Publ. Astron. Obs. Belgrade No. 90 (2010), 61 - 64 *Contributed Paper*

A REVIEW ON TEMPORAL LAG CORRELATIONS IN GRBs

M. HAFIZI[1] and S. BOÇI[2]
[1]*Faculty of Natural Sciences, Bul. Zogu I, Tirana, Albania*
E–mail: mimoza.hafizi@yahoo.com
[2]*Faculty of Natural Sciences, Bul. Zogu I, Tirana, Albania*
E–mail: sonilaboci@yahoo.com

Abstract. Gamma ray bursts (GRBs) are high energy photons detected during a short interval of time, they are signs of the most energetic events in the universe. This work is devoted to temporal lags, which reveal to be important parameters correlated to GRBs spectrum and luminosity. We perform a theoretic analysis and compare the results with observational data obtained by BATSE and BAT-Swift detectors.

1. INTRODUCTION

Gamma ray bursts (GRBs) are high energy photons (from keV to MeV) detected during a short interval of time (from some ms to some hundreds of seconds). Releasing some 10^{52} $ergs$ of energy in such a short time, they are signs of the most energetic events in the universe.

Their time profiles show individual or superposed pulses.

The GRBs spectra are generally well described by a function $B_{\alpha\beta}(E)$ composed by two smothly joined power laws:

$$\begin{aligned} N(E) &= A\left(\frac{E}{100}\right)^{\alpha} exp(-\frac{E}{E_p}), E \leq E_p(\alpha-\beta) \\ N(E) &= A\left[\frac{(\alpha-\beta)E_p}{100}\right]^{(\alpha-\beta)}\left(\frac{E}{100}\right)^{\beta} exp(\beta-\alpha), E > E_p(\alpha-\beta). \qquad (1) \end{aligned}$$

This function is called Band spectrum (Band et al. 1993). It normally evolves during the burst, E_p (peak energy), α (low energy index) and β (high energy index) are generally time dependent. The shape of GRB pulses evolves, as well, with energy: at high energy, pulses are narrower and peak earlier.

The pulse temporal lag is the time interval between the maxima in two different energy bands. The two commonly used bands are BATSE (the most important detector operated between 1991 and 2000) ones, the first $[20, 50]$ keV and the third $[100, 300]$ keV. For that reason, this lag is written Δt_{13}.

Another method is used for calculating the whole burst temporal lag, by the cross-correlation (CCF method) of the full burst profile between the two bands. Recently, there are several works to recognize that lags are better defined using individual pulses rather than the entire burst (see e.g. Hafizi and Mochkovitch, 2007; Hakkila et al., 2008). It is shown (Hakkila et al., 2008) that the global lag represents some average where the brightest pulse (which generally has the shortest lag) makes the dominant contribution.

With a non evolving spectrum, the flux in any band would remain the same fixed fraction of the bolometric flux. In such conditions, we would obtain identical profiles in any energy band and the lag would be zero. Therefore, lags are a consequence of GRBs spectral evolution.

Observed lags vary between 0 (short GRBs) to several seconds (see e.g. Kocevski and Liang 2003; Ryde 2005).

A short time ago, an important relation is found between lags and burst peak luminosities (Lag-Luminosity Relation or LLR, Norris et al., 2000):

$$L = 1.3 \times 10^{53} \left(\frac{\Delta t_{13}}{0.01 s} \right)^{-1.14} erg.s^{-1}, \tag{2}$$

which is a power-law dependency between luminosity and lag. Remark that Norris relation is found for burst lags (CCF method).

If the LLR holds for most GRBs (with however some remarkable outliers), it provides a way to estimate the redshift and distancies of GRBs sources.

In addition, the lag is proposed to be used as a parameter for classification of GRBs in two categories, short and long ones (see e.g. Donaghy et al., 2006).

2. A THEORETICAL REVIEW

We aimed to find theoretical arguments for LLR. For this reason, we approximate the lag by the difference $\Delta t_{13} = t_1 - t_3$ between the maxima of a given pulse in bands 1 and 3. If Δt_{13} is small compared to pulse duration t_p, it can be obtained by a development of equations to first order.

