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Research Article

MASTER Prompt and Follow-Up GRB Observations

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We presented the results of last years GRB observations obtained on the MASTER robotic telescope, which is the only telescope of its kind in Russia. These results include 5 prompt observations of GRB in 2008 and 2009, follow-up observations of 15 other GRBs in 2008-2009, the first observations in different polarization angles of optical emission from the gamma-ray bursts GRB091020, and observations in different polarization angles for GRB091127 and GRB090820.

1. Introduction

The construction of robotic telescopes, which not only automatically acquire but also automatically process images and choose observing strategies, is a rather new and vigorously developing area in modern astronomy. MASTER (Mobile Astronomy System of Telescope Robots, http://observ.pereplet.ru), which is the first and still unique robotic telescope network in Russia, was started 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 MASTER-NET [1–3].

MASTER is dedicated to the observation and detection of optical transients on time scales from few seconds to several days. The emphasis is on gamma-ray bursts (GRBs), the most powerful explosions in our Universe. 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 also to recognize objects lacking in astronomical catalogs: supernovae, new asteroids, optical transients, and so forth. This software allowed us to discover several supernovae: SN2008gy, SN 2006ak, SN2005ee, and SN 2005bv [4].

We observed 20 error boxes of gamma-ray bursts in 2008-2009 and report the results obtained. There are a total of five prompt observations made with very-wide-field cameras (VWFC) during the past half-year after we mounted these cameras in Kislovodsk and Irkutsk in autumn 2009.

2. MASTER System

MASTER network currently consists of six facilities deployed near Moscow (MASTER-Moscow), Kislovodsk, Irkutsk, Ekaterinburg (MASTER-Ural system), and Blagovesh'ensk (MASTER-Amur one) [3]. We have distant observatories for only a year and a half, and for about five years, observations have been made only with the Moscow telescope facility located in a village near Domodedovo airport. Its location close to Moscow State University allowed us to design, test, and modify the robot system, repair eventual technical faults, and develop reduction software with no financial support from the state. But the negative side is that we had to observe under poor weather conditions near megalopolis (less than

Figure 1: MASTER-II system in Kislovodsk observatory (D = 400 mm).

70 clear nights per year and most of them are summer white nights). However, we observed several tens of error boxes during five years (HETE and Swift epochs), and in most of the cases our observations were the earliest [2].

MASTER characteristics [3] are the closest to those of the American ROTSE-III network [5] (http://www.rotse.net/). MASTER differs in that its facilities have a larger field of view and several telescopes mounted on a single axis, allowing images to be taken at several different wavelengths simultaneously, as in the case of MASTER-Ural and MASTER–Kislovodsk observations.

Until 2008, most of the GRB observations were made with the MASTER-Moscow system, and we therefore report here its main properties.

The main telescope (with a 355 mm aperture) takes images in white light and serves as the main searching unit of the system. It has an Apogee Alta U16 (4096 × 4096 pixels) camera mounted on it, making it possible to obtain images in a six-square-degree field. In addition, MASTER has a very-wide-field camera ($50^\circ \times 60^\circ$) that covered the field of view of the HETE orbiting gamma-ray telescope and made it possible to obtain simultaneous observations with HETE down to a limiting magnitude of 9 m using a separate automated scheme. This wide-field facility is capable of searching for bright, transient objects exclusively.

MASTER-Kislovodsk allows us to take images of observed GRB in different wavelengths or in different polarizations simultaneously. This system has 2 main telescopes (D = 400 mm, [3], Figure 1) with filters. And we have very wide-field cameras (Figure 2) on the Mountain Solar Station of the Pulkovo Main Astronomical Observatory, allowing us to continuously monitor a 420-square-degree sky field down to 13 m with five-second exposures. We have also installed such cameras in *Irkutsk* and *Tunka systems*. MASTER-Tunka has also a main telescope (D = 400 mm). And now we have *MASTER-Amur* with a 200 mm aperture.

