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Kiso observations of 20 GRBs in the HETE-2 era(*)

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Summary. — We established a GRB follow-up observation system at the Kiso observatory (Japan) in 2001. Since prior to this the east Asian area had been a blank for in GRB follow-up observational network, this observational system is very important for studying the temporal and spectral evolution of early afterglows. We have thus been able to make quick observations of early phase optical afterglows based on *HETE-2* and *INTEGRAL* alerts. Thanks to this quick follow-up observational system, we have so far been able to use the Kiso observatory to monitor 20 events, and conduct follow-up observations in the optical and near-infrared wavelengths.

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1. – Kiso observatory

The TOO system for prompt GRB follow-up observations has been in operation at the Kiso observatory since 2001 [1]. We have also established a follow-up observation system based on this system at the Lulin observatory, Taiwan [2]. The Kiso observatory is located in Nagano-Prefecture, Japan, It has a 105 cm Schmidt telescope and two other instruments, a 2k × 2k CCD camera, and a near-infrared camera named KONIC (Kiso Observatory Near-Infrared Camera). The 2k×2k camera's FOV is 50×50 arcmin and the limited magnitudes are 22.0 mag, 22.5 mag, 21.0 mag and 21.0 mag. (for each B, V, R, I band, 10 σ, 900 s exposure). The KONIC's FOV is 20 arcmin and the limited magnitude are 13.0 mag, 12.3 mag and 10.8 mag (for each J, H, K band). Otherwise, we also use

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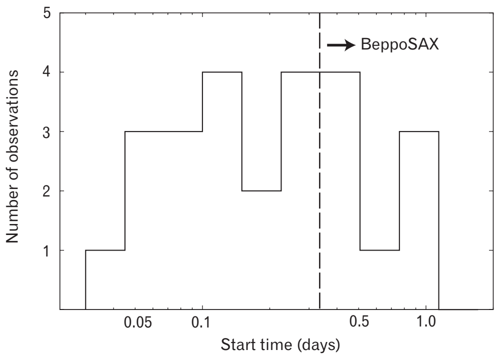

Fig. 1. – The number of follow-ups, plotted against the time when the observations were started. The dashed line indicates the typical delay time of the *BeppoSAX* alerts (~ 8 hours).

two objective prisms. These prisms allow low-dispersion slit less spectroscopy with a 2k $\times$ 2k CCD. The FOV is 50 $\times$ 50 arcmin.

2. – Observations

We have thus made 20 follow-up observations in response to the *HETE-2* and *INTEGRAL* alerts, and successfully detected the optical afterglows of 6 GRBs. There 20 observations (16 GRBs and 4 XRFs) were performed earlier than the delay timing (~ 8 hours) of the *BeppoSAX* position alerts (see fig. 1). In the *BeppoSAX* era, the afterglows were only observable for a single power-law, or at best, the jetted achromatic broken power-law behavior could be seen.

3. – Results

3·1. *GRB 030329.* – In fig. 2, we plot the *Rc* band light curve of the afterglow of GRB 030329, based on our photometry, using the Kiso and RTT150 data. Over a time range of 0.075–0.293 days, the light curve is well fitted for a single power law, which temporal index is $\alpha = -0.894 \pm 0.004$ with a reduced $\chi^2(\chi^2/\nu)$ of 1.12 for $\nu = 53$ [3]. In order to better constrain the early (< 0.3 days) behavior of the light curve, we combined our data with the two *Rc* band photometric points observed using the SSO 40-inch telescope

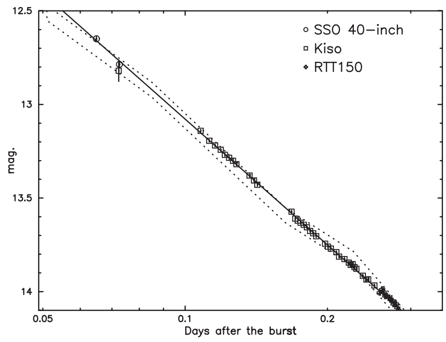

Fig. 2. – The *Rc*-band light curve based on the photometry at Kiso, shown together with the SSO [4] and the RTT150 [5] data points. The solid line indicates the best fit power-law to the Kiso, RTT150 and SSO points. The dashed lines indicate ± 0.04 mag error band around the unfiltered light curve reported by Uemura *et al.* [6].

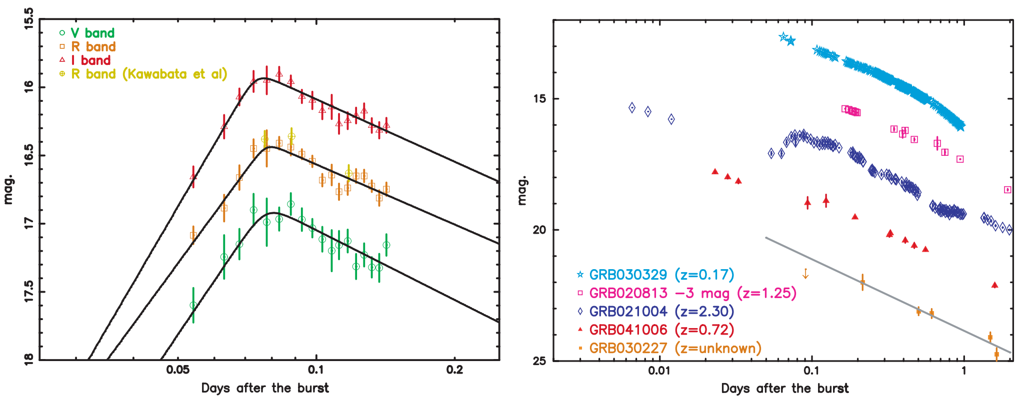

Fig. 3. – Left: the V, Rc and Ic band light curve of GRB 021004. The solid lines indicate the best fit power law functions. Right: the Rc band light curves of the 5 GRB afterglows which we observed in the early phases.

