

THE FIRST LIGHT OF Mini-MegaTORTORA WIDE-FIELD MONITORING SYSTEM

A. Biryukov^{1,4}, G. Beskin^{2,4}, S. Karpov^{2,4}, S. Bondar³, E. Ivanov³, E. Katkova³, A. Perkov^{3,4} and V. Sasyuk⁴

¹ *Sternberg Astronomical Institute of M. V. Lomonosov Moscow State University, 13 Universitetskij pr., Moscow, 119991 Russia*

² *Special Astrophysical Observatory, Karachai-Cherkessia, Nizhnij Arkhyz, 369167 Russia*

³ *Precision Systems and Instruments Corp., 53 Aviamotornaya str., Moscow, 111024 Russia*

⁴ *Kazan Federal University, 18 Kremlevskaya str., Kazan, 420008 Russia*

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Abstract. We describe the first light of a new 9-channel wide-field optical monitoring system with sub-second temporal resolution, Mini-MegaTORTORA, which is being tested now at the Special Astrophysical Observatory in Russian Caucasus. The system is able to observe the sky simultaneously in either wide (~ 900 deg²) or narrow (~ 100 deg²) fields of view, either in clear light or with any combination of color (Johnson *B*, *V* or *R*) and polarimetric filters installed, with exposure times ranging from 100 ms to 100 s. The primary goal of the system is the detection of rapid (with sub-second characteristic time scales) optical transients, but it may be also used for studying variability of sky objects over longer time scales.

Key words: instrumentation: photometers – methods: observational – techniques: photometric

1. INTRODUCTION

Mini-MegaTORTORA is a new robotic instrument just commissioned for the Kazan Federal University and developed according to the principles of MegaTORTORA multi-channel and transforming design formulated by us earlier (see Beskin et al. 2010a; Karpov et al. 2012, and references therein). It is a successor to the FAVOR (Zolotukhin et al. 2004; Karpov et al. 2005) and TORTORA (Molinari et al. 2006) single-objective monitoring instruments we built earlier to detect and characterize fast optical transients of various origins: cosmological, galactic, and near-Earth. The importance of such instruments became evident after the discovery and detailed study of the ever-brightest optical afterglow of a gamma-ray burst, GRB080319B (Karpov et al. 2008; Racusin et al. 2008; Beskin et al. 2010b).

The Mini-MegaTORTORA (MMT) system includes a set of nine individual channels (see Fig. 1) installed in pairs on equatorial mounts (Figs. 2 and 3). Every channel has a coelostat mirror installed before the Canon EF85/1.2 objective for a rapid (faster than 1 s) adjusting of the objective direction in a limited range (approximately 10° to any direction). This permits either a mosaic of the larger

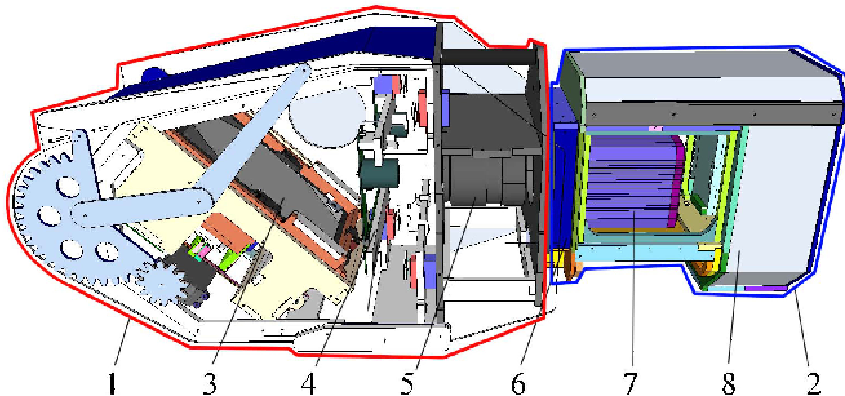


Fig. 1. Schematic view of a single MMT channel. 1: Coelostat unit; 2: camera unit; 3: coelostat mirror that can rotate by $\sim 10^\circ$ around two axes; 4: installable color and polarimetric filters; 5: Canon EF85/1.2 objective; 6: optical corrector; 7: Andor Neo sCMOS detector; 8: conditioner keeping stable environmental conditions inside the channel.

field of view or pointing all the channels in one direction. In the latter mode, a set of color (Johnson B , V or R) and polarimetric (three different directions) filters can be inserted before the objective to maximize the information acquired for the observed region of the sky (performing both three-color photometry and polarimetry).

