

The first light of Mini-MegaTORTORA wide-field monitoring system

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Abstract. Here we describe the first light of the novel 9-channel wide-field optical monitoring system with sub-second temporal resolution, Mini-MegaTORTORA, which is being tested 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 B, V or R) 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 the variability of the sky objects on longer time scales.

Key words:

1. INTRODUCTION

Mini-MegaTORTORA is a novel 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, 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 (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 Figure 1) installed in pairs on equatorial mounts (see Figure 2 and Figure 3). Every channel has a celostate mirror installed before the Canon

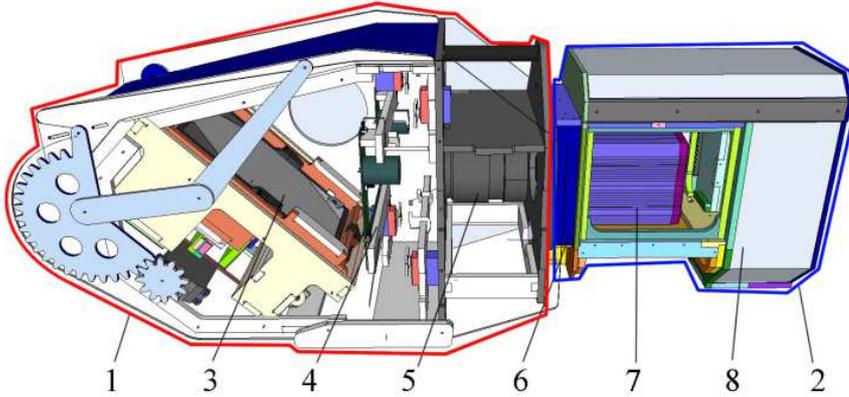


Fig. 1. Schematic view of single channel of MMT. 1 – celostate unit, 2 – camera unit, 3 – celostate mirror which can rotate for ~ 10 degrees around two axes, 4 – installable color and polarimetric filters, 5 – Canon EF85/1.2 objective, 6 – optical corrector, 7 – Andor Neo sCMOS detector, 8 – conditioner to keep stable environmental conditions inside the channel.

EF85/1.2 objective for a rapid (faster than 1 second) adjusting of the objective direction in a limited range (approximately 10 degrees to any direction). This allows for either mosaicking the larger field of view, or for pointing all the channels in one direction. In the latter regime, a set of color (Johnson’s B, V or R) and polarimetric (three different directions) filters may 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 an Andor Neo sCMOS detector having 2560x2160 pixels $6.4\mu\text{m}$ each. Field of view of a channel is roughly 9×11 degrees with angular resolution of roughly $16''$ per pixel. The detector is able to operate with exposure times as small as 0.03 s, in our work we use 0.1 s exposures providing us with 10 frames per second.

Every channel is operated by a dedicated PC which controls its hardware, acquires the images from the detector and performs the data processing. The amount of data acquired by a single channel is about 3Tb in 8 hours of observations. The complex as a whole is being controlled by a separate PC.

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

3. MMT FIRST LIGHT

The MMT seen its first light in March 2014, and is in test observations since then.

MMT data processing software implements both fast differential imaging pipeline intended for the 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.



Fig. 2. Photos of two channels of MMT installed on a single mount. The complete system consists of 5 such mounts, carrying 9 operative channels and one replacement one.



Fig. 3. Photo of the all 9 channels of MMT installed on 5 mounts in the single cylindrical dome, which is open at that moment. Russian 6-m telescope may be seen in the background.

The first pipeline is fully implemented and is being extensively tested, actively detecting meteor trails, satellite passes and rapid flashes on the sky in 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 current field of

