Robotic Telescopes for Quick Gamma-ray Burst Observations

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ABSTRACT

The design for robotic telescopes to observe Gamma-ray Burst (GRB) afterglows and the results of observations are presented. Quickly fading bright GRB flashes and afterglows are proved to be a good tool to study an extremely early universe. However, most large ground-based telescopes cannot afford to follow-up the afterglows and flashes quickly within a few hours since a GRB explosion. We re-modeled an existing middle-class 1.3 m ϕ telescope of the near infrared band at ISAS in Japan to mach for the above requirements. We also set up a small telescope of 30 cm diameter with a conventional CCD. These telescopes can monitor a GRB quickly within a few minutes in J, H, Ks and R band with a grism.

Keywords: Near Infrared, telescope, gamma-ray burst

1. INTRODUCTION: GRBS

Since the discovery of an X-ray and optical afterglow of Gamma-Ray Burst (GRB) with BeppoSAX in 1997[1],[2] the distance to several GRBs was established and was proved to be a cosmological,[4] .[5] The most distant GRB ever recorded, based on the optical afterglow is z 6.6.[3] This distance reaches to almost the detection limit of the ground-based large telescopes such as the Subaru and the Keck telescope.[5] On the other hand, a bright optical flash during a burst explosion was also detected from the very limited number of GRBs. In fact, the brightness of the flash of GRB 990123 reached to almost 8.9 magnitude in R-band even at the distance of z$\sim$1.6.[7] These huge brightnesses suggest a possibility to detect GRBs even at a distance of z$\sim$10 or more during the flashes and during the early afterglows. Due to the large redshift, we must use the near infrared to measure a shift of the break of Lyman α line or edge, which is the only good indicator of distance. Thus, it is clear that we need a robotic telescope, which can catch up GRBs within a few minutes in the near infrared band to observe a distant GRB flash. Here, we report the re-modeled telescopes to match for these requirements.

2. OPTICAL SYSTEM

2.1. Telescope

A telescope with a mirror of 1.3 m diameter and F=1.73 is located at the Institute of Space and Astronautical Science (ISAS) in Sagamihara.[6] Both of the Nasmyth and Cassegrain focuses of F = 18 are available. To keep the near infrared detector cool, a mechanical refrigerator is used. The near infrared system is placed on the Nasyith focus and the the R-band CCD system is placed on the Cassegrain focus. These two focuses are quickly exchangable using a tertiaty mirror just above the primary mirror. The acquisition speed of the azimuthal mount is slow of 0.5 degrees per second but enough to acquire an afterglow within a few minutes. This quick aquisition can be achieved using the information of the Swift's aim direction which is distributed from the satellite. Another small telescope in 30 cm daiameter is set up at the roof top of the Kanazawa university. This is a very small telescope but much faster than the large telescope in motion of 10 degrees per second.

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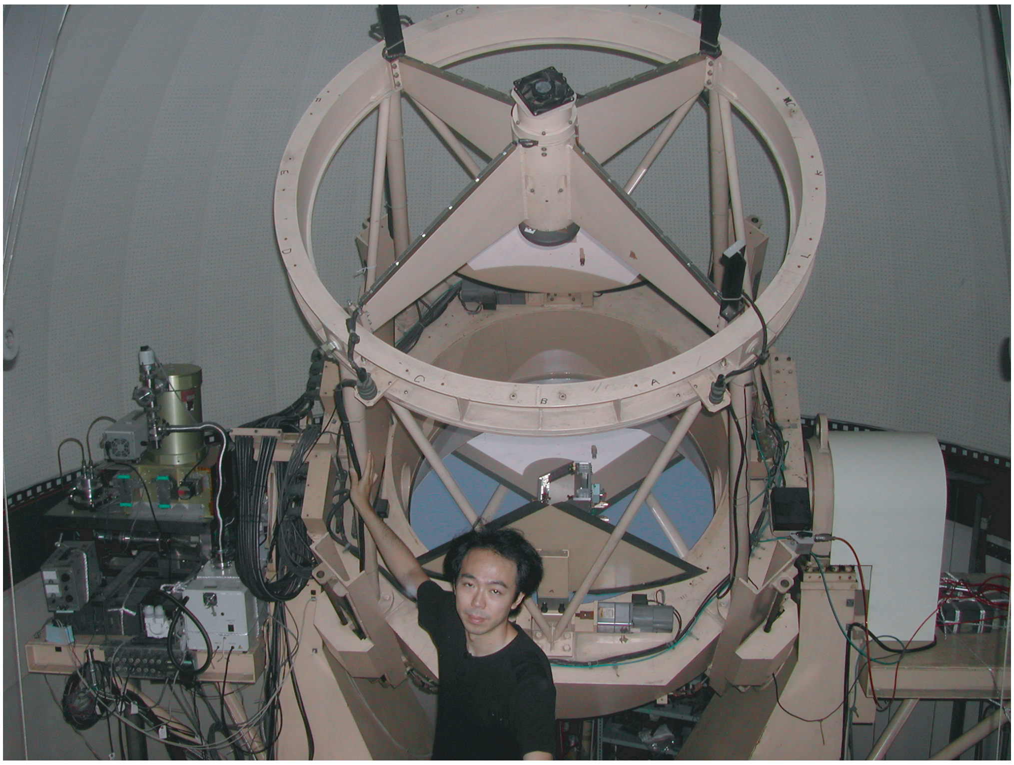

