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Relation between prompt emission and afterglow of GRBs observed by HETE-2 and BeppoSAX(*)

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Summary. — HETE-2 and BeppoSAX have localized and reported more than 110 GRBs. For about a third of them, optical afterglows have been detected and about 30 of them have known redshifts. Moreover, recent rapid follow-up observations enable us to study dim afterglows (so-called dark bursts) and afterglows of XRFs. We have studied properties of prompt emissions (E_{peak}, fluence) observed by HETE-2 or BeppoSAX and properties of optical afterglows (flux) reported in the literature and GCN circulars. We have found that the correlations between fluence of prompt emissions and flux of optical afterglows are significant in 0.03–0.1 day time interval. We will discuss implications of these results on the GRB mechanism, such as conversion efficiency from the kinetic energy into radiation, geometry of the jet, and their relation with the properties of the prompt emission.

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1. – Introduction

So far HETE-2 and BeppoSAX have observed and localized more than 110 GRBs. However, only $\sim$ 40% of them have optical transients (OTs). There are more bursts without optical counterparts, which are called "optically dark bursts". Our aim on this work is to find the properties of the prompt emission that control the darkness/brightness of optical afterglows from the study of correlation between the properties of the prompt emissions and the brightness of optical afterglow.

2. – Data analysis

In order to study correlations between the properties of prompt emissions and the brightness of optical afterglows, we collected data of prompt emissions and afterglows from from papers published in journals and GCN circulars.

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Table I. – *Statistics of the detection of optical afterglows.*

Source of localization	BeppoSAX	HETE-2
Number of well-localized GRBs	55	61
Detected optical afterglows	16	22
Number of events used for this study	11	41

2˙1. *Data of prompt emissions.* – We chose the following parameters for the correlation study:

1. the observed spectral peak energy ($E_{\rm peak}$)
2. the energy fluence in 2–30 keV and 30–400 keV ($S_{\rm X}$ and S_{γ}).

Most of the data of the parameters of prompt emissions we used were taken from the published papers. For the parameters of the bursts detected by BeppoSAX, we used the values in Amati *et al.* [1]. For the parameters of the bursts detected by HETE-2, we used the values by Sakamoto *et al.* [2].

2˙2. *Data of optical afterglows.* – BeppoSAX reported 55 GRB locations and HETE-2 reported 61 (as of middle of October 2004). We collected information on observations of optical afterglows of these GRBs from papers published in journals and GCN circulars. The collected data include both positive detections and upper limits (U.L. hereafter). With the examination of these results, we found that only 1/3 of the well-localized GRBs have confirmed optical afterglows. Details are shown in table I.

Each piece of the optical afterglow data consists of the observed epoch and the observed magnitudes (or upper limits in some cases). The data are extremely inhomogeneous in sensitivities and the elapsed time as measured from the burst onset. We therefore attempt to homogenize the data by using the afterglow magnitude observed at similar epochs.

In order to evaluate the measurements of the time-variable light curve, we estimated time-resolved magnitude of each afterglow. First, we divided light curves of afterglows in time by half order of magnitude of the elapsed time since the burst. Almost all of the afterglow observations are covered by the time interval from 0.001 day to 300 days after the burst. Therefore, we took 11 intervals logarithmically spaced by a half order of magnitude (0.001–0.003, 0.003–0.01, $\cdots$, 30–100, 100–300 days). Then we determined the representative magnitude of OT for each time interval with the following procedure (see fig. 1).

Time interval with multiple upper limits: adopt the dimmest upper limit as the limit for the time interval,

Time interval with a single upper limit: adopt the upper limit as the limit of the time interval,

Time interval with upper limit(s) and a single detected point: adopt the detected point as the brightness of the time interval and ignore limits,

Time interval with single detected point: adopt the detected point as the brightness of the time interval,

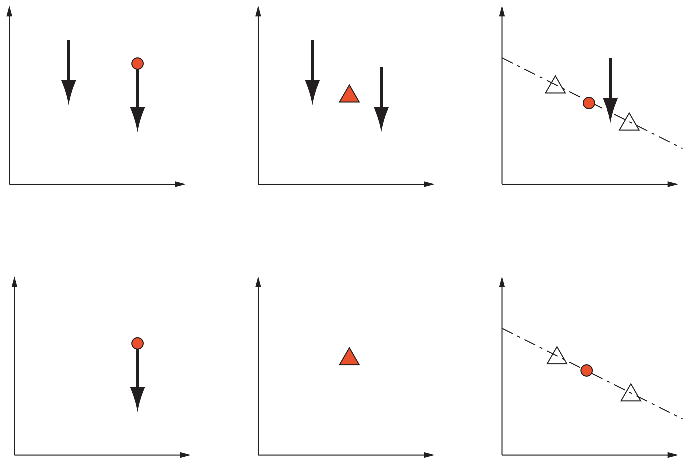

Fig. 1. – The definition of the data in each time interval (see text).

