

The state of development and observation of MITSuME telescope

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ABSTRACT

MITSuME (Multicolor imaging telescopes for survey and monstrous explosions, or which means three-eyed monster in Japan) consists of three robotic telescopes designed for gamma-ray burst (GRB) afterglow observations. Two 50 cm optical telescopes, located in Okayama (OAO/NAOJ) and in Yamanashi (Akeno Observatory/ICRR) are equipped with tri-color CCD cameras that perform simultaneous imaging in the g' , R_c and I_c bands. We have performed follow-up observations of 28 GRBs since April 2007 until May 2008 with *MITSuME* Akeno Telescope, and detected five afterglows. The telescope is automatically pointed to the GRB coordinates when a GCN notice is received. The images are automatically reduced, combined, and analyzed to detect uncatalogued objects in the field. While waiting for GRB alerts, the telescope performs patrol of pre-selected objects, such as variable active galactic nuclei (AGNs). The photometry of these patrolled objects is also performed automatically. In this paper, we report the results of the GRB afterglow observations at Okayama / Akeno *MITSuME* Telescopes. We also present the automatic observation and the analysis system.

KEY WORDS: gamma-ray - optical/NIR afterglows

1. GRBs

GRBs are the most energetic explosions in the Universe. Their origin and emission mechanism are at last starting to be revealed with the coordination of astronomy satellites and ground-based observations. Majority of long GRBs are now believed to be associated with death of massive stars. Their prompt emission, and their afterglows have been successfully explained by a synchrotron emission from relativistic shocks.

2. THE MITSuME PROJECT

The *MITSuME* project is conducted and supported by Tokyo Institute of Technology, the National Astronomical Observatory of Japan (NAOJ) and the Institute of Cosmic Ray Research (ICRR). *MITSuME* stands for *Multicolor Imaging Telescopes for Survey and Monstrous Explosions*. The objective of the project is multicolor photometry from K_s to g' of GRB afterglows within tens of seconds, which allows the photometric redshift measurements up to $z \approx 10$. We built two 50 cm optical robotic telescopes at Akeno Observatory of the ICRR and at Okayama Astrophysical Observatory (OAO) of

NAOJ. Each telescope has a *Tricolor Camera* capable of simultaneous photometry in g' , R_c , and I_c bands[1,2,3]. The specification of the two optical telescopes is shown in Table 1. In addition, we have started GRB observations with Tricolor Camera at Ishigakijima Astronomical Observatory in a southern island of Japan. In addition, an existing 91 cm telescope at OAO is being converted to a NIR telescope, which is designed to have a wide field of view of $56' \times 56'$ and perform K_S , H , J , and y photometry[4].

3. OBSERVATION SYSTEM

Our observation system has been designed to observe afterglows of GRBs automatically. This system can respond to notifications distributed by the Gamma-Ray Burst Coordinate NetWork (GCN). After receiving a GCN notice, our telescopes immediately slew to the GRB position and then start to take series of three color bands images simultaneously. These images that taken with both Akeno and OAO telescopes are processed by the analysis pipeline and transferred to the database at Tokyo Institute of Technology. Our images

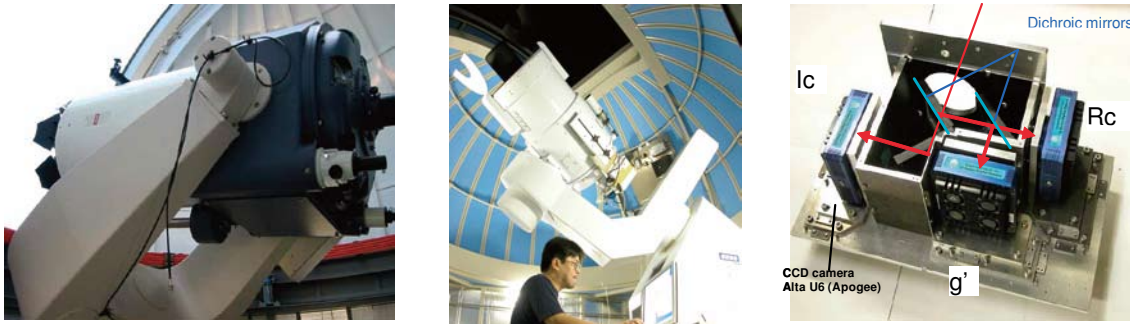


Fig. 1. Akeno 50 cm Telescope (left), OAO 50 cm Telescope (center), and Tricolor Camera (right). Each telescope has a Tricolor Camera. The light led in the camera from above is divided into three bands with two dichroic mirrors and distributed to three *Alta U6* CCDs.