Figure 1. A 1.3 m diameter telescope at the roof top of ISAS, viewing down from the top. The mechanically cooled near infrared detection system is mounted on the Nasmyth table at the left side of this picture. One of the coauthors, D. Yonetoku is standing in front of the telescope. More details of specification of this telescope are shown in the table and also in the attached pictures in each section.

Table 1. Specifications of two telescopes used for Quick GRB observations

Telescope at ISAS	Telescope at Kanazawa
1.3 m diameter	0.3 m diameter
Nasmyth and Cassegrain	Newton
18.4 cm dia. secondary	——
F= 1.73 (primary) and F=18 (Nasmyth)	F =12 (Newton)
FOV: 5.2 arcmin.	30 x 30 arcmin
motion speed: 0.5 deg. /s	10 deg. /s
Azimuthal mount	Equatorial mount

2.2. Filter and grism

To study an early universe, we must determine a distance to GRBs. To decide a distance or a redshift to a GRB, we require a dispersion system or narrow band filters. For this purpose, the ISAS telescope can use the standard J, H and Ks band cooled filters for the near infrared bands. For the optical band, we developed a low dispersion grism to the Cassegrain focus in a conversion-ray just above the CCD camera. A typical size of a GRB position error provided from the Swift satellite is about 4 arcmin radius, so we require to a measure dispersion spectrum to all the stars in the FOV. This requirement matches for a grism. A grism has a capability to measure a redshift inside the large FOV. The grism installed is 200 lines per mm and the dispersion is low of $\delta\lambda/\lambda$ is $\sim$ 50 at 623

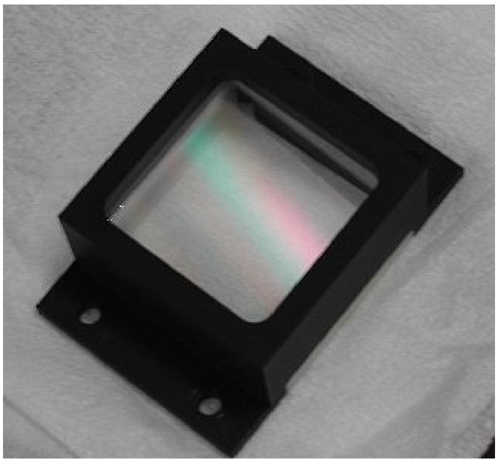

Figure 2. A grism designed for the 1.3 m telescope R band. The number of rule is 200 lines per mm and the size of the grism is 33 x 33 mm and 13.5 mm in thickness. This was inserted into the conversion-ray of the Cassegrain focus.

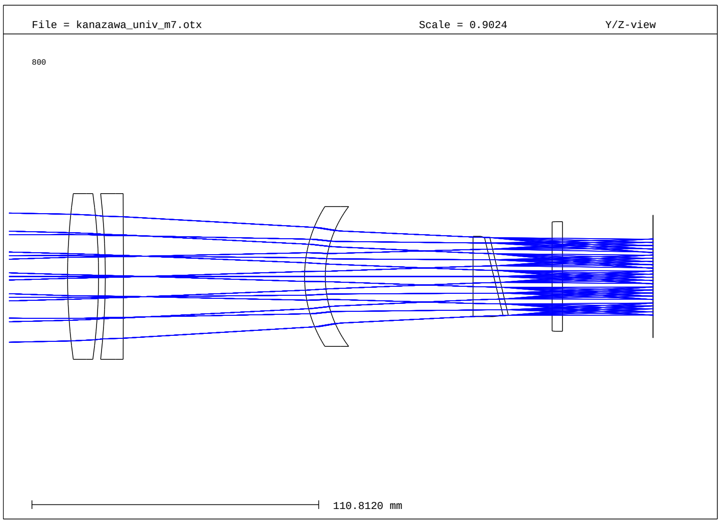

Figure 3. A ray trace simulation to check the quality of focus inserting this grism into a conversion-ray of the Cassegrain focus. The first achromatic lens and the second non-spherical lens are used for a wider FOV. The last flat glass is for an adjustment of the focal length to the case of without the grism.

