# Mini-MegaTORTORA wide-field monitoring system with sub-second temporal resolution: observation of transient events

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**Abstract.** Here we present the summary of first years of operation and the first results of a novel 9-channel wide-field optical monitoring system with sub-second temporal resolution, Mini-MegaTORTORA (MMT-9), which is in operation now at Special Astrophysical Observatory on Russian Caucasus. The system is able to observe the sky simultaneously in either wide (~900 square degrees) or narrow (~100 square degrees) fields of view, either in clear light or with any combination of color (Johnson-Cousins B, V or R) and polarimetric filters installed, with exposure times ranging from 0.1 s to hundreds of seconds. The real-time system data analysis pipeline performs automatic detection of rapid transient events, both near-Earth and extragalactic. The objects routinely detected by MMT include faint meteors and artificial satellites.

## 1. Introduction

Mini-MegaTORTORA is a novel robotic instrument developed according to the principles of MegaTORTORA multi-channel and transforming design formulated by us earlier (Beskin et al. 2010a; Biryukov et al. 2015) in order to detect and characterize fast optical transients of various origins, both cosmological, galactic and near-Earth. The importance of such instruments became evident after the discovery and detailed study of the brightest ever optical afterglow of a gamma-ray burst, GRB080319B (Beskin et al. 2010b).

It is a 9-channel wide-field (~900 square degrees) monitoring system with temporal resolution of 0.1 seconds and limit down to V~11 mag. Every channel of Mini-MegaTORTORA has 10x10 deg field of view and is equipped with installable photometric and polarimetric filters and coelostat mirror for a rapid repointing in a limited range. It allows to re-configure the system on the fly in order to rapidly follow-up the transients just detected.
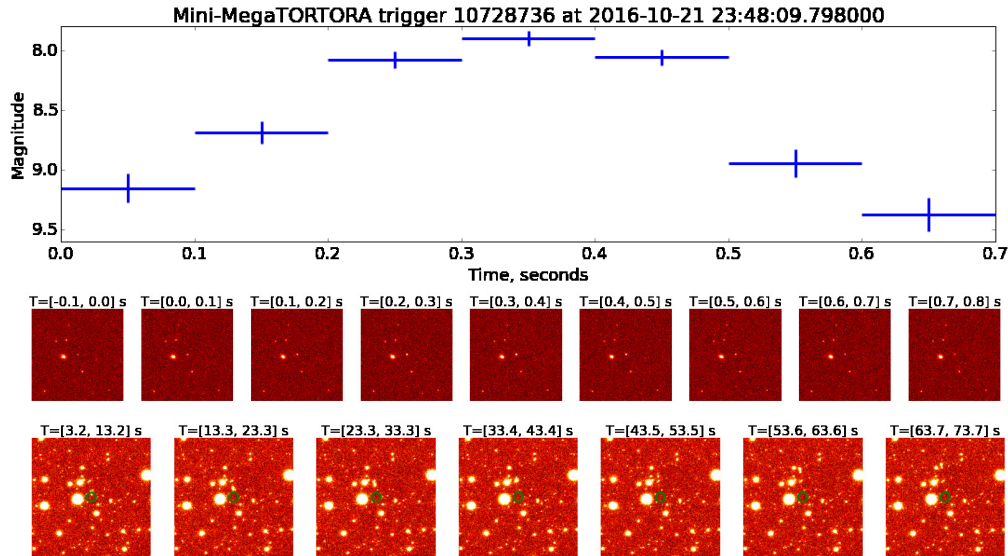
Figure 1.    Example of a rapid optical flash independently detected and followed-up by Mini-MegaTORTORA and not identified with satellites from NORAD database. Upper panel – light curve with 0.1 s temporal resolution, middle panel – corresponding detection images (50x́ 50áround the event), lower panel – follow-up images with 10 s exposures that clearly reveal slowly moving satellite.

## 2.   Untriggered search for rapid optical flashes

Mini-MegaTORTORA started its operation in Jun 2014, and since then continuously monitors the sky looking for fast optical transients. Its real-time transient detection system routinely extracts various kinds of transient from the data stream – rapid flashes, meteors, satellites etc. Data on detected transients are published online[1].

Transient detection software matches rapid flashes with stellar catalogues to exclude scintillation effects and with NORAD database of satellite orbits to filter out satellite flashes. Some fraction of detected flashes are not identified with satellites, but most probably are of satellite origin. Immediate follow-up observations using Mini-MegaTORTORA rapid reaction mode (seel Figure 1) typically reveal faint satellite trails. Durations and shapes of such flashes (Figure 2) are also consistent with satellite ones. Therefore we may conclude that no bright rapid flashes of astrophysical origin are detected in 2.5 years of Mini-MegaTORTORA operation.