The channels are equipped with Andor Neo sCMOS detectors having 2560×2160 pixels, $6.4 \mu\text{m}$ each. The field of view of a channel is roughly $9^\circ \times 11^\circ$, with an angular resolution of roughly $16''$ per pixel. The detector is able to operate with exposure times as short as 0.03 s; in our work, we use 0.1 s exposures providing us 10 frames per second.

Every channel is operated with a dedicated PC that controls its hardware, acquires images from the detector and performs data processing. The amount of data acquired by a single channel is about 3 Tb in eight hours of observations. The system as a whole is controlled by a separate PC.

Initial tests show that the FWHM of stars as seen by MMT channels is about 2 pixels wide. The detection limit with a signal-to-noise ratio of 5 in white light for 0.1 s exposure time is close to 11 mag, when calibrating to V -band magnitudes, and to 12 mag in the B band.

3. MMT FIRST LIGHT

The MMT saw first light in March 2014 and since then has been in test observations.

The MMT data processing software implements both a fast differential imaging pipeline intended for detection of transient objects and a slower image processing pipeline intended for performing astrometry and photometry of the whole field of view in order to detect variability on longer time scales.

The first pipeline is fully implemented and is being extensively tested, actively



Fig. 2. Two MMT channels installed on a single mount. The complete system consists of five such mounts, carrying nine operative channels and one replacement channel.



Fig. 3. All the nine MMT channels installed on five mounts in a single cylindrical dome, shown here open. The Russian 6 m telescope is seen in the background.

detecting meteor trails, satellite passes and rapid flashes on the sky in the sub-second time domain.

The principle used is, while working on high frame rate of 10 frames per second, to build an iteratively-updated comparison image of the current field of view using

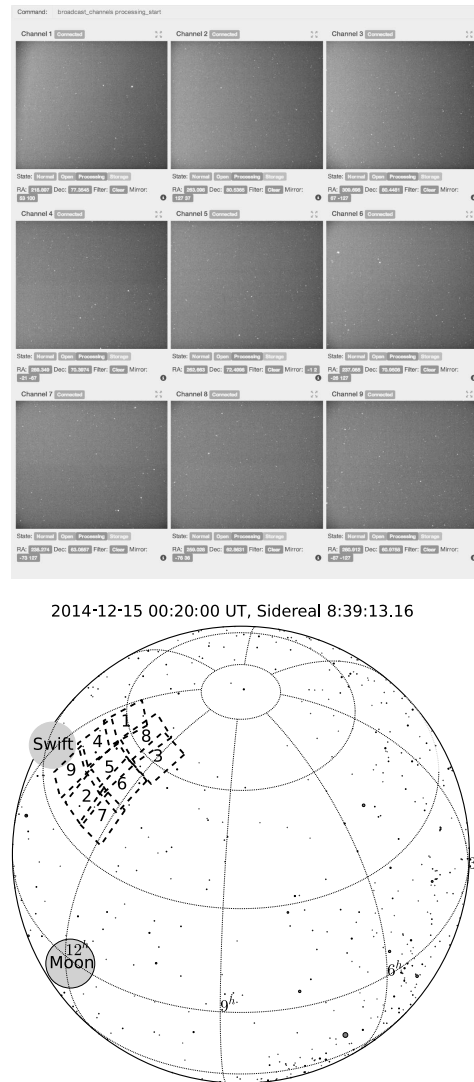


Fig. 4. Top panel: the sky view of all nine MMT channels as displayed by MMT control web interface. Bottom: actual placement of nine fields of view on the sky in the monitoring mode. The actual positions of the Moon and the Swift gamma-ray observatory viewfield are marked by the gray circles.

a numerically efficient running median algorithm, as well as a threshold image using a similarly constructed running *median absolute deviation* estimate, and to compare each frame to them, extracting candidate transient objects and analyzing these objects from consecutive frames, as described in our previous publications (see, e.g., Karpov et al. 2005).