Time interval with upper limit(s) and detected points: fit the detected points to a power law function (with the power law index fixed to −1 if data are not sufficient) and estimate the brightness at the middle of the time interval where upper limits are ignored,

Time interval with multiple detected points: fit the detected points to a power law function (with the power law index fixed to −1 if data are not sufficient) and estimate the brightness at the middle of the time interval.

3. – Correlation study

Using the data described in the previous section, we examined the correlation between properties of prompt emissions and brightness of optical afterglows.

To evaluate the significance of correlation, we calculated the significance level for the independence of properties (*i.e.*, no correlation) of prompt emissions and afterglows. We used the method introduced by Brown *et al.* [3, 4] (BHK method) to calculate null hypothesis probabilities; *i.e.*, the probability to see a correlation when there is no real correlation. This method has an advantage of being able to make use of upper limit data.

Figure 2 shows the significance of correlation. The significance of correlation is more or less sensitive to the number of samples. Therefore, we plotted both significance of correlation and number of data in a figure. From the figure, fluence of prompt emissions have significant correlation with OT magnitude in 0.03–0.1 day time interval. The significance of the correlation between fluence in 2–30 keV and OT magnitude in 0.03–0.1 day time interval is $\sim 99\%$. The significance of the correlation between fluence in 30–400 keV and OT magnitude in 0.03–0.1 day time interval is $\sim 98\%$. It is interesting to know the correlation in the even earlier time interval ($t < 0.03$ day). There are, however, much fewer samples in the time interval earlier than 0.03 day. We need more observations in early time, especially earlier than 0.03 day after the burst (*i.e.*, < 1 hour).

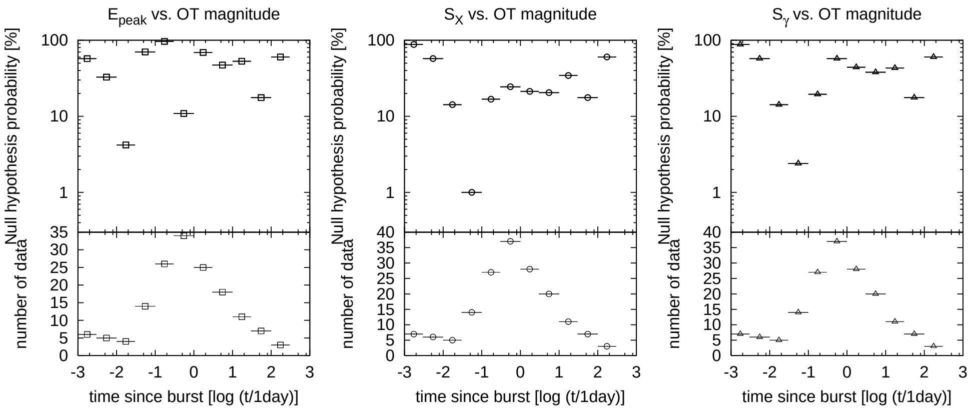

Fig. 2. – The summary of the significance of correlation. The top panels are null hypothesis probabilities and bottom panels are the number of data in the time interval.

4. – Discussion

As shown in fig. 2, the relation between fluence in 2–30 keV and OT magnitude in 0.03–0.1 day time interval is more significant (null hypothesis probability of the data set is 1.0%) than other combinations. It is important to know the probability of obtaining such high significance by chance. In order to evaluate the probability we used the data of 2–30 keV fluence *vs.* OT magnitude in 0.3–1 day time interval as original data set and took data points randomly to produce subset which contains 14 data points (the number of the data set of fluence in 2–30 keV and OT magnitude in 0.03–0.1 day time interval). We repeated random pickup 1000 times and calculated correlation significance for each subset. Although the original data set does not have significant correlation (null hypothesis probability of the data set is 24.4%), 22 out of 1000 subsets have null hypothesis probabilities less than 1%. The result means the good correlation between 2–30 keV fluence and OT magnitude in 0.03–0.1 day time interval might be due to poorness of data points. We need more observations to confirm the results. Swift will play an important role in such a study.

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