Network, Circular Service, 3882, 1 (2005)
[42] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 3769, 1 (2005)
[43] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 3767, 1 (2005)
[44] V. Lipunov, V. Kornilov, D. Kuvshinov et al., GRB Coordinates Network, Circular Service, 3755, 1 (2005)
[45] V. Lipunov, A. Krylov, V. Kornilov et al., GRB Coordinates Network, Circular Service, 3221, 1 (2005)
[46] V. Lipunov, A. Krylov, V. Kornilov et al., GRB Coordinates Network, Circular Service, 3188, 1 (2005)
[70] C.W. Akerlof, T.A. McKay, GRB Coordinates Network, Circular Service, 205, 1 (1999)
[71] D.W. Fox, GRB Coordinates Network, Circular Service, 1564, 1 (2002)
[72] M. Uemura, R. Ishioka, T. Kato et al., GRB Coordinates Network, Circular Service, 1566, 1 (2002)
[73] P.A. Price, D.W. Fox, GRB Coordinates Network, Circular Service, 1733, 1 (2002)
[74] P. Wozniak, W.T. Vestrand, D. Starr et al., GRB Coordinates Network, Circular Service, 1757, 1 (2002)
[75] H.S. Park, G. Williams, S. Barthelmy, GRB Coordinates Network, Circular Service, 1736, 1 (2002)
[76] D.A. Smith, C.W. Akerlof, R. Quimby, GRB Coordinates Network, Circular Service, 2338, 1 (2003)
[77] S.A. Yost, D.A. Smith, E.S. Rykoff et al., GRB Coordinates Network, Circular Service, 2776, 1 (2004)
[78] D.B. Fox, GRB Coordinates Network, Circular Service, 2741, 1 (2004)
[79] W. Li, A.V. Filippenko, R. Chornock et al., GRB Coordinates Network, Circular Service, 2748, 1 (2004)
[80] H. Fukushi, M. Isogai, Y. Urata, GRB Coordinates Network, Circular Service, 2767, 1 (2004)
[81] S. Maeno, E. Sonoda, Y. Matsuo et al., GRB Coordinates Network, Circular Service, 2772, 1 (2004)
[82] K. Kimugasa, K. Torii, GRB Coordinates Network, Circular Service, 2832, 1 (2004)
[83] R.M. Quimby, E.S. Rykoff, B.E. Schaefer et al., GRB Coordinates Network, Circular Service, 3135, 1 (2005)
[84] E. Rykoff, B. Schaefer, R. Quimby, GRB Coordinates Network, Circular Service, 3116, 1 (2005)
[85] E.S. Rykoff, S.A. Yost, D.A. Smith, GRB Coordinates Network, Circular Service, 3165, 1 (2005)
[86] R. McNaught, P.A. Price, GRB Coordinates Network, Circular Service, 3163, 1 (2005)
[87] S.A. Yost, H. Swan, B.A. Schaefer et al., GRB Coordinates Network, Circular Service, 3322, 1 (2005)
[88] A. Gomboc, I. A. Steele, A. Monfardini et al., GRB Coordinates Network, Circular Service, 3324, 1 (2005)
[89] E.S. Rykoff, S.A. Yost, H. Swan et al., GRB Coordinates Network, Circular Service, 3468, 1 (2005)
[90] K. Torii, M. Bendaniel, GRB Coordinates Network, Circular Service, 3470, 1 (2005)
[91] A. Klotz, M. Boer, J.L. Atteia, GRB Coordinates Network, Circular Service, 3473, 1 (2005)
[92] A. Sota, A.J. Castro-Tirado, S. Guziet al., GRB Coordinates Network, Circular Service, 3705, 1 (2005)
[93] A. Gomboc, C. Guidorzi, I. Steele et al., GRB Coordinates Network, Circular Service, 3706, 1 (2005)
[94] A. Klotz, M. Boer, J.L. Atteia, GRB Coordinates Network, Circular Service, 3720, 1 (2005)
[95] Y. Damerdji, A. Klotz, M. Boer et al., GRB Coordinates Network, Circular Service, 3741, 1 (2005)
[96] D.B. Fox, S.B. Cenko, GRB Coordinates Network, Circular Service, 3829, 1 (2005)
[97] S.B. Cenko, D.B. Fox, GRB Coordinates Network, Circular Service, 3834, 1 (2005)
[98] J. Wren, W.T. Vestrand, P. Wozniak et al., GRB Coordinates Network, Circular Service, 3929, 1 (2005)
[99] M. Jelinek, A.J. Castro-Tirado, A. de Ugarte Postigo et al., GRB Coordinates Network, Circular Service, 3929, 1 (2005)
[100] A. Klotz, M. Boer, J.L. Atteia, GRB Coordinates Network, Circular Service, 3917, 1 (2005)