The second, photometric pipeline is still in preparation, with astrometric mod-

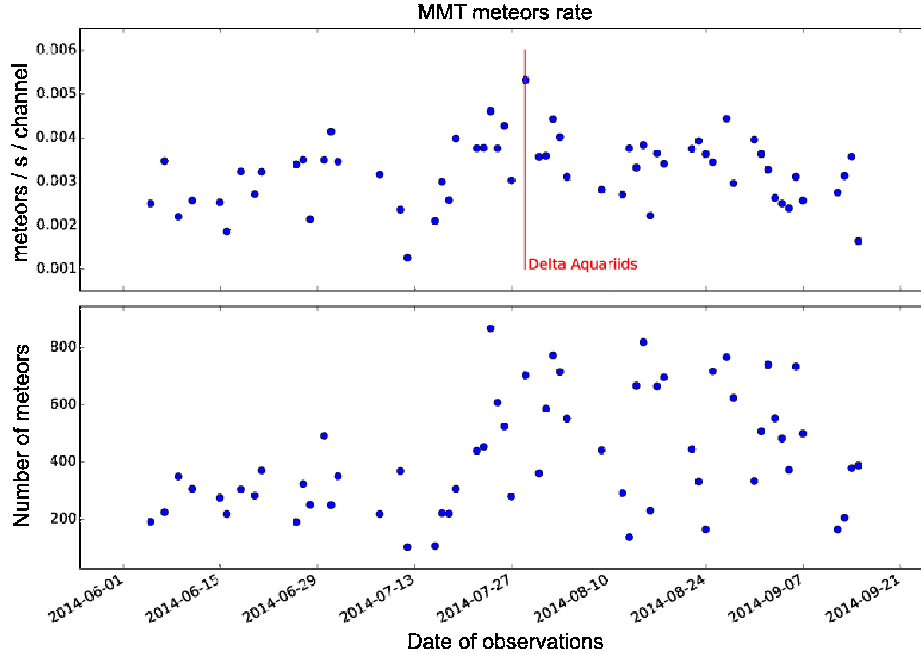


Fig. 5. Observations of meteors in monitoring mode: rate of events detected per second per channel (top) and total number of meteors detected per night (bottom). The rate of events is quite stable, while the total number reflects both the duration of dark night time and differences in weather conditions. Small-scale peaks in the rate might also correspond to small meteor streams.

ule already implemented (using Astrometry.net code described in Lang et al. 2010) and providing astrometric solutions for all the data acquired by MMT. The object detection and photometry is, however, still in development, which is complicated due to the relatively wide PSF of the Canon objective being used.

Below we briefly review various kinds of data being acquired.

3.1. Meteors

Meteors are probably the most frequent astrophysical phenomena flashing in the sky, and easiest to detect in the MMT data flow. Detection of meteor trails is performed on a differential image based on their typically elongated shapes. Then the elongated trails from consecutive frames, having similar directions of elongation, are being merged into single event. Dedicated analysis subroutine then extracts the meteor trail using Hough transformation, detects its range on every frame, and estimates the direction of meteor motion and its velocity. The software also performs the search for possible radiants of meteor streams by constructing a map of pair-wise intersections of all meteor trails detected over the night and studying its spatial distribution. Examples of such maps are presented in Fig. 6.

The typical rate of meteors detected by the MMT is ~ 0.003 events/s/channel (see Fig. 5), corresponding to ~ 700 meteors detected during an eight-hour dark night.