Tunka and Amur systems were mounted in October and November of 2009.

The Kislovodsk, Moscow, Ural, Irkutsk, and Amur facilities are linked via the Internet and are able to respond to the detection of uncatalogued objects (optical transients) within several tens of seconds (processing time included). The results of observations using the MASTER network will be reported separately.

All MASTER facilities can operate in a fully automated mode based on the ephemerides (sunset) provided there are satisfactory weather conditions: (the control computer is continuously attached to a weather sensor), the roofs (above the main mount and wide-field camera) are opened, the telescopes are pointed at bright stars, and pointing corrections are applied, and then, depending on the seeing, the facility 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 modes: survey and “alert” (e.g., observations of the already obtained coordinates of the gamma-ray bursts). In the former case, the main telescope automatically takes three frames of an arbitrary region in succession with exposures ranging from 30 to 60 s, moves to a neighboring region 2° away, performs the same procedure, and so on, repeating a given set of three frames every 40–50 minutes. Such a procedure makes it possible to avoid artefacts in the data processing and locate moving objects.

The alert mode is supported by a continuous connection between the control computer and the GCN international gamma-ray burst (GRB) network (http://gcn.gsfc.nasa.gov/). After detection of a GRB by a space gamma-ray observatory (Swift, Konus, Fermi etc.), the telescope receives the coordinates of the burst region (coordinate error box), automatically points to this direction, takes an image of this region, reduces the 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 developed, which is capable not only of performing astrometric and photometric reduction of a frame but also of recognizing objects not contained in astronomical catalogs: supernovae, new asteroids, optical transients, and so forth. Since the start of its operation, the MASTER system has taken the images for a lot of GRB error boxes (see the results of 2002–2006 observations in [1, 2, 4]). In half of the cases, these observations were the first in the world.

3. GRB Observations

We have observations of 20 GRBs in 2008-2009. The results of our prompt and follow-up observations are listed in Table 1.

We observed 80 GRB error boxes from 2002 to 2009 (20 in 2008-2009, 5 in 2007, 17 in 2006, 17 in 2005, 13 in 2004, 7 in 2003, and 1 in 2002). They represent the only 9 cases with optical counterpart. The reasons are the following: at the beginning of our observations we have a lot of technical problems (like with the Internet in our Moscow village with MASTER-I), then for about 5 years we observed only from Moscow region (with very bad astroclimatic conditions), and most of GRB in the first years of observations (mostly HETE results) came only in our day, so we could observe error-boxes only several hours later. But although we have the earliest observations in Europe of **GRB030329** and have 8 hours of continuous observations, we took the earliest images of **GRB050824.**

(a) (b)

Figure 2: There are 4 MASTER VWFCs located at Kislovodsk observatory.

Table 1: GRB observations by MASTER system in 2008-2009.

