Possible coordinate observations by MAXI and the AROMA wide-field optical monitor

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Abstract

In order to observe the early optical afterglows of GRBs, we have developed and operated the automatic telescope Aoyama Gakuin University Robotic Optical Monitor for Astrophysical objects (AROMA). It currently consists of amateur-oriented astronomical instruments to conduct immediate and automatic follow-up observations and analyses of the GRB optical afterglows. In order to expand the scope of AROMA, a development of an observation system using multiple digital single-lens reflex cameras (AROMA-W) is underway. The new function of AROMA can achieve simultaneous observations in multiple optical bands with a wide field of view. The software which analyzes massive amounts of imaging data automatically was also under development. Finally we aim at discoveries of the optical transients by monitoring all the stars which are visible in an AROMA-W view. We report a developmental status of AROMA-W and a possibility of the simultaneous observation to the X-ray transients (e.g., X-ray nova, Supernova) discovered with MAXI.

Key words: Optical, GRB, Transients

1. Introduction

Monitor of All-sky X-Ray Image (MAXI) can monitor a short time scale X-ray variability and spectra of various X-Ray objects (e.g., Black Hole Candidates, AGNs, Gamma-Ray Bursts (GRBs), X-Ray Novae). Among them, GRB is the most energetic transient with an isotropic energy up to $E_{\rm iso} = 10^{52}$ ergs. The initial X-ray and gamma-ray emission is often referred to as prompt emission. The prompt emission is typically followed by emission from radio to X-ray, so-called afterglows. In a few cases, the afterglows last several months (e.g., GRB 030329). Many observations and studies give important results such as an association between long duration GRBs and hypernovae (e.g., GRB 030329). An emission mechanism of optical afterglows is still unclear, because a very rapid flux decreasing $t^{-\alpha}$ ($\alpha \sim$ 1-2) discourages detailed studies. Therefore, a quick follow-up observation in multiple wavelengths is important for a detailed research of the optical afterglows.

2. AROMA-N

Aoyama Gakuin University Robotic Optical Monitor for Astrophysical objects with Narrow field of view (AROMA-N) is a rapid follow-up telescope for astronomical transients that we have built in the Sagamihara Campus of Aoyama Gakuin University (Latitude = 35.566 ° and Longitude = 139.403 °).

For GRB optical afterglows, this system autonomously make rapid follow-up observations within several tens of seconds based on positional informations from satellites such as *Swift*. AROMA-N currently consists of amateur-oriented astronomical instruments; a Schmidt-Cassegrain telescope of 30.5 cm diameter (MEADE LX200GPS-30), a cooled CCD camera (SBIG ST9-XE), and a filter wheel equipped with multiple band pass filters (B, V, R and I). Figure 1 shows overview images of AROMA-N and its dome. A limiting magnitude is typically about 16-17 magnutude in R-band (100 s integration with 3σ level), and it can reach to 18 magnutude in the best sky condition. Automatic analysis programs are developed in order to search an optical afterglow soon after a determination of a GRB position.

AROMA-N has made follow-up observations for 29 GRBs since it started a steady operation in April of year 2006. Unfortunately, it was cloudy for 17 out of 29 GRBs and there is no useful data for them. Although sky conditions for the other 12 GRBs were fine, any optical transient could not be found. Among 12 GRBs, we here report observational results of two GRBs 060502B and 060923C, because AROMA succeeded in observation at an early phase ($t < 180$ s). Observations of

GRB 060502B were started 85 s after the burst. Despite a very quick follow-up observation, no new source was found. A limiting magnitude is estimated as R $\sim$ 16.1 with 3σ confidence. Observations of GRB 060923C were started 164s after the burst. For this GRB, we succeeded the fastest follow-up observations among all telescopes in the world. However, no new source was found. A limiting magnitude was turned out to be R $\sim$ 15.4 with 3σ confidence.

However, there are two problems in observation by telescopes. The first problem is a time-lag. There has been rapid follow-up observations of GRB optical afterglows by telescopes containing the AROMA-N. Figure 2 shows light curves of the GRB optical radiation (235 GRB events). What seems to be lacking is optical observations before and during prompt emission because of a time delay in the follow-up observations. The time-lag from GRB alert to ground based observations exists. In order to observe a GRB optical variablity in earliest stage, we always have to monitor the field of view of the satellites. The second problem is a pointing accuracy of the satellites. Although It is expected that GLAST Burst Monitor (GBM) on the GLAST which launched in June, 2008 detects 200 GRBs for every year, the pointing accuracy of the GBM/GLAST is 8 degrees. Since the field of view of the conventional telescope systems are a few degrees, they cannot cover an error circle at once. Therefore, the system which always observes a large view is needed to solve these problems. In order to correspond to the GRB follow-ups which reaches the whole sky by MAXI and GBM/GLAST, the largest possible field of view should be taken.

