Spectral lag analysis of GRBs deteceted by HETE-2

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Abstract

Spectral lags of gamma-ray burst (GRB) become a valuable tool in the study of its radiation mechanism. We present the analysis of the spectral lags in a GRB sample from HETE-2 satellite. Using WXM and FREGATE on HETE-2, we can study the lags between the traditional gamma-ray band (30-400 keV) and the X-ray band (2-25 keV). We derive relations between peak lag, peak luminosity and duration in GRB pulses in the wide band of HETE-2. These results are consistent with those of BATSE and we verify that the BATSE correlations are still valid at lower energies (6−25 keV).

Key words: gamma-rays: bursts — X-rays: bursts

1. Introduction

Prompt emission of gamma-ray bursts (GRBs) should carry the key to clarify the emission mechanism and origin of the explosion.

One of the characteristics of GRB prompt emission is the spectral lag. It is the delay of the photons in the soft energy band with respect to the higher energy band in the GRB light curve. From the theoretical point of view, the spectral lag is important because it could be an indicator of the jet opening angle and of the Lorentz factor(Ioka & Nakamura 2001). Empirically from analyses of GRBs detected by BATSE, the spectral lags show correlation with both GRB peak luminosity and time history morphology; GRBs with shorter lags have higher variability and greater luminosities than long-lag, smooth bursts (Hakkila et al. 2007). Furthermore, Hakkila et al. 2008 derived a new peak lag versus peak luminosity relation in GRB pulses. This result shows that GRB spectral lags are pulse rather than whole burst properties, implying that most GRB pulses have similar physical mechanisms.

HETE-2 satellite has two scientific instruments, the Wide-field X-ray Monitor (WXM, 2−25 keV) and French Gamma-ray Telescope (FREGATE, 6−400 keV). We study the prompt emission of GRBs in a lower enegy band (2−25 keV) than that of BATSE instruments (25 keV −2 MeV). We examine if the correlations found in the BATSE gamma-ray bands also hold for the lower-energy bands.

2. GRB samples and spectral lag measurements

We study a sample of 16 pulses from 9 GRBs with known redshift (Table 1). Each pulse is fitted with a five-parameter pulse model (Norris et al. 1996)

Table 1. GRB samples

GRB	redshift
010921	0.45
020127	1.9
020819B	0.41
021004	2.33
021211	1.01
030528	0.78
040924	0.86
041006	0.45
050408	1.24

$$I(t) = A\exp\left(-|t-t_{max}|/\sigma_r\right)^{\nu} \quad t < t_{max}, \quad (1)$$
$$= A\exp\left(-|t-t_{max}|/\sigma_d\right)^{\nu} \quad t > t_{max}, \quad (2)$$

with background, where t_{max} is the time of the pulse's maximum intensity A, σ_r and σ_d are the rise ($t < t_{max}$) and decay ($t > t_{max}$) time constants respectively. ν is a measure of pulse sharpness (lower values imply a more peaked pulse). Pulses and background are fitted simultaneously over the whole burst using chi-square fitting routine ROOT (http://root.cern.ch/).

Spectral peak lags are defined as the difference between the maximum-intesity times (t_{max}) in different energy bands. Other measurable pulse properties include the pulse duration $w = (3^{\frac{1}{\nu}}\sigma_r + 3^{\frac{1}{\nu}}\sigma_d)$ defined as the time intervals where intesities equal to Ae^{-3}. We calculate the spectral lags between 6−25 keV and 50−400

