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Different Luminosity Correlation of GRBs

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Abstract. We report our recent understanding about a tight correlation between relative spectral lag and luminosity (or redshift) for γ-ray bursts. The latest investigations indicate that the empirical correlations got from BATSE bursts also exist for Swift/BAT ones. The special luminosity-lag correlation is much similar to that of the luminosity with pulse number proposed by Schaefer (2003), but largely different from most others ever discovered. Note that our newly built luminosity-lag correlation predicts that luminosity should evolve with cosmological redshift as $L_p \propto (1+z)^{2.4\pm0.7}$ that is excellently confirmed by Salvaterra *et al.* (2012) and Geng & Huang (2013). In addition, it is also surprisingly found that the luminosity-lag correlation can account for both long and short Swift/BAT bursts, which might be an evidence of the same radiation mechanism for diverse burst groups.

Key words. γ-ray bursts: general—radiation mechanisms: non-thermal—methods: numerical.

1. Introduction

In the past ten years, several empirical luminosity correlations of gamma-ray bursts (GRBs) had been discovered and some of them were proposed for cosmological studies (see Zhang (2007) for a review). Using nine BATSE bursts, Zhang *et al.* (2006) also put forward a new luminosity/redshift estimator of Relative Spectral Lag (RSL), between energy bands 1 and 3, $\tau_{\mathrm{rel},31}$, which is defined as the ratio of spectral lags (τ) to the Full Width at Half Maximum (FWHM) of the light curve, viz. $\log z = (1.6 \pm 0.2) - (9.7 \pm 1.9)\tau_{\mathrm{rel},31}$ and $\log L_p = (55.4 \pm 0.6) - (23.1 \pm 4.9)\tau_{\mathrm{rel},31}$ with higher confidence level. Because either τ or FWHM is proportional to $(1+z)/\Gamma^2$ and $E^{-0.4}$, respectively, the definition of RSL has thus eliminated the influence of the Doppler effect, cosmological expanding as well as the instrumental effect. In such a sense, RSL would be an intrinsic quantity. Based on the method of Separate Variable Function (SVF, Schaefer & Collazzi 2007), Zhang *et al.* (2008) tested the luminosity-lag correlation and concluded that it was indeed a prospective cosmological distance indicator.

2. Recent results

Very recently, Zhang & Zhang (2012) re-analysed ten Swift long GRBs with single-pulsed FRED profile. In Fig. 1, they got a similar correlation between redshift (or distance) and RSL, parametrized as $\log z = (1.1 \pm 0.5) - (11.8 \pm 5.4)\tau_{\rm rel,31}$ with a slightly smaller confidence level than that of BATSE bursts. Five luminosity correlations including peak energy vs. isotropic energy ($E_{\rm p} - E_{\rm iso}$, Amati *et al.* 2002), peak energy vs. jet-corrected energy ($E_{\rm p} - E_{\gamma}$, Ghirlanda *et al.* 2004), peak energy vs. peak luminosity ($E_{\rm p} - L_{\rm p}$, Yonetoku *et al.* 2004), pulse number vs. peak luminosity ($N_{\rm p} - L_{\rm p}$, Schaefer 2003) and $\tau_{\rm rel,31} - L_{\rm p}$ (Zhang *et al.* 2006) are compared and displayed on the right panel of Fig. 1, from which we find that $N_{\rm p} - L_{\rm p}$ and $\tau_{\rm rel,31} - L_{\rm p}$ follow the same evolution of SVF with redshift, unlike other three correlations, from pre-Swift to Swift era. This implies that $N_{\rm p} - L_{\rm p}$ and $\tau_{\rm rel,31} - L_{\rm p}$ are most probably two intrinsic luminosity correlations. Moreover, larger discrepancies of SVF between pre- and post-Swift bursts at higher redshifts can be obviously