3. AROMA-W

We are developing an large view observation system AROMA-Wide (AROMA-W) using multiple digital single-lens reflex cameras to achieve the optical observations before and during the prompt emission. This implies that an optical flash (e.g., GRB 990123, GRB 080319B) can be observed by this system. Figure 3 shows an overview image of AROMA-W prototype. Similar systems are operated at various locations (e.g., Pi of the Sky, RAPTOR, TORTORA). In GRB 080319B, the brightest prompt optical emission that peaked at a visual magnitude of 5.3 was discovered by these systems during ths burst.

3.1. Instrument

The AROMA-W consists of multiple digital single-lens reflex cameras (DSLR), and an equatorial. Control of the cameras and an equatorial telescope is operated remotely. The cameras to be used are Canon EOS 5D, EOS kiss DN (EOS D Rebel) etc.. The lens which have various focal lengths attached to those cameras. Now, as a test, we are observing with the two cameras on an equatorial. In the future, we will apply about ten cameras to the mount for exclusive use. The shutters of the cameras are controlled by the pulse from the DIO board in the Personal Computer (PC), and these cameras simultaneously make exposures. The acquired data are transferred to the PC by every frame via USB. The equatorial is controlled by the PC and follows the field of view of the GRB observation satellites (eg. *Swift*, GLAST).

3.2. Field of view

AROMA-W sees the large field of view by arranging the field of view of the multiple cameras to make a mosaic image. For example, when a EOS 5D and a EF200mm F2.8 lens are combined, the field of view which amounts to $10.2^\circ \times 6.8^\circ$ can be secured. Since this system is designed for the purpose of constant observations to cover 50% of a *Swift* field of view, continuous observations before and after the prompt emission can be achieved. Figure 4 shows an example of the AROMA-W field of view, the BAT/*Swift* field of view and the GBM/GLAST error circle. .

3.3. Multiple bands Observation

The optical filter is placed along with a bayer arrangement on the image sensor of a camera (here we call R', G' and B' to distinguish AROMA filters). Simultaneous multiple bands observations can be achieved with a wide field of view by reading the data of these filters individually. Since the digital cameras employs R', G' and B' filters which differ a little from AROMA (R, V and B), a relation between the new system filters and the AROMA filters should be investigated. Then, a relative photometry in each filter was performed and magnitude relations (i.e., R-R', V-G' and B-B') are investigated. For example, the relations for EOS5D are well fitted by a linear function; R = (0.88 ± 0.02)R'$-(3.1 \pm 0.3)$, B = (0.93 ± 0.02)B'$-(0.2 \pm 0.3)$ and V = (0.90 ± 0.01)G'$-(2.8 \pm 0.2)$, where the quoted errors are 68.3% confidence levels.

3.4. Limiting Magnitude

Limiting magnitudes for all digital cameras were investigated in each filter. The 3σ limiting magnitude of EOS5D (10 times 20 s exposure), for example, were R = 12.8, V = 13.8 and B =14.1. This implies that our new system can observe an optical flash like GRB 990123 with $\sim$ 9 magnitude and GRB 080319B with $\sim$ 5.3 magnitude. Table 1 shows a summary of limiting magnitute in various cases.

3.5. Data Reduction System

The data obtained by observation will be analyzed in parallel and automatically with multiple PCs. Basic processes of the programs are as follows. First, basic data reductions such as dark count subtraction, flatfielding

Table 1. A summary of limiting magnitute in various cases (3σlimit)

Camera	EOS 5D		EOS kiss DN		EOS 5D
Exposure	20sec		20sec		20sec×10
Lens (mm)	200	100	200	200 (no IR)	200
B	13.5	12.7	13.4	13.1	14.1
V	12.8	12.0	12.3	12.2	13.8
R	12.1	10.9	11.9	12.4	12.8

and image conbine are performed. Second, astronomical objects are detected and compared with star catalogs (mainly USNO B1.0). 3000 to 5000 objects are detectable from the data of one camera (EOS 5D). The light curves of magnitude and flux ratio are obtained about all the objects within the AROMA field of view from the acquired data. These processes are done almost simultaneously with observation. By always monitoring the light curves, variable stars and transient objects (GRB, SNe, X-ray nova etc.$\cdots$) should become detectable. And unexpected brightening and variability also may be also detectable. When strong brightening and variability are detected by AROMA-W, AROMA-N will make rapid follow-up observations autonomously. Figure 5 shows a prospective schematic view of AROMA-W and AROMA-N.

