The development of an automatic reduction system for Gamma-Ray Burst afterglow

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ABSTRACT

Our automatic reduction system was developed for the multi-band photometry of the Gamma-Ray Burst (GRB) optical afterglow. The advantage in this system is the real-time reduction with a data quality check routine. The processing sequences for the obtained image are two stages. First step is to distinguish useful quality data, which is judged by the field zero-point in real-time parallel processing. Second step, is executed about only GRB, consists of the dark and flat corrections, image stacking, search of GRB afterglow, photometry and output of result. Finally, we get e-mail containing an analyzed result and submit to the GCN Circular. Our robotic telescope with simultaneous three-band imager has provided immediate follow-up observation of multi-wavelengths. Our automatic analysis of GRB afterglows enabled quickly report to the community. We present the development of this automatic reduction system, the review of our robotic telescope and our past results.

Keywords: Gamma-Ray Bursts, GRB Afterglow, Robotic telescope, Automatic analysis

1. INTRODUCTION

Gamma-Ray Bursts (GRBs) are short lived and the most luminous electromagnetic events in the known space. The flashes of gamma rays are detected on the monitoring satellites (HETE-II, INTEGRAL and Swift). A GRB alert trigger from satellite is distributed to the GRB Coordinate Network (GCN), in response to this, follow-up and additional observations on ground-based observatories are started. Rapid follow-up observations are paramount to the understanding of the early phase GRB afterglows, which has important information about the origin and environment of GRBs.

Our project is named MITSuME (**M**ulticolor **I**maging **T**elescopes for **Su**rvey and **M**onstrous **E**xplosions), we are available three optical telescopes and one near-infrared telescope in Japan. One of MITSuME telescopes which has a 0.5m primary mirror and simultaneous three-band imager was set up at 2004 on Okayama Astrophysical Observatory (OAO), National Astronomical Observatory of Japan. This observation has been designed to search for optical afterglows of GRB and is called the Okayama MITSuME.[8, 22] The analysis pipeline of GRB afterglows has also been developed in our project since 2005.[14, 17, 18] In this paper, we introduced the observation system of MITSuME Okayama telescope in Section 2. Section 3 contained a description about our automatic reduction system. Section 4 reported the past results.

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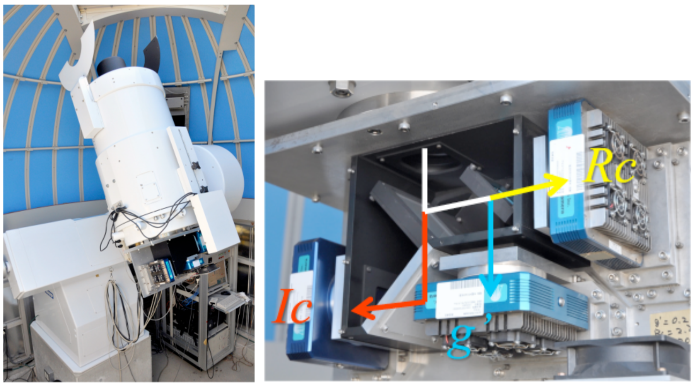

Figure 1. Telescope and camera system of MITSuME Okayama. Left panel is the 0.5m reflector with the simultaneous three-band imager. Right panel is the closeup picture of the three-band imager. This imager, which has a wide field of view (26" × 26"), enables to take simultaneous images in g', Rc, and Ic bands.

2. OBSERVATION SYSTEM

We have preformed optical follow-up observations of GRB afterglows since 2004. Figure 1 shows the robotic telescope and simultaneous three-band imager of MITSuME Okayama. This telescope was improved a commercial product for GRBs and has a maximum pointing speed of 8.3 degrees per second. The three-band imager enables to taken simultaneous images with g', Rc and Ic bands which respond similarly to SDSS and Johnson-Cousins system. This imager was also developed at OAO. Two dichroic mirrors and one gold-coated mirror split incident light into the three directions, and the identical cameras with g', Rc and Ic filters are located in each direction. These specifications are summarized in Table 1. The detail of this observation system is referred to Yanagisawa et al. (2010).