Burst	Optical limits, m	Comments (observatory, time after trigger information, exposures, circular number, etc.)
GRB091130B	15	MASTER-Amur, unfiltered image, 10-s exposures. The time delay is 40 s after the notice time (65 s after the GRB time). There is no OT brighter than 15 m at the Swift XRT position [6].
GRB091130	14.5	MASTER-Amur observations. 23 seconds after the notice time (7 min 22 s after the GRB time). We do not see OT brighter than 14 mag in BAT error box [7].
GRB091127	~14 mag	MASTER-II-Kislovodsk observed 9 seconds after notice time (91 s after the GRB time). OT images in both *polarizations* [8].
GRB091020	17.9 R	MASTER-II-Kislovodsk *has optical transient polarimetry* observed OT 3422 s after the GRB time in R and unfiltered. There are images in different polarization angles [9].
GRB090820	11	MASTER-Kislovodsk and Irkuts VWFC responded to Fermi trigger 272421498, 9 s after the GRB time. We took 1300 images with 5-second exposition *in different polarization angles* [10].
GRB090715B	**20**	MASTER-Moscow observations, 19 s after the GCN notice time (8 m 04 s after the burst). 160 images with 30-second expositions. No OT [11].
GRB090528B	R > 19.0 V > 18.1	MASTER-URAL, 7 hours after GRB, 180-s exposures in R and V filters. Our images cover 30% last 1-σ Fermi error box. No OT [12].
GRB090424	~8, ~9	*Prompt observations* by 6 MASTER VWFC in Kislovodsk and Irkutsk with common FOW = 6000 sq·deg., 1-s exposures. Unfiltered images (close to V band). No OT [13].
GRB090408B	17	MASTER-URAL, R and V 60-s exposure, starting after sunset (87 min after trigger time). No OT [14].
GRB090328B	9.1	*Prompt observations* at MASTER VWFC located at Irkutsk. 1-s exposures during night: before, during, and after GRB. No OT [15].
GRB090320B	V ~ 9.0	*Prompt observation* by MASTER VWFC located at Kislovodsk. We observed ~80% 1-σ Fermi error box with 1-s exposure during all night: before, during, and after GRB time. No OT [16].
GRB090305B	V ~ 9.5	*Prompt observation* by MASTER VWFC located at Kislovodsk observed ~80% 1-σ Fermi error box with 1-s exposure 7 hours before, during, and 1 hour after GRB time [17].
GRB081215A	V ~ 11	MASTER VWFC located at Kislovodsk observed Fermi trigger (SGR 0044+42) during all night with 5-s expositions [18].
GRB081130B	V ~ 12	*Prompt observation.* MASTER VWFC located at Kislovodsk observed Fermi trigger with 5-s exposures. No OT [19].
GRB081110	19	MASTER-Moscow observed error box 6 hours 42 minutes after the GRB time. We have 89 images with limit for coadded one up to 19 m (S/N = 4). No OT [20].
GRB081102	V ~ 13	2 of MASTER VWFC at Kislovodsk observed this error box with 5-s exposures during all night. There are two separated (~702 m) mount with double cameras [21]
GRB080822B	18.8	MASTER-Moscow observed his gamma-ray burst 18 m 43 s after the GRB time with 30-s exposures. Each image has 17 m. Summary image (25 × 30 s) has 18.8 m. The unfiltered images are calibrated relative to USNO A2.0 (0.8 R + 0.2 B) [22].
GRB080605	R ~ 11.5	MASTER VWFC at Kislovodsk observed it 46 s after the GRB time (12 s after the notice arrival time) with a series of 5-s exposures. Unfiltered (close to V). No OT [23]
GRB080319D	V ~ 11.5	MASTER VWFC at Kislovodsk observed Swift-BAT trigger with a series of 5-s exposures starting 92 s after notice arrival time (708 s after GRB time). Unfiltered (close to R, i.e., another camera). No OT [24].
GRB080205	19.5	MASTER-Moscow observed it 481 minutes after the GRB time. No OT [25].

Table 2: The result of the unfiltesred polarization.

West-telescope			East-telescope		
GRB time, hour	OT mag	error	GRB time, hour	OT mag	error
1.605	18.65	0.10	1.605	18.60	0.06
1.983	18.91	0.08	1.983	18.46	0.06
2.286	19.04	0.08	2.286	19.14	0.09
2.563	19.28	0.11	2.563	19.11	0.09
2.840	19.36	0.09	2.840	19.56	0.10
3.117	19.32	0.08	3.117	19.38	0.09
3.395	19.35	0.06	3.395	19.70	0.17
3.672	19.23	0.10	3.672	19.53	0.11
3.949	20.07	0.16	3.949	19.92	0.16
4.227	20.67	0.28	4.227	20.03	0.19
4.505	20.07	0.22	4.505	19.99	0.16

Table 3: The results of observations in 2007.