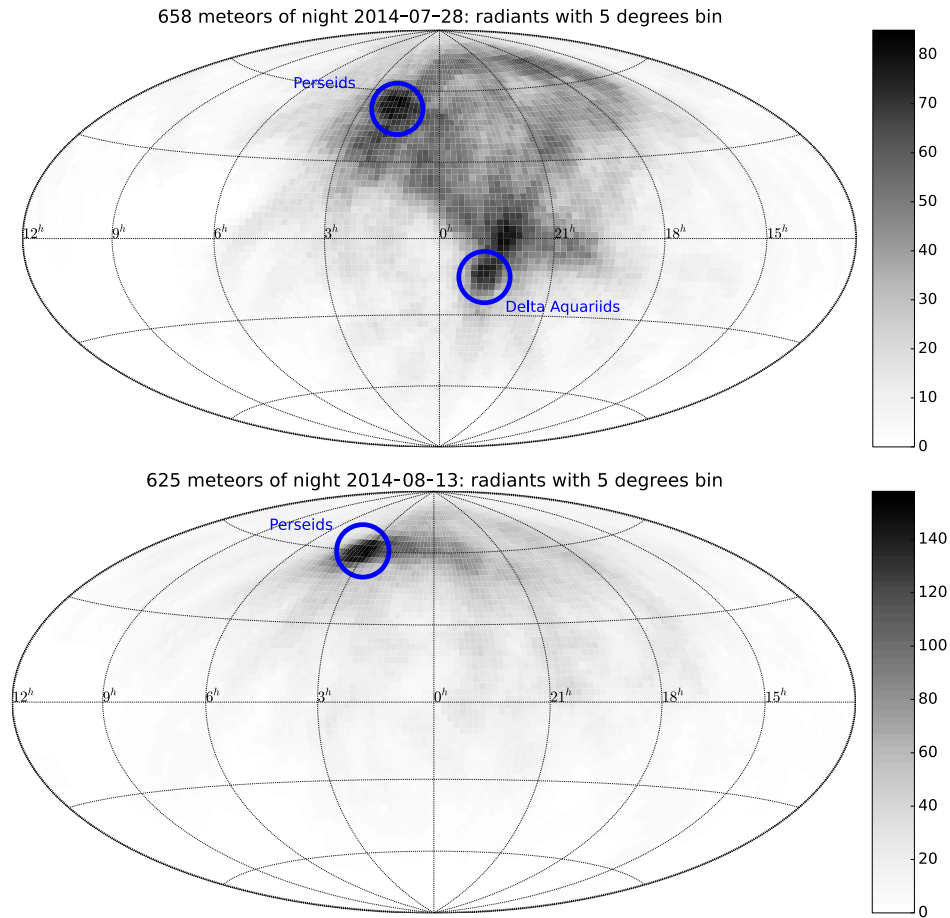


Fig. 6. Observations of meteors in monitoring mode. Top: pair-wise intersections (map of possible radiants) of meteor trails detected on 2014 July 28 (the highest peak in the top panel of Fig. 5). The radiant corresponding to the Delta Aquariids meteor stream is clearly seen, along with the onset of the Perseids meteor stream that peaked two weeks later. Bottom: map of possible radiants of meteor streams detected on 2014 August 13. The radiant corresponding to the Perseids meteor stream is evident.

3.1. Satellites

Detection of rapidly moving objects is implemented by comparing lists of objects detected on consecutive differential frames and extracting those that move along (nearly) straight lines with a (slowly varying or) constant velocity. This is being done iteratively, starting from the third appearance of the object on the frame. After initial detection, the object is being tracked until it fades below the detection limit or leaves the field of view; afterwards, its trajectory and light curve are stored in the database.

An example of satellite trails detected by the MMT on a single night is displayed in Fig. 7, and the distribution of their mean magnitudes over seven months of MMT operation is shown in Fig. 8.

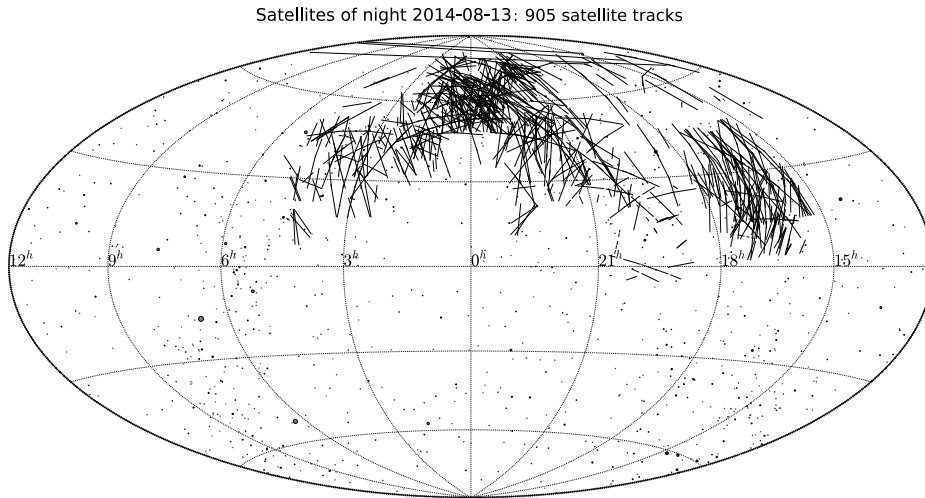


Fig. 7. Satellite trails detected by the MMT on the night of 2014 August 13. Only trajectories with more than 100 detection points are displayed.