[101] S.B. Cenko, D.B. Fox, E. Berger, GRB Coordinates Network, Circular Service, 3944, 1 (2005)
[102] S. Piranomonte, L. Calzoletti, P. D’Avanzo et al., GRB Coordinates Network, Circular Service, 3953, 1 (2005)
[103] W. Li, GRB Coordinates Network, Circular Service, 3945, 1 (2005)
[104] K. Torii, GRB Coordinates Network, Circular Service, 3943, 1 (2005)
[105] J. Kirschbrowm, C. MacLeod, D. Reichart et al., GRB Coordinates Network, Circular Service, 3947, 1 (2005)
[106] D.T. Durig, N.P. McLarty, J.R. Manning, GRB Coordinates Network, Circular Service, 3950, 1 (2005)
[107] E.S. Rykoff, S.A. Yost, W. Rujopakarn, GRB Coordinates Network, Circular Service, 4011, 1 (2005)
[108] E.S. Rykoff, S.A. Yost, W. Rujopakarn et al., GRB Coordinates Network, Circular Service, 4012, 1 (2005)
[109] M. Andreev, A. Pozanenko, GRB Coordinates Network, Circular Service, 4016, 1 (2005)
[110] M. Andreev, A. Pozanenko, V. Loznikov et al., GRB Coordinates Network, Circular Service, 4048, 1 (2005)
[111] E.S. Rykoff, B. Schaefer, W. Rujopakarn et al., GRB Coordinates Network, Circular Service, 4211, 1 (2005)
[112] B.E. Schaefer, E.S. Rykoff, W. Rujopakarn et al., GRB Coordinates Network, Circular Service, 4214, 1 (2005)
[113] M. Jelinek, A. de Ugarte Postigo, A.J. Castro-Tirado et al., GRB Coordinates Network, Circular Service, 4227, 1 (2005)
[114] P.R. Wozniak, W.T. Vestrand, J. Wren et al., GRB Coordinates Network, Circular Service, 4239, 1 (2005)
[115] P.A. Milne, G.G. Williams, H.S. Park et al., GRB Coordinates Network, Circular Service, 4218, 1 (2005)
[116] N. Mirabal, J.P. Halpern, S. Tonnesen, GRB Coordinates Network, Circular Service, 4215, 1 (2005)
[117] W. Rujopakarn, H. Swan, E.S. Rykoff et al., GRB Coordinates Network, Circular Service, 4247, 1 (2005)
[118] E.S. Rykoff, W. Rujopakarn, H. Swan et al., GRB Coordinates Network, Circular Service, 4251, 1 (2005)
[119] C.G. Mundell, E. Rol, C. Guidorzi et al., GRB Coordinates Network, Circular Service, 4250, 1 (2005)
[120] P. Milne, G. Williams, H.-S. Park et al., GRB Coordinates Network, Circular Service, 4252, 1 (2005)
[121] W. Li, GRB Coordinates Network, Circular Service, 4254, 1 (2005)
[122] I.A. Smith, H.F. Swan, GRB Coordinates Network, Circular Service, 4267, 1 (2005)
[123] G. Paturel, C. Petit, P. Prugniel et al., Astron. Astrophys., 412, 45 (2003)
[124] J. Cummings, S. Barthelmy, N. Gehrels et al., GRB Coordinates Network, Circular Service, 5005, 1 (2006)
[125] D.Q. Lamb, G.R. Ricker, J.-L. Atteia et al., New Astron. Reviews, 48, 423 (2004)
[126] E.S. Rykoff, F. Aharonian, C.W. Akerlof et al., Astrophys. J., 631, 1032 (2005)
[127] D.G. Monet, S.E. Levine, B. Canzian et al., Astron. J., 125, 984 (2003)
[128] H.E. Jorgensen, V.M. Lipunov, I.E. Panchenko et al., Astrophys. J., 486, 110 (1997)
[129] S. Perlmutter, G. Aldering, G. Goldhaber et al., Astrophys. J., 517, 565 (1999)
[130] V. Lipunov, A. Krylov, V. Kornilov et al., IAU Circ., 8520, 1 (2005)
[131] M. Modjaz, R. Kirshner, P. Challis, IAU Circ., 8522, 1 (2005)
[132] J. Frieman, J. Barentine, V. Lipunov et al., IAU Circ., 8603, 1 (2005)
[133] M. Modjaz, R. Kirshner, P. Challis et al., IAU Circ., 8606, 2 (2005)
[134] N. Tyurina, V. Lipunov, V. Kornilov et al., IAU Circ., 8677, 1 (2006)
[135] S. Blondin, M. Modjaz, R. Kirshner et al., Central Bureau Electr. Telegrams, 408, 2 (2006)
[136] V. Lipunov, IAU Circ., 8677, 2 (2006)
Optical Observations of Gamma-Ray Bursts, the Discovery of Supernovae 2005bv, 2005EE, and 2006ak, and Searches for Transients Using the "MASTER" Robotic Telescope

