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The search for optical emission on and before the GRB trigger with the WIDGET telescope(*)

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Summary. — *WIDGET* is a robotic telescope for monitoring the *HETE-2* field-of-view to detect Gamma-Ray Burst optical flashes or possible optical precursors. The system has $62° \times 62°$ wide field-of-view which covers about 80% of *HETE-2* one with a 2k×2k *Apogee* U10 CCD camera and a *Canon* EF 24 mm f/1.4 wide-angle lens without a bandpass filter. *WIDGET* has been in operation since June 2004 at Akeno observing site where is about 200 km apart from Tokyo. Typical limiting magnitude with S/N = 3 at the site is $V = 10^{\rm mag}$ for 5 seconds exposure and $V = 11^{\rm mag}$ for 30 seconds exposure. We had already six coincident observations with *HETE-2* position alerts. It was, however, cloudy for all cases due to rainy season in Japan. The expected number of coincident observations under clear sky is about 5 events per year. We will extend the system in early 2005 for *Swift* era to monitor optical transients in wider field-of-view, multi-color or polarization modes.

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1. – Introduction

Detection of optical emission on and before Gamma-Ray Burst (GRB) triggers provide us knowledge of gamma-ray emission mechanism at early stage of an ejecta expansion from a massive star explosion. The optical flash can be produced by a reverse shock in the ejecta [1], or produced from loaded electron-positron plasma by prompt gamma-ray emission [2-4]. Although there is much effort to search such prompt optical emission from GRB, only one flash has been detected as far; during the GRB 990123 was active, very bright optical flash was observed by ROTSE-I telescope at 8.9^{th} magnitude about 50 seconds after the burst trigger [5].

Recently several groups are developing and operating wide-field telescopes for hunting the optical flashes; *e.g.* RAPTOR [6], BOOTES [7], Ashra [8], WFOC [9], π of the Sky [10] and so on. We also started construction of a wide-field telescope named *WIDGET* (Wide-field telescope for GRB early timing) in late 2003.

2. – The *WIDGET* System

The *WIDGET* telescope consists of an *Apogee* Alta U10 CCD camera and a 24 mm f/1.4 *Canon* EF wide-angle lens. The U10 camera uses a 2048×2048 format *Atmel* THX7899 CCD chip with 14-micron pixels. The chip is front-illuminated type with quantum efficiency of 38% at 720 nm. The camera provides a $62^\circ \times 62^\circ$ field of view (FOV). Electronics onboard the CCD camera have been optimized to provide fast readout of the entire array in 5 seconds with a 16 bit AD converter through an USB2.0 serial line. The standard exposure in our operation is 5 seconds, so that we take sky images every 10 seconds. The optics and the CCD camera are attached to a *Takahashi* NJP Temma-2 polar mount. The mount is capable of slewing at a speed of about 90 arcmin/s. It is controlled by an PC running Linux OS via a serial line.

The telescope, related computers and electronics are housed inside the hut whose roof is sliding to one direction. It is custom build by *Human Comm Co. Ltd.* The height and width are 2 meters, and the length is 3 meters (see fig. 1). Control of the roof is provided by relay boards attached on a side-wall of the hut. The relay boards accept commands via a socket connection from a control PC running Linux. The roof is opened and closed according to a preplanned schedule. In case of rain the roof is closed by a circuit connecting to weather stations located outside the hut. When a power outage occurs, the roof is automatically closed by weight of some steel bars without any electrical power. The timing of the whole system is provided by a network timing protocol (NTP) server and a radio clock with an average error less than 1 second.

The *WIDGET* telescope is placed at the Akeno campus which belongs to the Institute for Cosmic Ray Research, University of Tokyo. The site was used for the air shower experiment, Akeno Giant Air Shower Array (AGASA) [11]. Since we design the system for fully automatic operation, almost all of the devices are robust against software errors, hardware failures, or network troubles. We started observations at the site in June 2004, and established the fully automatic operation in September 2004. The station is currently unmanned except for regular maintenance.

3. – System performance

Astrometric and photometric calibrations are based on the standard stars in the Tycho catalog [12]. For calibration and monitoring of data quality, we uses more than 10 well