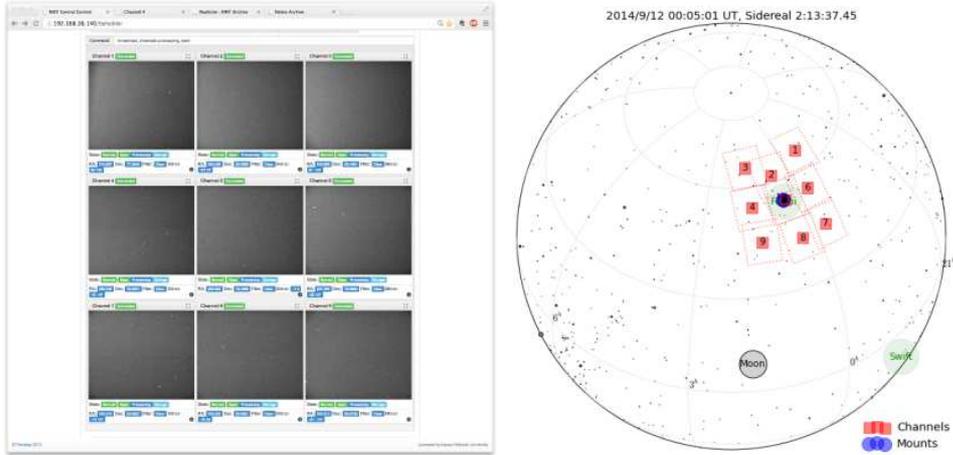


Fig. 4. Left panel – sky view of all 9 MMT channels as displayed by MMT control web interface. Right panel – actual placement of 9 fields of view on the sky in monitoring regime, with the system following the Fermi gamma-ray telescope field of view.

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

The second, photometric pipeline is still in preparation, with astrometric module 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, though, still in development which is complicated due to relatively wide PSF of Canon objective being used.

Below we briefly review various kinds of data being acquired.

3.1. Meteors

The meteors are probably the most frequent astrophysical phenomena flashing in the sky, and easiest to detect in MMT data stream. 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 radiant of meteor streams by constructing the map of pair-wise intersections of all meteor trails detected over the night, and studying its spatial distribution. Examples of such maps are given in Figure 5.

Typical rate of meteors detected by MMT is ~ 0.003 events/s/channel, which leads to ~ 700 meteors being detected in 8 hour dark night.