The effective detection and research of GRB optical afterglows are required immediate observation and report to the community. The flowchart about our observation and analysis system is shown in Figure 2. In order to catch the fast-fading GRB afterglows, the automated scheduling observation, which is required no human operation after receiving a GCN alert, has started operation since 2008. After receiving the alert, MITSuME Okayama telescope starts immediately pointing to a target and the simultaneous imaging. Each imaging sequence for GRB is continued to take 60 seconds exposure under 3 × 3 dithering patterns of 40 arc-seconds separation. The obtained images are processed by the image analysis pipeline and transferred to a database server of Tokyo Institute of Technology. These images are available as data archive through Subaru Mitaka Okayama Kiso Archive system (SMOKA).[5,6]

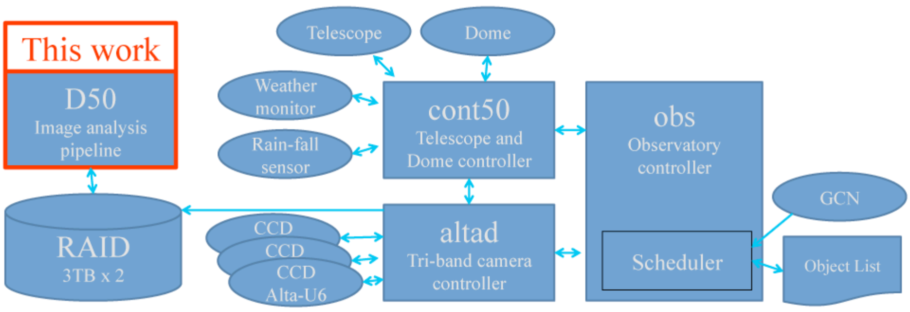

Figure 2. Flowchart for observation and reduction of MITSuME Okayama. This robotic system is mainly controlled by Java based software (cont50 and obs). The CCD camera is managed in altad. The image analysis pipline D50 is this work.

Table 1. Specifications of MITSuME Okayama system. This system was specialized in the rapid follow-up and mutli-band observation of GRBs. The limiting magnitudes were defined as detection limit at S/N = 10 with 10 minutes integration.

Telescope	
Diameter	0.5m
Optics	Classical Cassegrain reflector + Coma corrector
F ratio	F/6.5
Hartmann constant	0.7 arcsec
Mount	Fork equatorial
Max. slew speed	8.3 deg./sec
Pointing accuracy	9 arcsec
Dome	
Diameter	4m
Max. speed	9.3 deg./sec (39 sec/rev)
Three-band Imager	
CCD Camera	ALTA U6 (Apogee, USA)
CCD	KAF-1001E (KODAK, USA)
Format	1024 × 1024
Field of View	26 arcmin. × 26 arcmin.
Image scale	1.52 arcsec/pixel
Filters	SDSS g', Rc, Ic (Asahi Spectra)
Beam splitter	Dichroic mirrors (Asahi Spectra)
Limiting magnitude	g'=18.4, Rc=18.5, Ic=17.7

3. AUTOMATIC REDUCTION SYSTEM: D50

Our reduction system D50 is automatically controlled by Ruby script. Two processing sequences, which are to evaluate data quality (Section 3.1) and to detect GRB afterglow(Section 3.2), are executed for the obtained multi-band images. The flowchart of these two sequences is shown in Figure 3.

3.1 Real-Time Parallel Processing

This step are conducted the data quality evaluation and greatly important for our automatic reduction system. As soon as an image is taken, several information of data qualities such as sky-level and field zero-point are appended. This pipeline was constructed using in-house ruby based software and other applications. The star-like sources are extracted in the raw image by using SExtractor.[3] Matching between sky and image coordinates based on World Coordinate System (WCS) is computed by imwcs (in WCSTools[11]) within referring to the astrometric star catalog USNO-B 1.0.[12,13] A field zero-point, is the magnitude of an object that has one count per second, provides a decisive indication of the permitted condition for subsequent analysis.