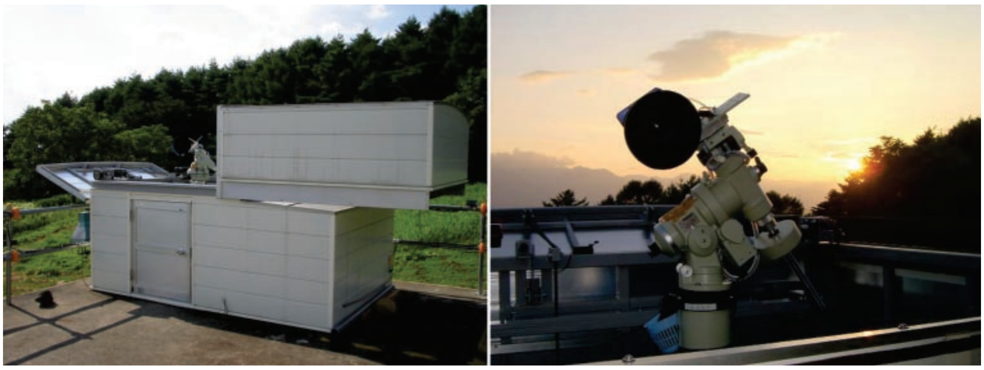

Fig. 1. – Left: The *WIDGET* enclosure hut with a sliding roof. Right: The CCD camera and the wide-angle lens attached on the polar mount housed inside the hut.

calibrated standard stars. The limiting magnitude is about $V = 10^{mag}$ for 5 seconds exposure and $V = 11^{mag}$ for 30 seconds exposure with S/N = 3 at the Akeno observing site. The limiting magnitude is somewhat reduced when the moon is in the FOV. Stability of the magnitude of a star measured by the photometry is about $\Delta V = 0.2^{mag}$ in a night.

Because of the optics distortion, we can not simply fit a celestial coordinate to the whole image. To reduce the distortion effect, we restrict the field for astrometry in the $10° \times 10°$ region which enclose the GRB position reported by a satellite or ground-based observations. As the result, we set the astrometric precision about 1.5 arcseconds even around the edge of the *WIDGET* FOV. Since the precision is well below a size of one pixel, we can identify the position of GRBs on the chip without any ambiguity (fig. 2).

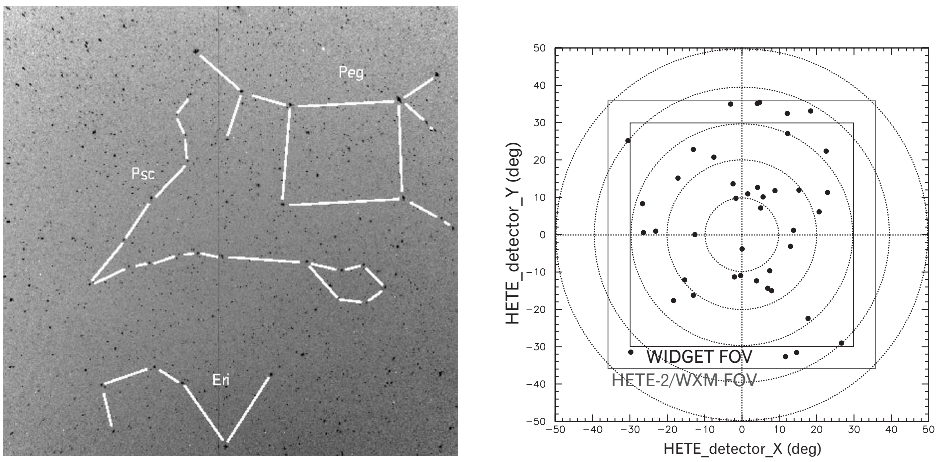

Fig. 2. – Left: A sky image taken by WIDGET measuring 62° on a side. Right: The comparison of the WIDGET FOV (inner rectangle) and the HETE-2 FOV (outer rectangle) in the HETE-2 detector coordinate. Dots in the image denote the GRB positions reported by HETE-2 in the last three years [13].

TABLE I. – *WIDGET GRB observations coincident with the HETE-2 position alerts.*

GRB	Time (UT)	θ_{GRB} (†)	WIDGET status	Results
040810	14:15:35	28°	running	cloudy
040825B	16:21:37	9°	running	cloudy
040912	14:12:16	7°	running	cloudy
040924	11:52:11	34°	running	cloudy
041006	12:18:08	6°	running	cloudy
041211	11:31:51	13°	running	cloudy

(†) Angle between GRB position and the centre of the WIDGET FOV.

4. – Current status and future plans

Since June 2004 where we started scientific operation, we have carried out six coincident observations with *HETE-2* position alerts listed on table I. Unfortunately, we missed all of the chances due to 2004's bad weather condistions in Japan. We continue the automatic observation when it is fine. About five coincident observations are estimated per year under clear sky.

We are extending the system in early 2005 for the *Swift* era. One of the extensions is to add three more telescopes on the mount. Totally four telescopes cover the larger sky area of about $100^\circ \times 100^\circ$ which is fair part of the *Swift* FOV. The other option is to add some bandpass filters for measuring color variation of the GRB optical flashes. Although the present system is not capable of mounting the filters, we can install them by remodeling of the camera attachment. We expect that the color variation will probably tell us the physical conditions or the origin of the optical flashes. The other extension is to add three polarized filters with polarization angles of 0°, 60°, and 120° for measuring polarization of the optical transients. High liner polarization in the optical flashes may be detected in some GRBs [4].

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