4. Possible coordinate observations with MAXI

This section describes about targets and time schedule of the coordinate observation by MAXI and AROMA.

4.1. Observable objects

The targets of the coordinate observation by MAXI and AROMA are SNe and X-Ray Novae besides GRB. Multiple bands simultaneous observation is enabled by X-ray light curves and spectra of the MAXI and the optical light curves of the AROMA. Their generating mechanism and environment should be presumed from the correlation and the time delay of the light curves or spectrum variability.

We verify whether each object can be observe by AROMA below. As for supernovae, optical light and X-rays become very bright. Sence the time scale of them variability is tens of days, and the peak of brightening in optical is about 12∼13 mag (V band) when it is brightest, it can be observed from an early stage also by AROMA-W. Figure 6 shows a light curve of SN 2007sr (Brightest SN in 2007) with the limiting magnitudes of AROMA-W and AROMA-N. As for X-ray novae, part of them become brighter in optical with their brightening in X-ray. Some they can be observed also by the sensitivity of AROMA-W. Generally, after an X ray nova is detected with X ray detectors, such as MAXI, it is observed by visible light, but if a full-time, an extensive view observation like AROMA-W is performed, it may be able to be detected in optical before being detected with X-rays. For example, V4641 Sgr become bright almost every year and it become bright to 9 magnitude in September, 1999. Figure 7 shows a light curve of V4641 Sgr in 2003 with the limiting magnitudes of AROMA-W and AROMA-N.

4.2. Time Schedule

AROMA-W prototype (1∼2 DSLR) operation has started in July, 2008. AROMA-W will start the main operation in November, 2008. Since *Swift* and GLAST are already launched and MAXI will be launched in March, 2009, AROMA-W start the coordinete observations with various satellites (e.g., MAXI, *Swift*, GLAST) in 2009.

5. Conclusion

In order to observe optical afterglows of GRBs, SNe, X-Ray novae, and variable star etc., we are developing the full-time wide-field observation system using multiple digital single-lens reflex cameras. AROMA-W was designed for the purpose of constant observations to covercover 50% of a BAT/*Swift* field of view. Limiting magnitude of AROMA-W is 13∼14 magnitude. AROMA-W can monitor light curves of all the stars which are visible in its field of view. AROMA-W will soon start the simultaneous observation of the transients (e.g., GRBs,X-ray novae, Supernovae) discovered with various detectors, such as MAXI.

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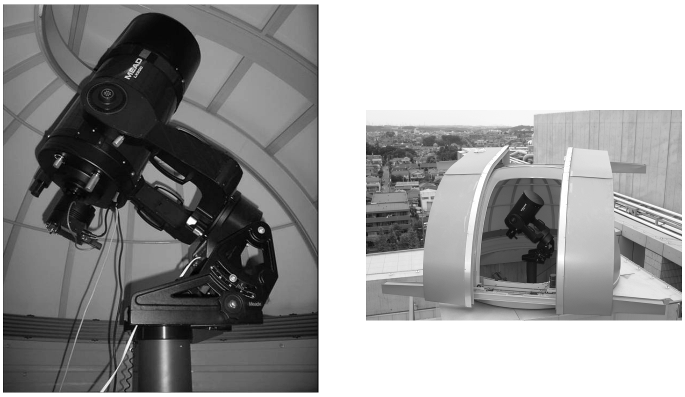

Fig. 1. Overview images of AROMA-N and its dome.