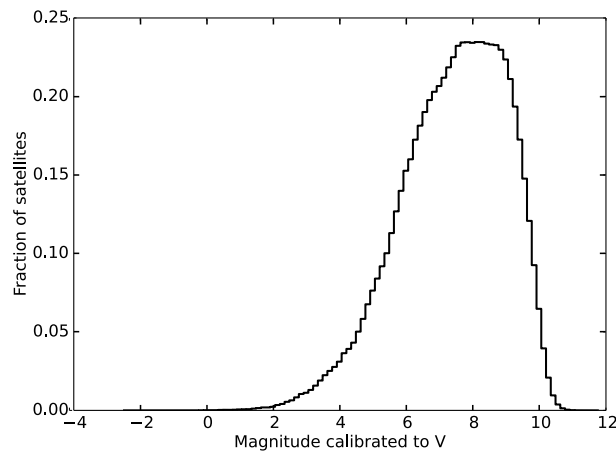


Fig. 8. Overall distribution of mean magnitudes of satellite tracks detected over seven months of MMT operation.

3.3. Fast optical bursts

The original aim of the MMT differential imaging pipeline is detection of rapid optical flashes of astrophysical origin, which is being performed by detecting star-like objects visible on several consecutive differential images (to filter out sporadic noise events and cosmic rays) and not changing their position. As of now, we are still in process of calibrating this part of the pipeline, as it is highly contaminated by stellar scintillations and detector noise spikes. We are, however, able to detect a number of rapid flashes caused by rotation of high-altitude, slowly moving satellites, which produce short (to half a second) events with negligible motion. Such flashes are practically indistinguishable from anticipated astrophysical bursts and

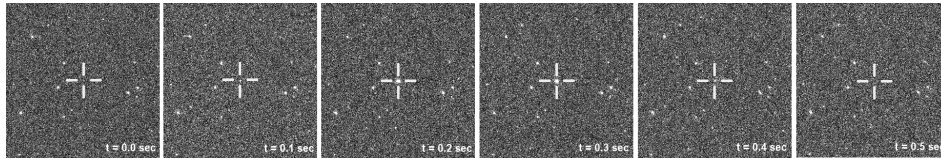


Fig. 9. A rapid optical flash detected by the MMT, with a duration less than 0.5 s and peak brightness reaching ~ 6.5 mag. The flash coincides with a high-altitude passage of MOLNIYA satellite, according to the NORAD database (predicted distance is less than $400''$, a typical error for satellite positions).

can be filtered out only by comparing their positions to those predicted for known satellites, what is being done in the MMT software using the NORAD database.

An example of such an event is shown in Fig. 9.

As of now, we did not detect any rapid flashes not coincident with a high-altitude satellite and not having a light curve identical to those produced by such satellites.

4. CONCLUSIONS

The Mini-MegaTORTORA (MMT) instrument is already operational and shows the performance close to that expected. We hope it will be useful for studying various phenomena on the sky, both astrophysical and artificial in origin. We expect it to be used for studying faint meteoric streams crossing the Earth's orbit, for detecting new comets and asteroids, as well as for finding flashes of flaring stars and novae, studying variable stars of various types, detecting transits of exoplanets, searching for bright supernovae and optical counterparts of gamma-ray bursts. It will also be used for citizen science by providing imaging capabilities for users of the GLORIA robotic telescopes network project.

The novelty of the MMT is its ability to re-configure itself from a wide-field to narrower-field instrument, which may open new ways of studying the sky, as it may, in principle, autonomously perform a thorough study of objects it discovers – simultaneously acquire three-color photometry and polarimetry of them. We will demonstrate MMT performance in such a mode in subsequent papers.

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