and reported in Price *et al.* [4]; $Rc = 12.6 \pm 0.015$ at 0.065 days and $Rc = 12.786 \pm 0.017$ at 0.073 days. These observations are among the earliest filtered observations of this afterglow. We have successfully fitted the combined Rc band light curve again to a single power law, form which the decay index is -0.891 ± 0.003, with $\chi^2/\nu = 0.817$, for $\nu = 36$. Thus, we have successfully fitted the very early (0.065–0.293 days) Rc band light curve to a single power law. Obviously, our light curve does not show the wriggle structure reported by Uemura *et al.* [6]. For a more quantitative comparison, we tried to fit the present light curve (Kiso, SSO and RTT150) to the best-fit model function reported by Uemura *et al.* [6], in which the all over normalization alone is allowed to vary. The fit failed with $\chi^2/\nu = 6.91$ for $\nu = 50$. Based on this large value of χ^2/ν, we can rule out Uemura *et al.*'s model (2003), at a more than 99.99% confidence level.

There are two possible explanations for the structures reported by Uemura *et al.* [6], and Sato *et al.* [7]. First, Uemura *et al.* included a variable star in their list of standard stars, and used it in their calibrations. Second, an "under-sampling system" (which means that the pixel scale for the sky is larger than the point spread function of the sources), due to using a "front illuminated CCD", which potentially produce a wiggling light curve, even if we observe stable objects. This is because the electrode structure on the CCD chip reduces the brightness of as object located on it. When observations are performed with de-focus, or larger-sized seeing conditions, this effect is relaxed [8]. They however do not discuss the information of their system clearly, such quick GRB observations system tend to lead to "under-sampling" when entire GRB error regions are concerned.

3·2. *GRB 021004*. – We started follow-up observations of the GRB 021004 field with a 1.05 m Schmidt telescope at 12:06:13 UT on 2002 October 4 (80 min after the burst). The early afterglow spectrum was first detected utilizing the strong point of the slit-less spectrometes before optical identification. The spectrophoto metric results are plotted together with the Bisei Rc band points [9] as seen in fig. 3 (left). The Ic, Rc and Ic band light curves early show the re-brightening phase. The photometric points are fitted to smooth broken power law function. The re-brightening is independent of the color. Its indices are ~ -2. These characteristics are different from the predictions of the standard afterglow model. The temporal index $\alpha_1 \sim 2$ is steeper than that of the value (~ 0.5)

predicted by the standard afterglow model. The reddening maps of Schlegel *et al.* [10] give a galactic reddening of $E_{B-V} = 0.060 \pm 0.020$ mag in the optical afterglow direction. The corresponding Galactic extinction are $A_V = 0.195$, $A_{Rc} = 0.160$, and $A_{Ic} = 0.116$. The spectral index at 0.142 days after the burst is $\beta = -1.01 \pm 0.10$. Although, the light curves are not consistent with the standard afterglow model for < 0.1 days, the β at 0.142 days is close to value predicted by the model, in the regime of $\nu_c < \nu_{opt}$, with a spherical geometry.

3˙3. *GRB 030227*. – In fig. 3 (right), we plot the upper limit together with the Rc band photometric points reported by Castro-Tirado *et al.* [11]. The single power law function which has an index of $\alpha = -1.10 \pm 0.14$ with $\chi^2/\nu = 1.53$ [11] is also shown. Over a period of 0.09–0.1 days after the burst, our upper limits give stronger constraints than the back-extrapolated power law evolution line. These results imply that there is a plateau phase around 0.1 days after the burst, as found for GRB 041006 [12]. According to the standard afterglow model, the afterglow component is expected to show a brightening phase with a temporal index about 0.5. Thus, the break time is constrained as 0.12–0.20 days after the burst, and the upper limit of the peak calculated brightness is $Rc = 21.3$. The former value is close to that of GRB 041006 in the Rc band, ~ 0.1 days.

As described, the early light curves of 4 out of 5 afterglows (fig. 3 right), GRB 020813 [13], GRB 021004 [14], GRB 041006 [12] and GRB 030227, also deviate significantly from the single power-law decay. Such effects are particularly prominent in the cases of GRB 041006, GRB 030227 and GRB 021004. In fact, the Rc band light curve of the GRB 041006 afterglow exhibits a plateau phase around 0.09 days [12]. The afterglow of GRB 021004 shows a clear re-brightening phase which peak at ~ 0.07 days [14] and that of GRB 030227 is suggestive of a similar plateau at 0.12–0.20 days after the burst. These results, based mainly on our own data, also indicate that the early optical afterglow emissions are composed of two components: the initial "flash" or other jet component emissions which have a fast power law decline and the genuine afterglow component, which emerges after of a few hours.

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