V.M. Lipunov, V.G. Kornilov, A.V. Krylov, N.V. Tyurina, A.A. Belinski, E.S. Gorbovskoy, D.A. Kuvshinov

2 февраля 2008 г.

Аннотация

We present the results of observations obtained using the MASTER robotic telescope in 2005–2006, including the earliest observations of the optical emission of the gamma-ray bursts GRB 050824 and GRB 060926. Together with later observations, these data yield the brightness-variation law $t^{-0.55 \pm 0.05}$ for GRB 050824. An optical flare was detected in GRB 060926: a brightness enhancement that repeated the behavior observed in the X-ray variations. The spectrum of GRB 060926 is found to be $F_E \approx E^{-\beta}$, where $\beta = 1.0 \pm 0.2$. Limits on the optical brightnesses of 26 gamma-ray bursts have been derived, 9 of these for the first time. Data for more than 90 were taken and reduced in real time during the survey. A database has been composed based on these data. Limits have been placed on the rate of optical flares that are not associated with detected gamma-ray bursts, and on the opening angle for the beams of gamma-ray bursts. Three new supernovae have been discovered: SN 2005bv (type Ia), the first to be discovered on Russian territory, SN 2005ee — one of the most powerful type II supernovae known, and SN 2006ak (type Ia). We have obtained an image of SN 2006X during the growth stage and a light curve that fully describes the brightness maximum and exponential decay. A new method for searching for optical transients of gamma-ray bursts detected using triangulation from various spacecraft is proposed and tested.
Abstract

Optical observations of gamma-ray bursts, the discovery of supernovae 2005bv, 2005ee, 2006ak, search of transients at telescope-robot MASTER

V.M. Lipunov, V.G. Kornilov, A.V. Krylov, N.V. Tyurina, A.A. Belinskii, E.S. Gorbovskoy, D.A. Kuvshinov, P.A. Gritsyk, G.A. Antipov, G.V. Borisov, A.V. Sankovich, V.V. Vladimirov, V.I. Vysbornov, A.S. Kuznetsov

Sternberg astronomical institute, Moscow, Russia Moscow state university, Moscow, Russia