nm. We could not find a place to insert this grism in a pallarel-ray, so inserted in a conversion-ray. The size of the grism is 33 x 33 mm and 13.5 mm in thickness. A first achromatic lens and the second lens shown in the picture are used for a wider FOV. The last flat glass inserted after the grism is for an adjustment of the focal length without the grism. The grism is inserted in a conversion-ray, we should do a ray trace simulation. A ray trace simulation shown in the figure was done to check the quality of spots to insert this grism into a conversion-ray of the Cassegrain focus. Although inserting a grism in a pallarel-ray is ideal, the quality of the focus or image can be achieved better than 1 arcsec at any position of the FOV even in the conversion-ray. A dispersion image of 3C273 of 12.8 magnitude is shown in figure-2. The Hydrogen α and β are clearly seen. This grism can cover the redshfts roughly between z=2.3 and z=5.6 to the spectral break of the Lyman α line.

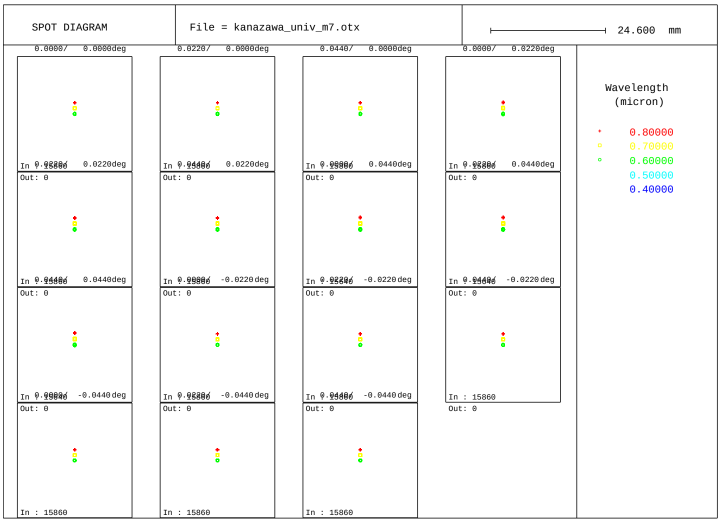

Figure 4. A ray trace simulation to check the quality of focus inserting this grism into a conversion ray of the Cassegrain focus. The figure shows a image quality of dispersion in 600, 700 and 800 nm for several different incident angles.

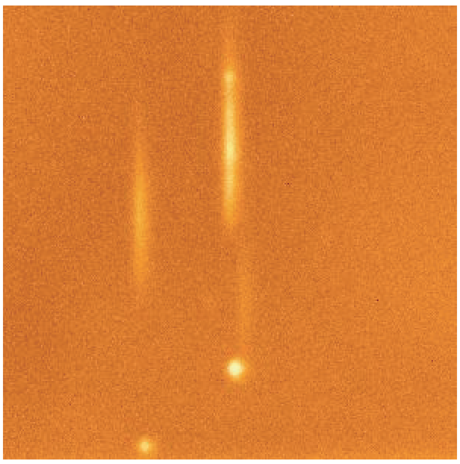

Figure 5. A dispersive image of 3C273 by the grism, mounted on the path of Cassegrain focus. A 0-th order image of the 12.8 magnitude QSO: 3C273 and the dispersive image is seen in the center. The Hydrogen α and β are clearly seen. Refer to the 0-th order spots, we can calibrate the wavelength.