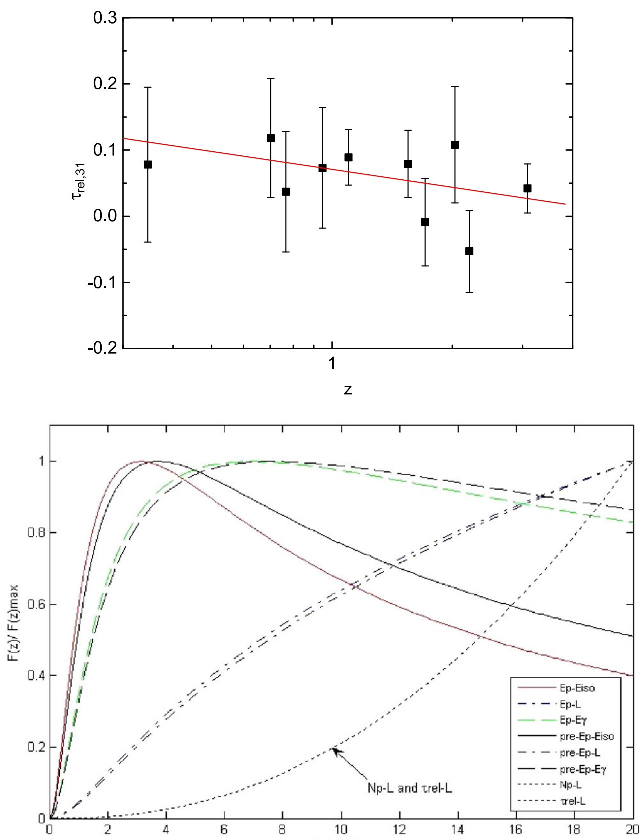

Figure 1. *Top panel*: Correlation between $\tau_{\rm rel,31}$ and redshift for ten Swift long bursts. The best fit to observations is symbolized by the solid line. *Bottom panel*: Relative SVF vs. redshift. The black lines stand for those correlations obtained from pre-Swift GRBs. Coloured lines stand for correlations derived from Swift long bursts.

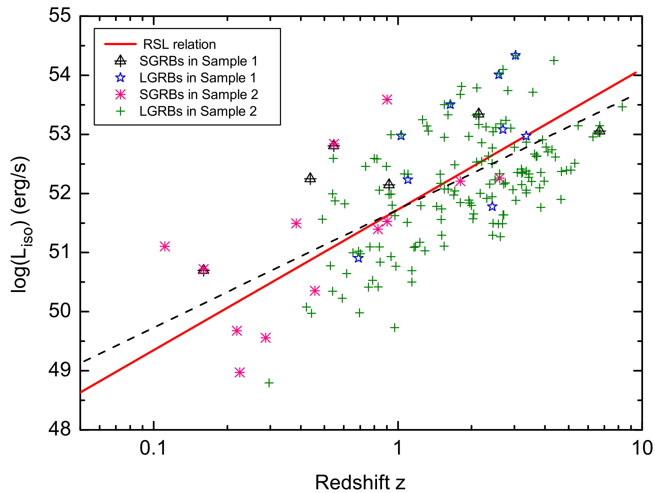

Figure 2. Luminosity vs. redshift for Swift long and short bursts. The solid and dashed lines represent the empirical RSL and theoretical luminosity correlations, respectively. Six short and nine long bursts in sample 1 are taken from Ghirlanda *et al.* (2009). Sample 2 includes 13 short and 149 long Swift bursts collected from Nat Butler's online repository and official NASA Swift homepage.

measured for the three luminosity correlations, particularly for the so-called Amati relation.

From the two RSL correlations listed in section 1, one can easily see that $L_\mathrm{p} \propto (1+z)^{2.4\pm0.7}$ is marginally consistent with a previous result $L_p \propto (1+z)^{1.4\pm0.5}$, proposed by Lloyd-Ronning *et al.* (2002). Our result is highly supported by recent results, say $L_p \propto (1+z)^{2.3\pm0.6}$ given by Salvaterra *et al.* (2012) for a complete sample of bright Swift long GRBs, and $L_p \propto (1+z)^{2.6\pm0.7}$ derived by Geng & Huang (2013). In Fig. 2, we compare the evolution of the isotropic luminosity derived from RSL correlations, the Swift observations and the theory. Note that we have assumed a standard cosmological model with $H_0 = 71$ km s^{-1} Mpc^{-1}, $\Omega_\mathrm{m} = 0.27$, $\Omega_\Lambda = 0.73$ and $k = 1$ throughout this paper. Surprisingly, both long and short bursts are found to have coincident luminosity evolution with redshift, hinting the same radiation mechanism (see also Zhang *et al*. 2012). Considering different progenitors for two kinds of bursts, this result is even more interesting but somewhat puzzling. It needs to deeply disclose the physical implications of RSL and rethink the basic theoretical models. This may bring us a revolutionary comprehension on GRB physics.

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