Moscow Union “Optic”, Moscow, Russia

The results of observations over 2005–2006 years at the robotic telescope MASTER are presented. There are the first in the world observation of optical emission of GRB050824 and GRB060926 gamma-ray bursts. Our data combined with more later one gives the law of brightness drop $t^{-0.55±0.05}$ for GRB050824. We discovered optical flare for GRB060926 around 500–700 sec. The power low spectral index ($F_E \sim E^{-\beta}$) is equal $\beta = 1.0 ± 0.2$. In the course of sky survey we have images of more than 90% possible sky. The virtual data-base and pipe-line was made. The limit to the orphan optical bursts rate is presented. We discovered 3 supernovae stars, they are the following: SN2005bv (Ia-type) is the first one, opened from Russian territory, SN2005ee is one of the most powerful among II-type supernovae, SN2006ak (Ia-type). New method of the OT search after IPN-triangulation gamma-observation is proposed and tested.
INTRODUCTION

The construction of robotic telescopes, which not only automatically acquire but also automatically process images and choose observing strategies, is a new and vigorously developing area in modern astronomy.

MASTER (Mobile Astronomy System of TeleScope Robots), the first robotic telescope in Russia, began to be created through the efforts of scientists at the Sternberg Astronomical Institute of Moscow State University and the Moscow Optika Association in 2002, and continues to be developed to the present [1, 2]. In its current form, the system has four parallel telescopes on an automated equatorial mount, capable of slewing at a rate of up to 6°/s (located near Domodedovo, Moscow region), and two very-wide-field cameras with separate mounts and domes, with one located on the Mountain Solar Station of the Pulkovo Observatory (near Kislovodsk), roughly 1500 km from the other (which is also near Domodedovo). The parameters of the telescopes and CCD arrays are given in [3].

The system whose characteristics are closest to the MASTER system (http://observ.pereplet.ru) is the American ROTSE-III system [3] (http://www.rotse.net). MASTER (photo ??) differs in its larger field of view and the presence of several telescopes on a single axis, which makes it possible to obtain images at several different wavelengths simultaneously. The main telescope, Telescope 1 (355 mm diameter, a modified Richter-Slevogt system initially invented by V. Yu. Terebzh) takes images in white light, and is the main search element of the system. An Apogee Alta U16 (4096 × 4096 pixels) is installed on this telescope, making it possible to obtain images in a six square degree field. A Sony video recorder is mounted on Telescope 2 (200 mm diameter, a Richter-Slevogt system constructed by G. V. Borisov), providing images to 13 ÷ 14m with a time resolution of 0.05 s. A prism is mounted at the focus of Telescope 3 (280 mm diameter, a Flugge system), providing spectra of objects to 13m in a 30′ × 40′.

The system whose characteristics are closest to the MASTER system is the American ROTSE-III system (http://www.rotse.net). MASTER (photo ??) differs in its larger field of view and the presence of several telescopes on a single axis, which makes it possible to obtain images at several different wavelengths simultaneously. The main telescope, Telescope 1 (355 mm diameter, a modified Richter-Slevogt system initially invented by V. Yu. Terebzh) takes images in white light, and is the main search element of the system. An Apogee Alta U16 (4096 × 4096 pixels) is installed on this telescope, making it possible to obtain images in a six square degree field. A Sony video recorder is mounted on Telescope 2 (200 mm diameter, a Richter-Slevogt system constructed by G. V. Borisov), providing images to 13 ÷ 14m with a time resolution of 0.05 s. A prism is mounted at the focus of Telescope 3 (280 mm diameter, a Flugge system), providing spectra of objects to 13m in a 30′ × 40′.

The field of view with a resolution of 50.4A (with a Pictor-416 camera). Telescope 4 (200 mm diameter, a Wright system constructed by A. V. Sankovich) is equipped with a filter cassette and SBIG ST-10XME camera. In addition, MASTER has a very-wide-field camera (50° × 60°), that covers the field of view of the HETE orbiting gamma-ray telescope, making it possible to obtain simultaneous observations with HETE to 9m using a separate automated scheme. This widefield equipment enables searches for bright, transient objects.

In the Summer of 2006, we installed a widefield camera (MASTER-VWF-Kislovodsk) on the Mountain Solar Station of the Main Astronomical Observatory in Pulkovo, making it possible to continuously monitor a 420-square-degree field of sky to 13m in a five second exposure.