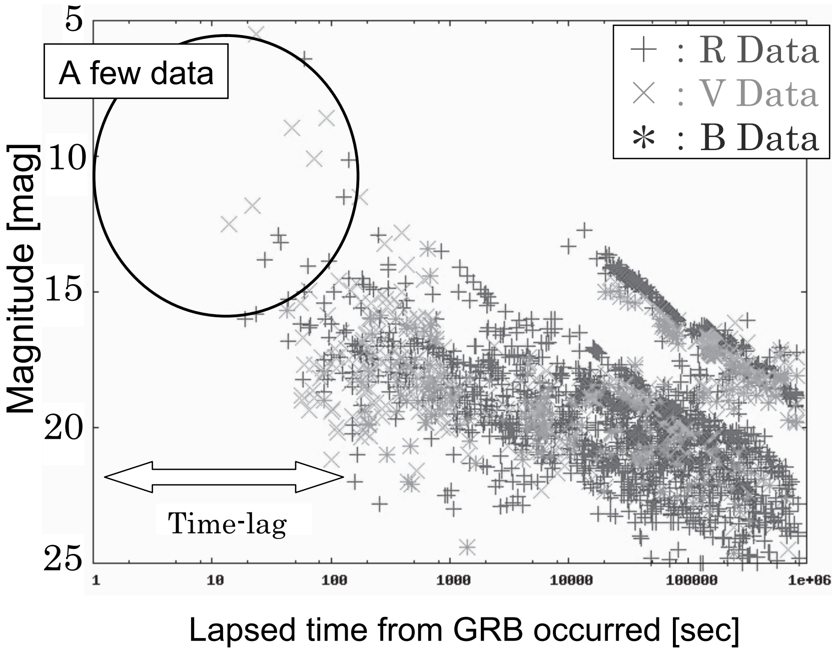

Fig. 2. Light curves of the GRB optical radiation (235 events)

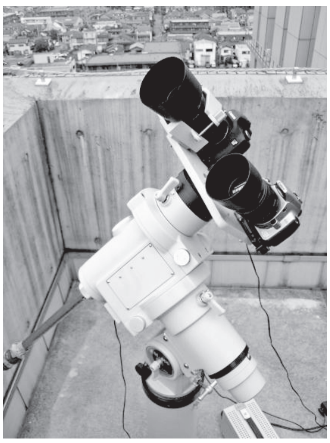

Fig. 3. An overview image of AROMA-W prototype.

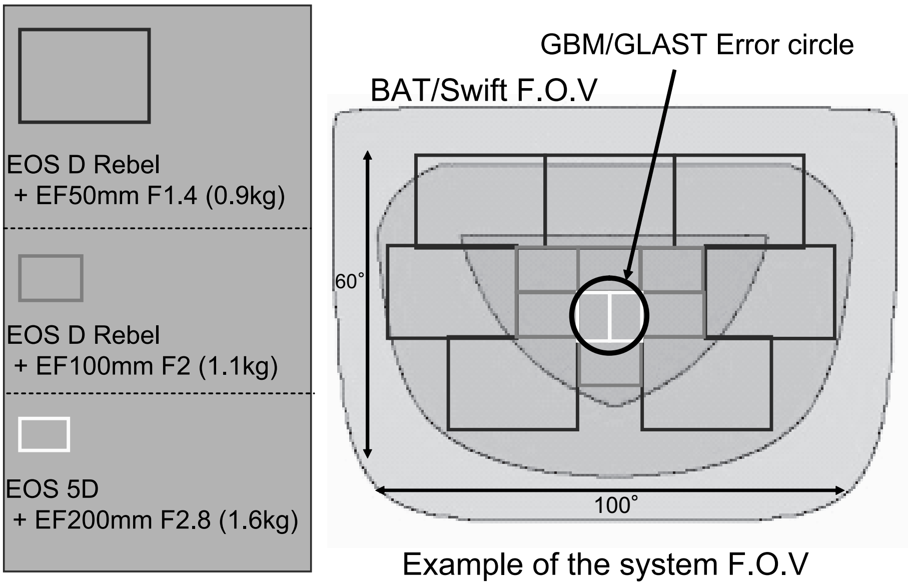

Fig. 4. An example of the AROMA-W field of view, the BAT/*Swift* field of view and the GBM/GLAST error circle