Burst	Optical limits, m	Comments (observatory, time after trigger information, exposures, circular number, etc.)
GRB071122	16	MASTER-Moscow observed it 151 s after the GRB time (61 s after notice time). No OT [35]
GRB070810.8	14.8	MASTER-Moscow observed it 125 s after the GRB time. No OT [36].
GRB070224	13	MASTER VWFC observed error box in Kislovodsk with series of 5-s exposures starting 2 s after notice arrival time. Unfiltered (close to R). No OT.
	18	MASTER-Moscow observed error box 51 s after notice arrivel time. Unfiltered. No OT [37].
GRB070223	13	MASTER VWFC observed error box in Kislovodsk 5-s exposures starting 1 s after notice arrival time. No OT. Unfiltered (close to R) [38].
GRB070219	13.5	MASTER VWFC observed error box in Kislovodsk 5-s exposures starting 76 s after the GRB time and 15 s after notice arrival time. No OT [39].

We obtained a total of **5** *prompt* observations with the very-wide-field cameras in Irkutsk and Kislovodsk stations during the past half-year (after we had mounted several VWFC cameras there): GRB090424, GRB090328B, GRB090320B, GRB090305B, and GRB081130B. We found no optical candidate in the reduced images, and we give only the optical limits for GRBs. And we have several GRB's observations *in different polarization angles* (**GRB091127**, **GRB091020**, and **GRB090820**).

If we found no optical counterpart in the reduced images, we give only the optical limits for GRBs, that is, there is no optical transient brighter than this limit.

Kislovodsk and Irkutsk VWFC had different cameras during 2008, and that is why we give V- and R-band data in the second column of the table. We have unfiltered images from these cameras, but they are the closest to V and R bands, and we calibrated them using Tycho catalogue [26]. We also calculate the ratio of optical to gamma fluence [26] for GRBs.

We detected several interesting GRBs during this two years, and we now briefly discuss them.

3.1. GRB091127. MASTER-II robotic telescope located at Kislovodsk has early optical transient polarimetry of this burst. System responded to the GRB 091027 [27] 9 seconds after notice time and 91 s after the GRB time at very large zenit distance (~4 degrees up to horizon). We have bright optical counterpart (~14 mag, 91–111 seconds after the GRB time) at Liverpool position [28] in both polarizations. We have ~20 images with synchronous exposition in two polarizations before GRB setting with growing exposition from 20 to 160 seconds. And we had possible brightening around 2 minutes (after GRB Time).

3.2. GRB091020. MASTER-II robotic telescope located at Kislovodsk was pointed to the GRB 091020 [29] by the Internet 3422 s after the GRB time. The large delay was caused with technical problems on site [30].

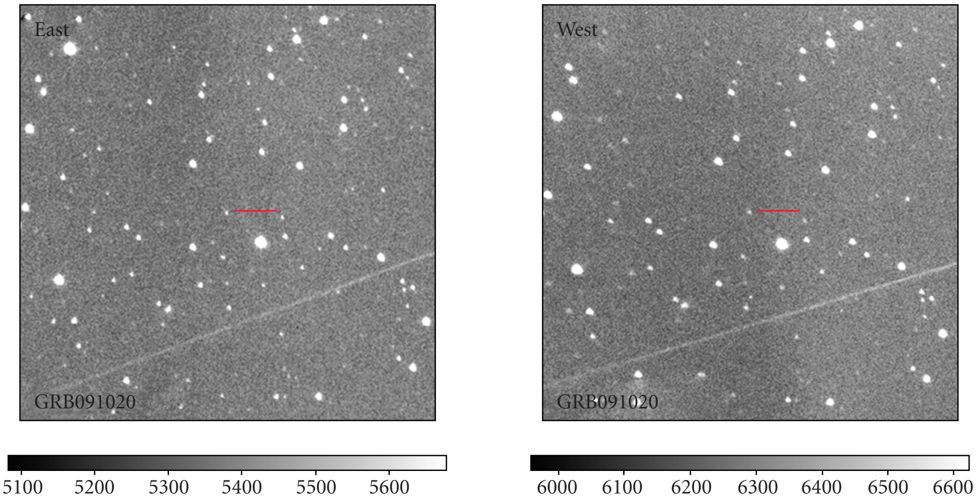
We have 2 *first images in different polarization angles* (East telescope and West one, Figure 3).