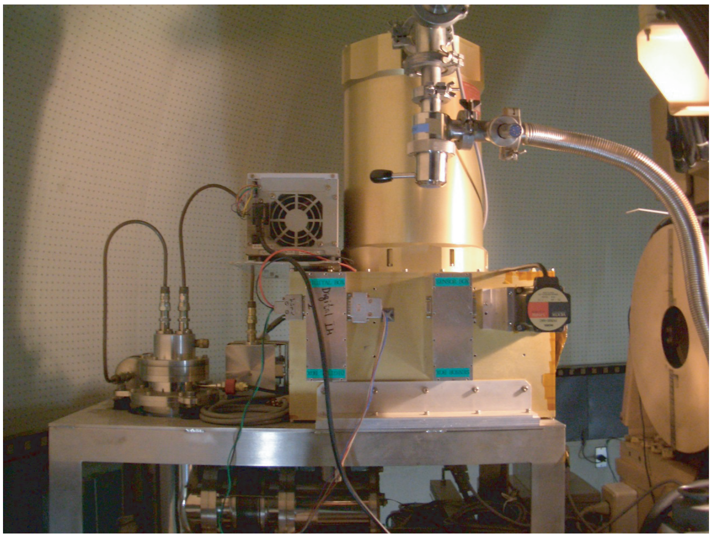

Figure 6. A vacuum chamber of the IR Lab. is used for installing the NICMOS (CdHgTe) chip with 256x256 pixels. At the right side of the picture, a mechanical refrigerator, which is connected to the vacuum chamber beneath the chamber, is mounted to keep this system 70K. The Nasmyth hole is seen at the right side of the picture. A stepping motor to control the three filters of J, H and Ks is also seen on the right corner of the vacuum chamber

2.3. Focal plane detectors: PICNIC and CCD

The detector chip for the 1.3 m Nasmyth focus is the so-called PICNIC (NICMOS: CdHgTe)) by the Rockwell Co. This system is already reported in detail by Kobayashi et al. in the proceeding of the 1993 SPIE symposium at Kona Hawaii.[6] The optical system in the PICNIC consists of three chromatic aberration free metal mirrors. The major changes in design from the previous report in 1993 is the connection to an internet and the use of a mechanical refrigerator installed, instead of the liquid N_2 cooling. To wait for a GRB in long time interval, we require to use a mechanical cooling system instead of the liquid N_2, which requires us to the frequent supply. The detector is a NICMOS of CdHgTe with 256x256 pixels operating at 70K through the Ge lens of an incident window of a vacuum chamber. A CCD used for the 1.3 m Cassegrain focus is a CCD of Kodak: KAF1001E chip with 1024x1024 pixels. A CCD used for the small telescope at Kanazawa is a model of BITRAN: 213E with Kodak KAF0261E chip with 512x512 pixels cooled by a peltier cooler. The spectral response of these chip is very resemble to the Rc band.

Table 2. Specifications of detectors at the focus for two telescopes

ISAS telescope	Kanazawa telescope
NICMOS (Rockwell)	CCD (Kodak)
256x256 pixels CdHgTe	1024x1024 pixels KAF 1001E
J, H, Ks filters with a grism	no filter

3. OBSERVATIONS

3.1. GRB 030329

An observation of GRB 0303029 was done using the 30 cm telescope at Kanazawa. The system respond to an alert mail of the GRBl automatically but due to a small miss-alignment of the telescope, we could not detect the afterglow in the FOV. We thus manually corrected the pointing direction and re-started the observation at

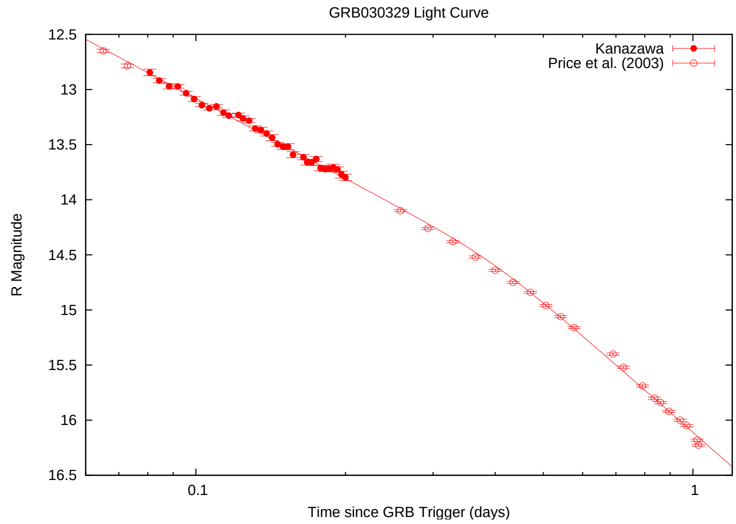

Figure 7. The lightcurve of GRB 030329. The first detections were done by Peterson and Price and Torii. The dots in bold and filled were the data of the Kanazawa telescope. Combining our data with other data, mostly Price et al, the lightcurve showed a break in slope at about 0.4 days after the GRB explosion. Data from B.A. Peterson and P. A Price, GCNs 1985, 1986, 1988 and K. Torii GCN 1986