3.2 Analysis for GRB afterglow

The processes are mainly performed in this step by using the tasks in IRAF (Image Reduction and Analysis Facility) package.[19,20] These are complemented by PyRAF (STScI, AURA for NASA), which is invoked directly the IRAF command. First processes are including overscan region ($\sim$ bais) subtraction, bad pixel and cosmic ray correction, dark current subtraction and flat fielding. Dark frames were taken about 30 images before

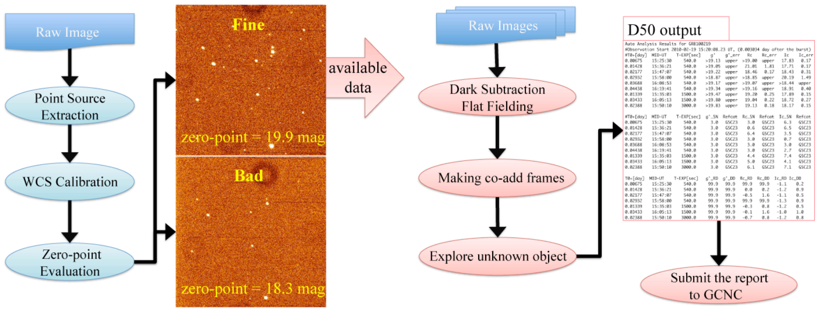

Figure 3. Flowchart of two analysis sequences. Left half and Right half show in real-time parallel processing and about the analysis for GRB afterglow, respectively.

daily observation sequence. A composite flat frame is created from object self frames as sky flat. To use the twilight or dome flat preclude an investigation of faint object such as typical GRB afterglow, because the scratch background pattern arises from CCD nonlinearity of low level in our camera. Second processes are to make co-add frames, and to update the photometric and astrometric information. Several integrated frames (per 10, 30, 60, 90 and 120 minutes) are created with based on WCS information in this process. The field zero-point and the limit magnitude for signal to noise ratio of 3 are derived from each co-add frame. Third process is to explore unknown object and its photometry in those images. A missing object within USNO-B1.0 and GSC2.3 catalog is explored around the reported position from satellite. The brightness of unknown object is measured by the method of the aperture photometry (apphot task in IRAF). The photometric magnitude is computed from the measured instrumental magnitude and the field zero-point. Finally, The analysis result is submitted for us as the observation report via E-mail. Later, we publish this result to GCN Circular. In the case of non-detection, we report only upper limit magnitude.

3.3 GSC2.3 for photometric reference catalog

We adopted star magnitudes in GSC2.3[10] or SDSS-DR7[1,2] catalog as photometric local reference (Jordi et al. (2006) transformations between SDSS and Johnson-Cousins system, and Sesar et al. (2006) equation for g' from GSC magnitudes). The relation between catalog magnitude and instrument magnitude of a sample field is shown in Figure 4. We found widely mismatch for the linear function (fixed slope = 1.0, as shown the solid lines in Figure 2) of USNO-B1.0. Sesar et al. (2006) also concluded that the most accurate photometry for SDSS (about 0.07 mag error) is provided by the GSC2.2 catalog in other POSS catalogs (USNO-B1.0, and so on).