The first 7 images was taken in R-band. The exposure of each image is 180 s.

The result of the unfiltered polarization is in Table 1.

Using all our polarized magnitudes, we find that the light curve is very well described by a single power-law decay with alpha = 1.2 ± 0.1, that is in good agreement with the following observations [31].

The light curve of our observations is available at http://observ.pereplet.ru/images/GRB091020/grb.html.



(a) (b)

Figure 3: GRB091020 images.

3.3. GRB 090820. We had MASTER-Net optical polarization observations.

There are 6 MASTER very-wide-field cameras located at Kislovodsk and Irkutsk with common FOW = 2000 + 1680 square degrees observed this bright Fermi trigger [32].

MASTER VWFC, located in Kislovodsk, has produced images beginning at 9 s after the GRB time (first alert notice). We have 1300 images with 5-second exposition in *different polarization angles*. Individual images have limiting magnitudes ~11. Our unfiltered images are calibrated relative to Tycho stars (V) and very close to V-band.

3.4. GRB090715B. MASTER robotic telescope located at Moscow (D = 355 mm, Apogee Alta U16) responded to the GRB 090715B (Swift trigger, [33]). We have images beginning at 19 s after the GCN notice time. An automated response took the first image at 21:11:18 UT, 8 m 04 s after the burst, under summer Moscow sky.

We have 160 images with 30-second exposition each. These unfiltered images are calibrated relative to USNO 08.R + 0.2B (Usno A2.0). Individual images have limiting magnitudes ranging from 17.8 to 17.0.

No optical transient was found brighter 20.0.

3.5. GRB090305B-MASTER-Net Prompt Optical Short Burst Observations. We observed this burst by 6 MASTER very-wide-field cameras located at Kislovodsk and Irkutsk with common FOW = 6000 square degrees. One of the four MASTER very-wide-field Cameras located at Kislovodsk (D = 50 mm, 4 × 1000 square degrees, 11 Mpx) has observed ~80% 1-sigma Fermi error box [34] with 1-s exposure during all night: 7 hours before, during, and 1 hour after GRB time without time gap between images.

Our unfiltered images were calibrated relative to Tycho stars (V). The magnitude limit of each image is ~9.5 m at the edge of FOW. We do not detect OT inside the part of the error box brighter than 9.2 mag before and after trigger time. So we conclude (in the case that GRB is inside our FOW) that the optical fluence during the short 2- s GRBburst is limited by $\sim \leq 1 \times 10^{-8}$ erg/cm^2 (excluding possible host galaxy absorption).

3.6. Summary. There were 5 observations in 2007 with no optical counterpart, because we observed them by Moscow telescope and only VWFC in Kislovodsk, that was just mounted and worked in a half-tested mode.

4. Conclusions

We presented the results of last years GRB observations obtained on the MASTER robotic telescope, which is the only telescope of its kind in Russia. These results include 5 prompt observations of GRB in 2008 and 2009, follow-up observations of 15 other GRBs in 2008-2009, the *first* observations *in different polarization angles* of optical emission from the gamma-ray bursts GRB091020, and observations *in different polarization angles for* **GRB091127** *and* **GRB090820.**

Our experience of two years of operation of the MASTER wide-field robotic telescope has demonstrated its unique capabilities. We hope that new MASTER telescopes at Kislovodsk and Ural stations and also new Irkutsk and Blagoveschwnsk systems will justify our hopes. We have 3 optical counterparts in the last half of 2009. When such systems will 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.

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