Table 1. Properties of *MITSuME* telescopes

	<i>Akeno 50 cm</i>	<i>OAO 50 cm</i>
Mirror Diameter	500 mm	500 mm
Focal Length	3040 mm	3250 mm
F Number	6.0	6.5
FOV	$28' \times 28'$	$26' \times 26'$
Bands	g', R_c, I_c	g', R_c, I_c
Limiting Mag. (10 min, S/N=10)	$g' = 18.4$ $R_c = 18.4$ $I_c = 17.7$	$g' = 18.4$ $R_c = 18.5$ $I_c = 17.7$
Slew speed	9 deg.s^{-1}	4 deg.s^{-1}
Location	Akeno Observatory/ICRR Akeno, Yamanashi, Japan $138^\circ 30' \text{ E}, 35^\circ 47' \text{ N}, 900 \text{ m ASL}$	OAO/NAOJ Kamogata, Okayama, Japan $133^\circ 35' \text{ E}, 34^\circ 34' \text{ N}, 372 \text{ m ASL}$

are available through *Subaru Okayama Kiso Archive system (SMOKA)*¹. We have started scheduled observations for variable and transient objects including supernovae and active galactic nuclei (AGNs) when we do not observe GRBs. If we observe other objects, we can point the telescope at GRBs at the maximum time of 20 seconds.

4. ANALYSIS PIPELINE

The analysis pipeline of *MITSuME* is an automatic system that processes images taken with the multiband telescopes. It allows us to find early optical afterglow of GRBs. The process flowchart is shown in Figure 2. First, sources are found in raw images we take and they are matched to star catalogs. Based on this catalog matching, sky coordinate called the world coordinate system (WCS) is mapped to the image pixels. Second, the photometric measurements are performed for all the sources in the images. GRB afterglow coordinates are those that are not present in the USNO-B 1.0 and

NOMAD² catalogs, and are detected in more than one images and cross comparison of the source is carried out. Our analysis pipeline allows us to pick up a real GRB by eliminating as hot pixels and pixels hit by cosmic rays. The automatic detection worked well for observations of GRB061121 and GRB070920A. Finally, all images are registered to the database. We can easily access all data in the database through a web interface, which provides information of the images and displays their thumbnail images.

5. RECENT OBSERVATIONS

Recent observation of GRBs by *MITSuME* telescopes are shown in Table 2. From April 2007 to June 2008, we performed follow-up observation of 28 GRBs with the *MITSuME* Akeno Telescope, and detected five afterglows.

6. PATROL OBSERVATION

Telescope motion and operation of the CCD are under the computer control, allowing automated obser-