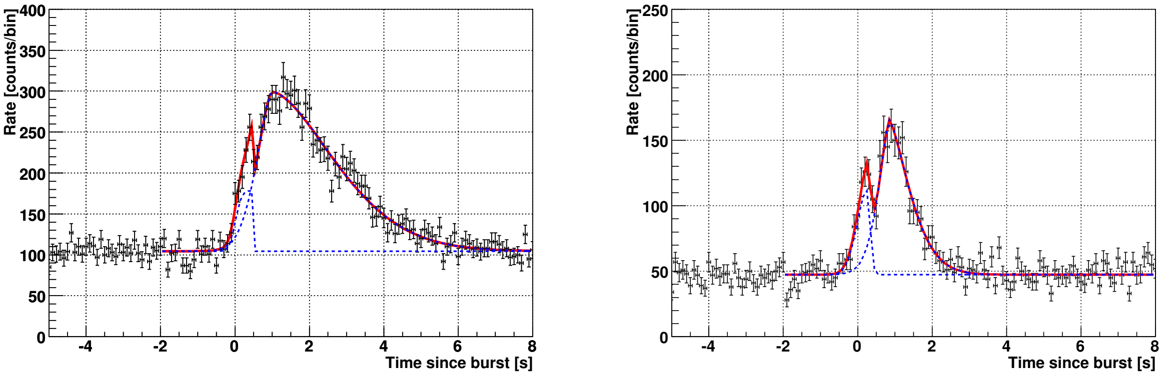

Fig. 1. Pulse-fitting result: GRB 021211 to 6−25 keV (left panel) and 50−400 keV (right panel).

keV using FREGATE light curve.

3. Discussion

We present an example of analysis procedures in 6−25 keV and 50−400 keV bands (GRB 021211, Fig. 1). GRB 021211 has two pulses: the first pulse has a lag of 0.246 $\pm$ 0.098s and the second one has a lag of 0.153 $\pm$ 0.094s. The durations w are 0.90 $\pm$ 0.26s and 2.53 $\pm$ 0.50s in the high-energy band, respectively. The spectral lag, pulse duration and pulse peak luminosity have been corrected to the GRB rest frame. In this case ($z = 1.01$ for GRB021211), the spectral lag becomes 0.122 $\pm$ 0.049s and 0.076 $\pm$ 0.047s, durations 0.45 $\pm$ 0.13s and 1.26 $\pm$ 0.25s and peak luminosity (1.26 $\pm$ 0.31) $\times$ 10^{52}erg/s, (0.48 $\pm$ 0.03) $\times$ 10^{52}erg/s, respectively. We do the same procedure for the other GRBs. The results are shown in Fig. 2 and Fig. 3. In Fig. 2, the pulse duration versus pulse lag is plotted and Fig. 3 shows the pulse luminosity versus pulse lag in the rest frame. We find that lag increases as pulse duration increases and pulse luminosity decreases. These correlations are most likely strong and we verify that similar correlations found in the BATSE gamma-ray bands also hold for the lower-energy bands. This implicates that each GRB jet emits X-ray photons with similar mechanisms in the X-ray band (6−400 keV). This result likely becomes a key to the energetics, jet structure, theoretical shock modeling and so on.

The analysis is done between 6−25 keV and 50−400 keV bands in the *observer* frame. In this situation, we cannot remove cosmological effect. To exclude the extrinsic effects, we need to do the analysis between two bands in the *rest* frame. The result of this analysis will be reported.

We thank the *HETE-2* team for their contributions. This work has been supoorted by Japanese Grant-in-Aid for Young Scientists (B) 20740102.

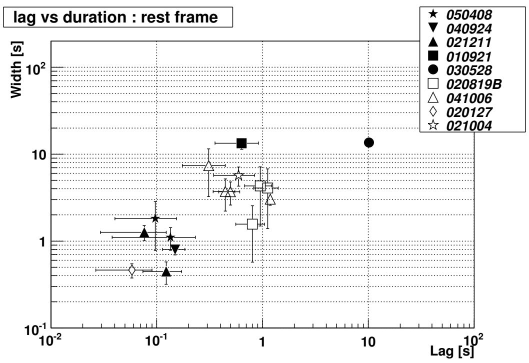

Fig. 2. Pulse duration vs. pulse lag for pulses between 6−25 keV and 50−400 keV. The same symbol represents the same GRB (16 pulses from 9 GRBs).

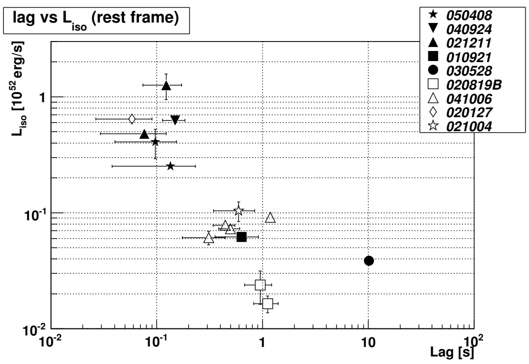

Fig. 3. Isotropic pulse peak luminosity vs. pulse lag for pulses between 6−25 keV and 50−400 keV.

References

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