3.1. Satellites

Detection of rapidly moving objects is implemented by comparing the lists of

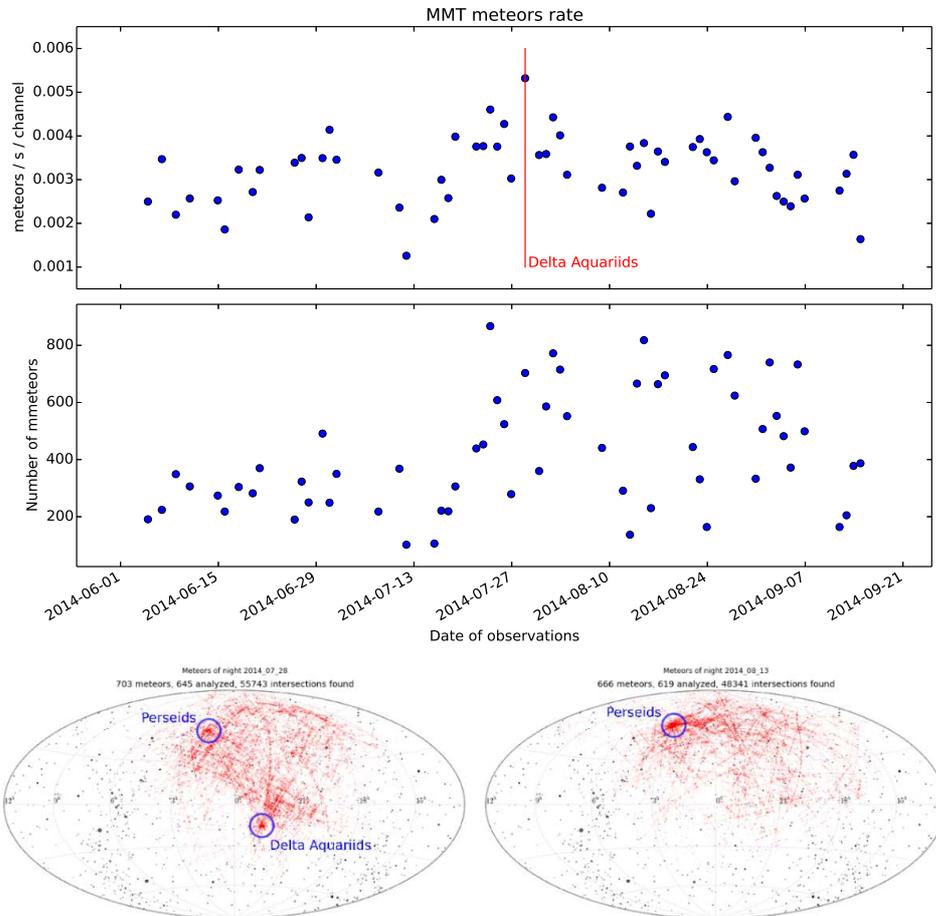


Fig. 5. Observations of meteors in monitoring regime. Upper panel – rate of events detected per second per channel, as well as total number of meteors detected per night. The rate of events is quite stable, while the number reflects both the duration of dark night time as well as differences in weather conditions. Small-scale peaks in the rate might also correspond to small meteor streams. Lower left panel – pair-wise intersections (map of possible radiants) of meteor trails detected on Jul 28, 2014 (highest peak in upper plot). Radiant corresponding to Delta Aquariids meteor stream is clearly seen, along with an onset of Perseids meteor stream, which peaked two weeks later. Lower right panel – map of possible radiants of meteor trails detected on Aug 13, 2014. Radiant corresponding to Perseids meteor stream is evident.

objects detected on consecutive differential frames and extracting the ones that moves along (nearly) straight lines with (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 is stored to the database.

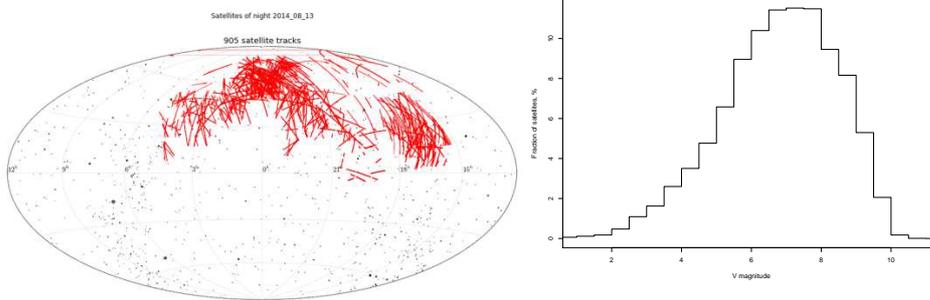


Fig. 6. Left panel – satellite trails detected by MMT on the night of Aug 13, 2014. Only trajectories with more than 100 detection points are displayed. Right panel – overall distribution of mean magnitudes of satellite tracks detected over three months of MMT operation.

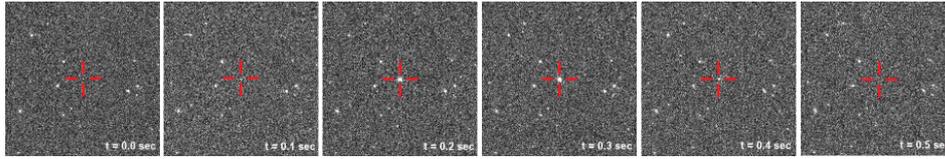


Fig. 7. Rapid optical flash detected by MMT, with duration less than 0.5 s and peak brightness reaching $\sim 6.5^m$. The flash coincides with the high-altitude passage of MOLNIYA satellite, according to NORAD database (predicted distance less than $400''$, which is a typical error for satellite positions).

An example of satellite trails detected by MMT on a single night is shown in Figure 6.

3.3. Fast optical bursts

The original aim of MMT differential imaging pipeline is the detection of rapid optical flashes of astrophysical origin, which is being performed by detecting the stellar-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 pipeline, as it is being highly contaminated by stellar scintillations and detector noise spikes. We are, however, able to detect a number of rapid flashes caused by the rotation of high-altitude slowly moving satellites, which produce short (up to half a second) events with negligible motion. Such flashes are practically indistinguishable from anticipated astrophysical bursts, and may be filtered out only by comparing their positions with predicted ones of known satellites, which is being done in MMT software using NORAD database.

An example of such event is shown in Figure 7.

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

4. CONCLUSIONS

The Mini-MegaTORTORA (MMT) instrument is already operational and shows the performance close to the 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 Earth orbit, for detecting new comets and asteroids, for finding flashes of flaring stars and novae, studying variable stars of various classes, 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 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 thorough study of objects it discovers – to simultaneously acquire three-color photometry and polarimetry of them. We will demonstrate MMT performance in such a regime in subsequent papers.

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