^{*1} <http://smoka.nao.ac.jp/index.jsp>

^{*2} <http://www.nofs.navy.mil/data/fchpix/>

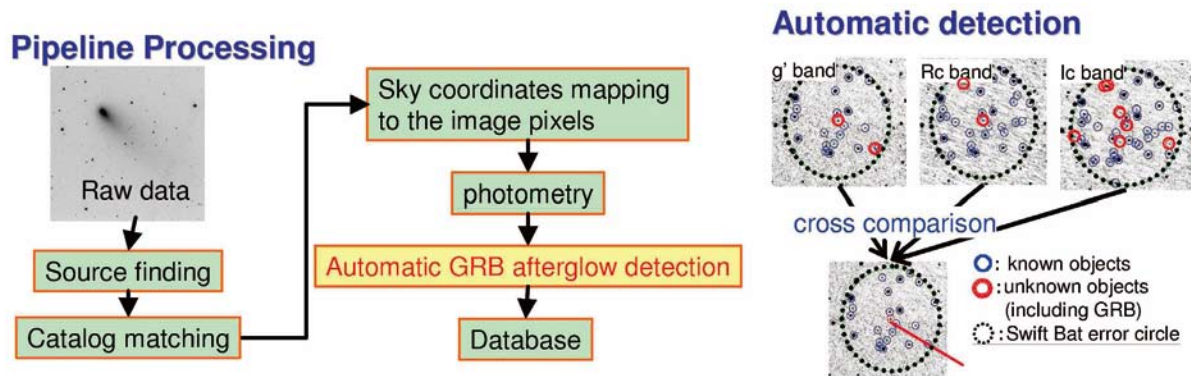


Fig. 2. The pipeline processing and the automatic detection. In the automatic detection, more than one images are compared and only a real GRB is picked up.

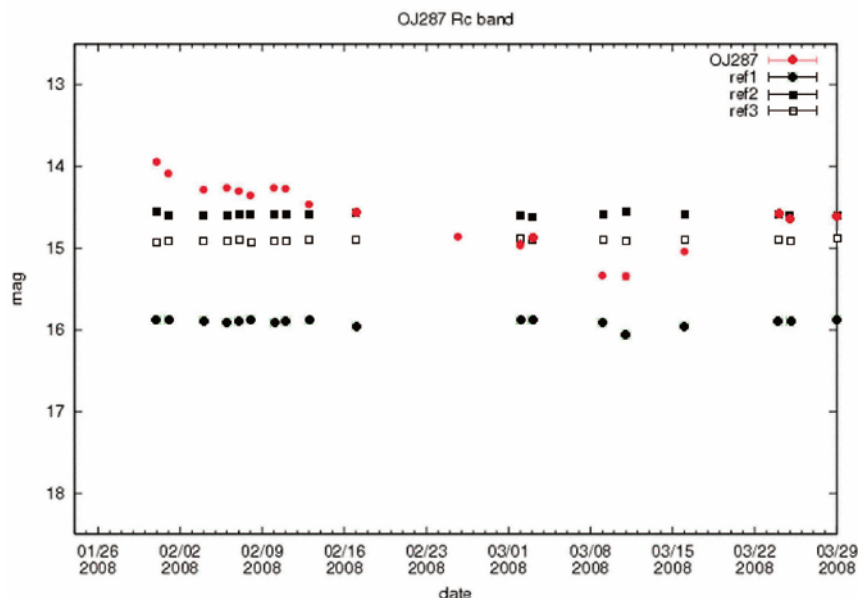


Fig. 3. Light curve of OJ287 at Rc-band.

variations for long-term monitoring of AGNs and transients, contributing to multiwavelength observation in the GLAST/MAXI era. We automatically image ~ 10 AGNs and update their light curves every night [ex. Fig.3].

References

1. H.L.Johnson, *Astrophysical Journal* **141**,923-+(1965).
2. A.W.J.Cousins, *Monthly Notes of the Astronomical Society of South Africa* **37**,8-+(1978).
3. J.A.Smith, D.L. Tucker, S. Kent, M.W. Richmond, M. Watanabe, A.Tolea, A. Henden, J. Annis, J.R. Pier, T.A. McKay, J.Brinkmann, B. Chen, J. Holtzman, K. Shimasaku, and D.G. York, *Astron. J.* **123**, 2121-2144(2002), arXiv:astro-ph/0201143.
4. K. Yanagisawa, "Wide-field Monitoring of the Galactic Plane in the K- and the H-band", in *The Proceedings of the IAU 8th Asian-Pacific Regional Meeting, Volume II*, edited by S. Ikeuchi, J. Harnshaw, and T. Hanawa, Astronomical Society of Japan, Tokyo, 2002, p.83.
5. T. Ishimura, T. Shimokawabe, Y. Mori, Y. Kudou, N. Vasquez, Y. Yatsu, and N. Kawai, *GRB Coordinates Network* **7087**, 1-+(2007).
6. T.Kotani, N. Kawai, K. Yanagisawa, J. Watanabe, M. Arimoto, H. Fukushima, T. Hattori, M. Inata, H. Izumiura, J. Kataoka, H. Koyano, K. Kubota, D. Kurota, M. Mori, S. Nagayama, K. Ohta, T. Okada, K. Okita, R. Sato, Y. Serino, Y. Shimizu, T. Shimokawabe, M. Suzuki, H. Toda, T. Ushiyama, Y. Yatsu, A. Yoshida, and M. Yoshida, *Nuovo Cimento C Geophysics Space C* **28**, 755-+(2005), arXiv:astro-ph/0702708.