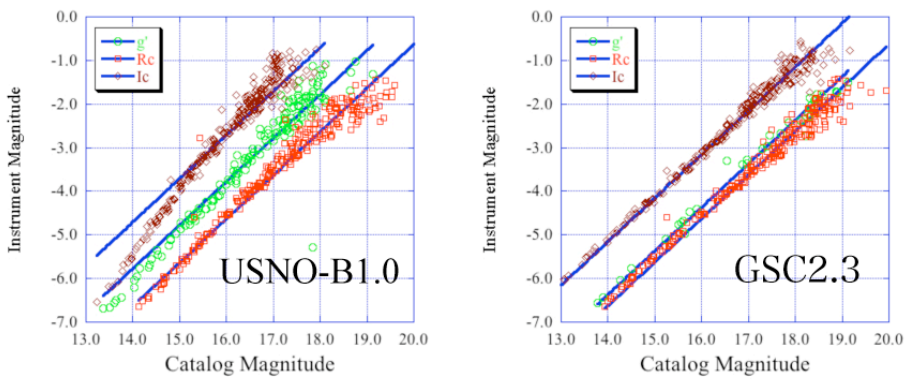

Figure 4. Relation between catalog magnitude and instrument magnitude. Left panel shows non-linear trends about USNO-B1.0. Right panel is the relation for GSC2.3. The vertical axis is the instrument magnitude and the horizontal axis is the magnitude from each catalog. Open circles, open squares and open diamonds show the data points for g', Rc and Ic, respectively. The solid lines are the fitted lines for the slope of 1.0.

Table 2. Summary of past observations. We detected 31 GRB afterglows and submitted 61 GCN Circulars in total tried observations (pointing colum) of 149.

Year	Pointing	Detect	UpperLimit	GCNC Submit
2004	3	1	2	1
2005	10	2	8	4
2006	11	3	8	6
2007	22	6	5	11
2008	41	10	4	9
2009	31	4	15	9
2010	26	4	12	15
2011	5	1	5	5

4. RESULTS

Since we have started the GRB follow up observations, to-date (Jan. 2011) we tried 149 observations and detected 31 GRB afterglows. We also published our results in 61 GCN Circulars. The summary of our past observations is listed in Table 2. The GRB afterglow allows us to potential probe of the early universe with measuring the redshift. The farthest GRB detected by MITSuME Okayama is GRB 100219A.[15] We started GRB 100219A observation on 262 seconds after Swift BAT alert and detected a fading object in integrated images of Rc and Ic band except g' band (see Figure 5).[9] The Rc and Ic magnitudes for total exposure time of 1500 seconds were 19.2 $\pm$ 0.3 and 17.9 $\pm$ 0.2 at 19 minutes after Swift alert. Three sigma upper limit for g' band was 19.5. This redshift value was reported approximately 4.7 (at a distance of 12.4 billion light-years) by Gemini South Spectroscopy.[4]

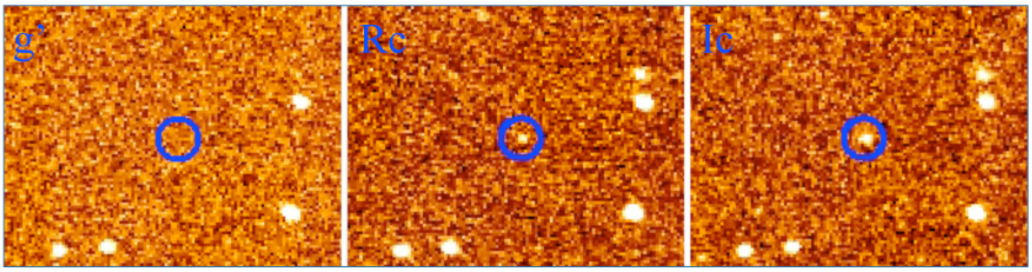

Figure 5. GRB 100219A images of g', Rc and Ic. The afterglow candidate was detected in Rc and Ic band. We reported to GCNC about the photometric results, three sigma upper limit for g' and the precision coordinates of this object.[9]

5. CONCLUSIONS

Our automatic reduction system has operated efficiently since 2009, resulting in real-time data analysis. The advantage of this system is the data quality evaluation by using the field zero-point. The real-time parallel processing ran at tens of seconds per frame, and subsequent analysis for GRB afterglow is finished at a few minutes to tens of minutes. Thus we enabled the immediate observation with multi-wavelengths, real-time analysis and prompt report to the community for the effective detection and research of GRB afterglows. This reduction system D50, which is also applied to other MITSuME system in Ishigakijima Astronomical Observatory, is available for other photometric data and other target with changing the several configurations.

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