Thus, we currently have three automated miniobservatories with the following equipment:

- Six telescopes and CCD arrays
- Three automated equatorial mounts.
- Three automated domes
- Two cloud-cover and temperature sensors
- One GPS receiver
- Six control and reduction computers

The Kislovodsk and Domodedovo systems are connected via the Internet, and are able to respond to the detection of uncataloged objects (optical transients) within several tens of seconds (including processing time). The results of observations using the MASTER network will be reported separately.

MASTER is able to operate in a fully automated regime: automatically, based on the ephemerides (sunset) and the presence of satisfactory weather conditions (the control computer is continuously attached to a weather sensor), the roof (above the main mount and wide-field camera) is opened,
the telescope is pointed at bright stars and pointing corrections introduced, and, depending on the seeing, it then either goes into a standby regime or begins a survey of the sky using a specialized, fully automated programme.

Thus, observations are conducted in two regimes: survey and alert (e.g. observation of the locations) of gamma-ray bursts based on coordinates obtained). In the former case, the telescope automatically takes three frames of an arbitrary region in succession, with exposures from 30 to 60 s, moves to a neighboring region $2^\circ$ away and carries out the same procedure, and so on, repeating a given set of three frames every 40-50 min. This makes it possible to avoid artefacts in the data processing, and to locate moving objects. The alert regime is supported by a continuous connection between the control computer and the GCN international gamma-ray burst (GRB) network [4] (http://gcn.gsfc.nasa.gov). After detection of a GRB by a space gamma-ray observatory (SWIFT, HETE, Konus-Wind, INTEGRAL etc.), the telescope obtains the coordinates of the burst region (the so-called coordinate error box), automatically points to this direction, obtains an image of this region, reduces this image, and identifies all objects not present in the computer catalogs. If a GRB is detected during the day, its coordinates are included in the observing program for the next night.

A special program package for image reduction in real time has been created, making it possible not only to carry out astrometry and photometry of a frame, but to recognize objects not contained in astronomical catalogs: supernovae, new asteroids, optical transients, and so forth.

Over the entire time observations have been obtained on the MASTER system (see the results for 2002-2004 in [1,2]), images have been obtained for 52 GRB error boxes. In 23 cases, these observations were the first in the world. In three cases, optical emission was detected (this was the earliest detection in Europe for GRB 030329, and the earliest in the world for the two cases reported here).

Note that, from February through August 2006, the main matrix of the search telescope was being repaired, so that the sky survey essentially was not conducted during this time.

**OBSERVATIONS OF GRBS IN 2005-2006**

Starting at the beginning of 2005 through October 2006, the Domodedovo MASTER station carried out observations of 31 GRBs (see [2]). In 16 cases, we obtained the first upper limits on the optical fluxes of the GRBs, i.e., fluxes brighter than which no optical candidate for the GRB was detected.

Note that, before 2005, only a few alerts for GRBs in the Moscow night-time sky in regions of sky accessible to MASTER were received from the SWIFT orbiting observatory, which provided more than 90% of all detected GRBs in 2005, with one of these occurring during rainy weather. Nevertheless, we were able to report the first optical detections in the world for two of these GRBs.

Unless otherwise indicated, we present instrumental magnitudes in white light. Our photometry was carried out in an automated regime using objects in the frame identified with stars in the USNO-A2.0 catalog [51] (there were usually about 2000 stars in a frame) and the combined USNO-A2.0. $R$ and $B$ magnitudes:

$$m = 0.89R + 0.11B$$

(1)

We chose this combination so that our instrumental magnitude was close to the $R$ magnitudes of minor planets, i.e., objects with solar spectra. As our observations show, these magnitudes are in poor agreement with the $R$ magnitudes of GRBs, due to the enhanced red sensitivity of the Apogee Alta U16 array.

The processing of a frame begins immediately after it is taken, and requires less than one minute. As a result, the robotic system can attempt to find unidentified objects within the error box and compose the text of a GCN telegram with the indicated brightness limit for an optical transient. In parallel, our full frame with the error box and an enlarged error box (usually $6 \div 8$ with an image of