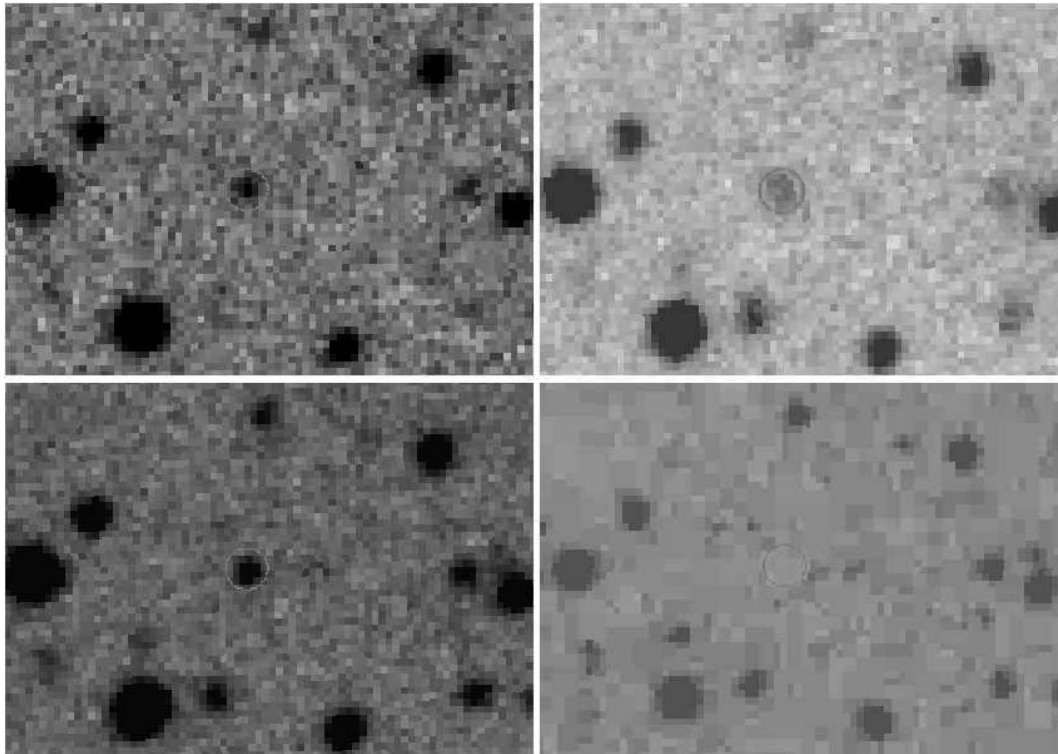


Fig. 4. GRB afterglow of GRB080506. g' -band(upper left), I_c -band(upper right), R_c -band(lower left), DSS catalog(lower right)

Table 2. Recent observations by *MITSuME* telescopes

GRB	g' [mag]	R_c [mag]	I_c [mag]	Site	Burst time
080604	>20.0	>19.2	18.6 ± 0.4	OA0	5h 12min
080506	-	17.5 ± 0.1	16.2 ± 0.2	Akeno	1min 57s
080310	20.0 ± 0.2	19.7 ± 0.3	19.1 ± 0.2	OA0	6h 31min
080205	>20.9	>20.9	19.6 ± 0.3	Akeno	1h 20min
071118	>18.9	-	-	Akeno	7min
071112C	17.3 ± 0.4	17.3 ± 0.3	-	Akeno	1min
071011	-	19.0 ± 0.3	18.2 ± 0.4	OA0	9m 53s
071011	-	20.1 ± 0.2	18.6 ± 0.2	Ishigakijima	24m 02s
070612A	-	>16.7	17.1 ± 0.3	OA0	8h41min
070419A	20.9 ± 0.2	>21.5	> 19.4	OA0	54min