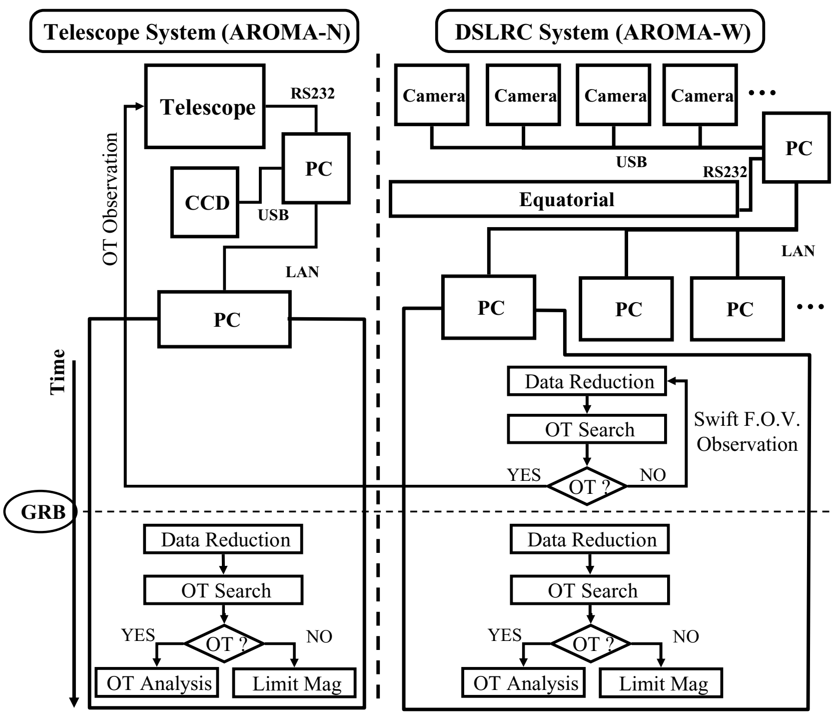

Fig. 5. A prospective schematic view of AROMA-W and AROMA-N

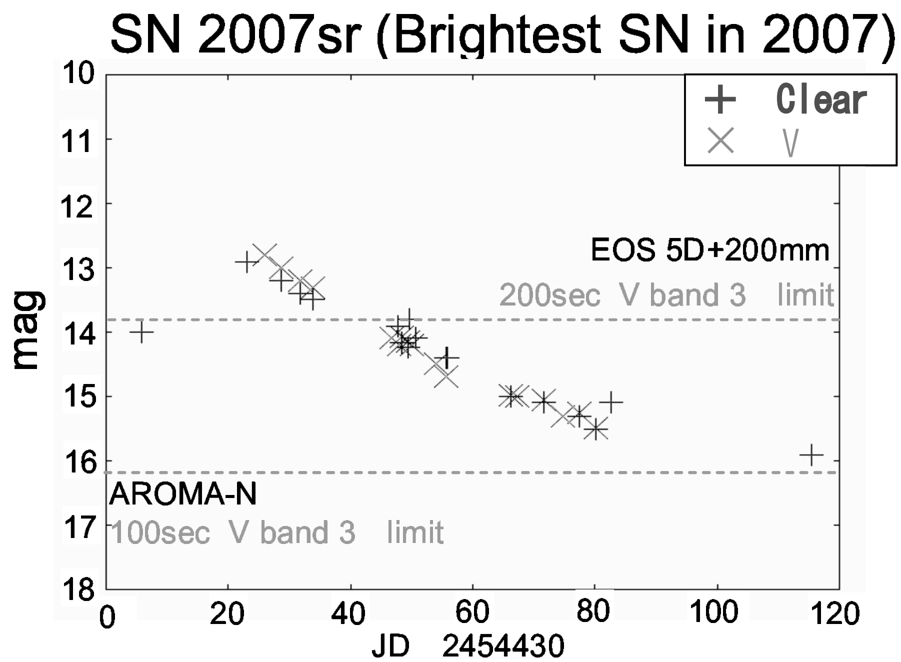

Fig. 6. A light curve of SN 2007sr (Brightest SN in 2007) with the limiting magnitudes of AROMA-W and AROMA-N.

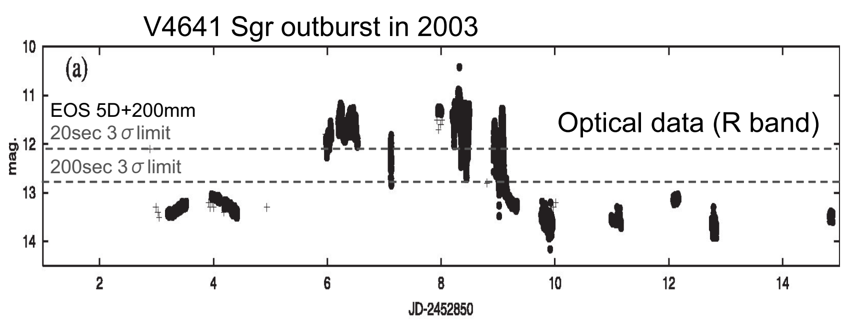

Fig. 7. A light curve of V4641 Sgr in 2003 with the limiting magnitudes of AROMA-W and AROMA-N.