## 3.   Follow-up observations of external triggers

Mini-MegaTORTORA also performs follow-up of Swift, Fermi and LIGO-Virgo triggers, including the ones with poor localization accuracy due to its large field of view allowing for simultaneous observations in  900 sq.deg. sky fields. For the triggers with

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[1]Public databases of meteors (Karpov et al. 2016b) and artificial satellites observed by Mini-MegaTORTORA are available at project website at http://mmt.favor2.info
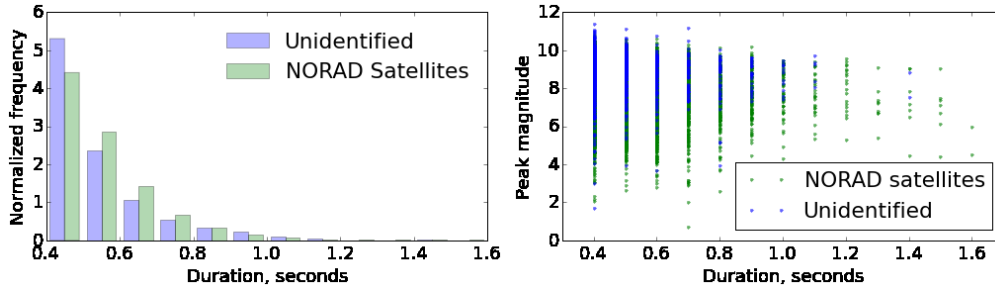
Figure 2.    Comparison of durations (left panel) and brightness (right panel) of rapid flashes detected by Mini-MegaTORTORA and identified/non-indentified with NORAD satellites.
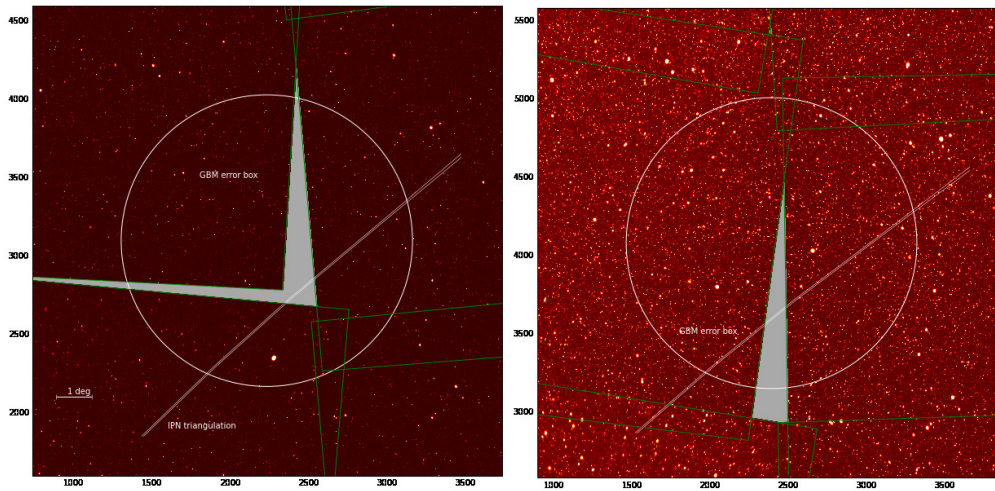


Figure 3.    The error box of Fermi GRB 151107B during the trigger as observed by several channels of Mini-MegaTORTORA during its routine monitoring of the sky (left panel) and during the wide-field follow-up (right panel).

better localizations, multicolor and/or polarimetric follow-up is performed. Since mid-2015, 4 of 89 Swift GRBs have been followed up in polarimetric mode in 30 to 60 seconds since trigger distribution through GCN network, with no optical emission detections. 9 of 250 Fermi GBM triggers have been also followed up in wide-field mode in 20 to 90 seconds from the trigger. All other events were either below the horizon or occurred in bad weather conditions.

The localization of Fermi GBM trigger GRB 151107B Karpov et al. (2015) has been observed before, during and just after the trigger time, covering nearly all its error box (see Figure 3) simultaneously since T-329.3 s till T+25.7 (including brightest part of first gamma-ray peak) with temporal resolution of 0.1 s in white light. Dedicated real-time transient detection pipeline did not detect any events longer than 0.3 s and brighter than approximately V=10.5 mag. Inspection of co-added images with 10 s effective exposure has not revealed any variable source down to V=12.0 mag during that interval.

Trigger LVC_194575 at 2015-10-22 13:33:19.942000
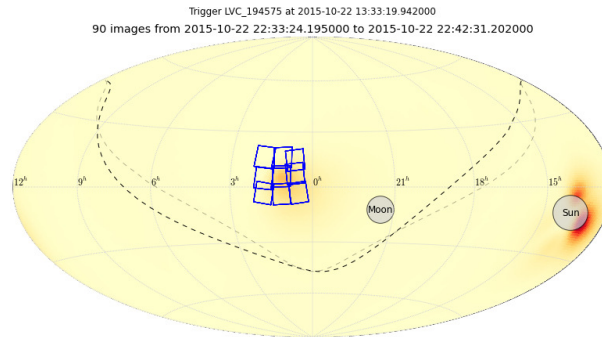90 images from 2015-10-22 22:33:24.195000 to 2015-10-22 22:42:31.202000

Figure 4.    Follow-up observations of LVT 151012 gravitational wave trigger.

After receiving GCN trigger the system initiated a wide-field follow-up and since T+62.7 s (during the continuing gamma-ray activity) till T+666.7 s acquired 20x9 deep images with 30 s exposures in a 30x30 degree field of view covering the whole final 1-sigma localization box. Analysis of the acquired data has not revealed any variable object down to roughly V=13.5 mag over the time interval Karpov et al. (2015).

One more Fermi event, GRB 160625B, has been followed up in the widefield regime, with bright optical flash of GRB 160625B clearly detected during the gamma activity (Karpov et al. 2016a).

Mini-MegaTORTORA performed follow-up observations of LVC trigger G194575 (LVT 151012) 9 hours after the event under bad weather conditions. 10x60-s exposures in a 900 sq.deg. field have been acquired in order to detect any new or variable object in anti-Sun lobe of trigger probability map (see Figure 4). Further observations have been interrupted due to heavy clouds. No transient object has been detected down to V~13.5 mag.

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