13:33:34 on 29 March 2003 (UT), roughly 0.08 days delay since the GRB explosion. The first detection of an afterglow was reported by B. A. Peterson and A. Price and also K. Torii in the GCNs 1985 and 1986 respectively. Following their detections, we continued to monitor until dawn. The Kanazawa observation was reported in the GCN 2044.[10] The exposure time of each frame was 30 second and in total 520 frames were obtained. The lightcurve of the Kanazawa observation is shown in the figure together with other observations. When the photometory started, the afterglow was already reached to ∼12.7 magnitude in the Rc-band. To estimate a magnitude of the afterglow, we refereed to the reference stars which were reported by A. Henden in the GCN 2023. It is clear from the figure that a break in the decay slope at 0.4 days after the GRB explosion is seen. This break suggests a jet morphology in the GRB emission. Several days after the our observation, a SNe was discovered, coincide with this position, which is well known as SN2003dh.[8] This association is the second firm case of coincidence a GRB with a SNe following the GRB 980425.[9]

3.2. GRB 041218

The GRB 041218 was detected by INTEGRAL at 15:45:25 (UT) on 18, December 2004. We started the observation of GRB 041218 in 22 minutes after the INTEGRAL detection using the 1.3 m telescope at ISAS under the very bad weather condition. First detection was reported by K. Torii in GCN 2860. At the start of the ISAS observation, this was already darken to about 17th magnitude, so we could not confirm the afterglow using the near infrared system. To estimate a magnitude of the afterglow, we used the reference stars which are reported by A. Henden in GCN 2869 . Combining our data in the GCN 2892[11] with the data of many other observations, the lightcurve of the afterglow is obtained as shown in the figure. It is also clear that there was a break in decay slope at 0.09 days since the GRB explosion. This suggests an existence of a jet configuration in GRB emission.

4. DISCUSSION

The middle size telescope at ISAS, which was not used for a long time, is re-designed to observe the GRB afterglow. Major changes are the connection of this telescope to an internet to control this telescope automatically and the installation of a mechanical cooler, always keeping the near infrared detector cool to 70K. For most case, a distance to a GRB is not known and the measurment of a distance to GRB is the key to explore the early universe. For this purpose, we designed a low dispersion grism in R band, which is inserted the in the conversion-ray. Based

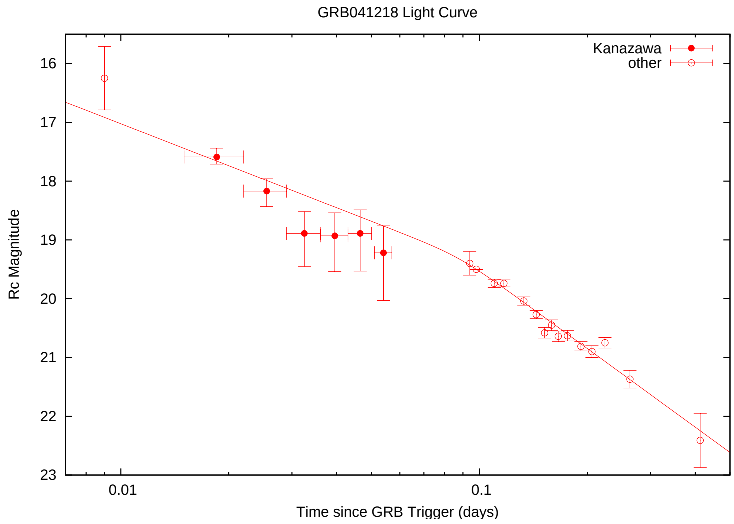

Figure 8. The lightcurve of GRB 041218. The bold and filled dots with error are the data of ISAS. Due to the bad weather condition, the errors of our data are larger than other data. This case also showed a break in slope at 0.09 days after the GRB explosion. Data from K.Torii GCN 2860, J. Gorosabel et al. GCN 2861, G.Greco et al. GCN 2863, J.P. Halpern et al. GCN 2873, B. Shaefer et al. GCN 2875, O. Trondal et al. GCN 2877, A. Monfardini et al. GCN 2878, P. Davanzo et al. GCN 2879, P. Ferrero et al. GCN 2897 and A. Klotz et al. GCN 2904

on the ray trace simulations and a low dispersion requirement, this design is still work within a requirement. Since the launch of the Swift satellite in late 2004, Swift observed GRBs and reported positions of almost 100 GRBs, however the constraints of observation such as the day-time, earth occultation and the bad weather, we only achieved two times in detections and two times in upper limit. We will continue our observation for three more years using this system to detect a distant GRB, which will reach to nearly z$\sim$10 where the most ground based telescope cannot to access.

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