We consider the count rate in energy band $[E_i, E_j]$:

$$N_{ij}(t) = A(t) \int_{x_i}^{x_j} B_{\alpha\beta}(x) dx. \tag{3}$$

Let us note by f_{13} the following function of spectrum for two BATSE observation bands:

$$f_{13} = \frac{\int_{\frac{100(1+z)}{E_p}}^{\frac{300(1+z)}{E_p}} B_{\alpha\beta}(x) dx}{\int_{\frac{20(1+z)}{E_p}}^{\frac{50(1+z)}{E_p}} B_{\alpha\beta}(x) dx}. \tag{4}$$

We find (see Hafizi and Mochkovitch, 2007):

$$\frac{\Delta t_{13}}{t_p} = \frac{f_{13,E} \dot{e}_p + f_{13,\alpha} \dot{a} + f_{13,\beta} \dot{b}}{C_1}, \tag{5}$$

with

$$f_{13,X} = \frac{\partial \log f_{13}}{\partial \log X}, \dot{e}_p = \frac{\dot{E}_p}{E_p} t_p, \dot{a} = \frac{\dot{\alpha}}{\alpha} t_p, \dot{b} = \frac{\dot{\beta}}{\beta} t_p, \frac{C_1}{t_p^2} = \frac{\ddot{N}}{N}, \tag{6}$$

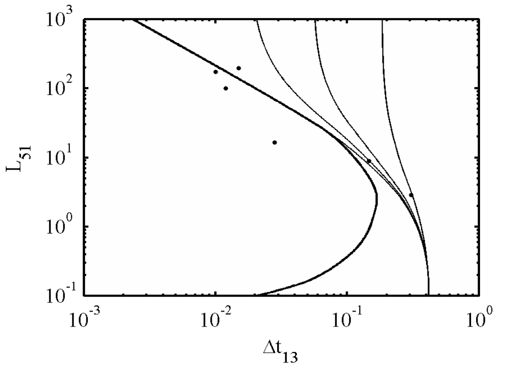

Figure 1: LLR obtained theoretically. The thick line corresponds to $\dot{a} = \dot{b} = 0$ and the thin lines (from left to right) to $\dot{a} = 0.01, 0.03, 0.1$; $\dot{b} = 0.1$. Points represent GRBs used by Norris to obtain LLR.

all calculated in the time of pulse maximum in BATSE band 1.

The two quantities C_1 and t_p are fixed by the pulse shape. They show that spiky pulses (large C_1) have shorter lags than broad pulses (small C_1) for a given spectral evolution and pulse duration and that short pulses are expected to have short lags, both effects in agreement with observations (e.g. Norris and Bonnell, 2006; Gehrels et al, 2006; Hakkila and Cumbee, 2009).

2. 1. ANALYTIC RESULTS AND LLR

With equations (5, 6) we can conclude about the correlation between lag and peak energy. For a LLR, we make use of a statistical relation between peak energy and peak luminosity, found by observational analysis and named Ghirlanda relation (see Ghirlanda et al. 2005):

$$E_p(keV) = 380 \times \left(\frac{L}{1.6 \times 10^{52} erg.s^{-1}} \right)^{0.43} . \tag{7}$$

This combination leads us to the the curves in the Fig. 1.

In the case of the thick line, in the high energy branch we recover the Norris behavior, so vanishing lags at large L. Note that the condition to find this LLR is $\dot{a} \sim \dot{b} \sim 0$. Anyway, observation suggests us that this condition on $\dot{a}$ is especially strong. In most GRBs, spectral evolution is not limited to a variation of E_p, but the spectral slopes a and b also evolve (see Crider et al, 1997; Preece et al, 1998).

2. 2. NEW RESULTS WITH SWIFT GRBS

Swift is a new satellite launched in 2004, with three instruments working in different wavelengths: BAT, XRT, UVOT. BAT bands for the lag calculation are $[15, 25]$ keV and $[50, 100]$ keV. Gehrels et al. 2006, performed a detailed analysis on a group of Swift bursts and found that:

1. LLR is globally confirmed, but with a larger dispersion than in the Norris case
2. There are sensibly more outliers

3. Short GRBs show very small lags and form another branch, separate from that of long GRBs

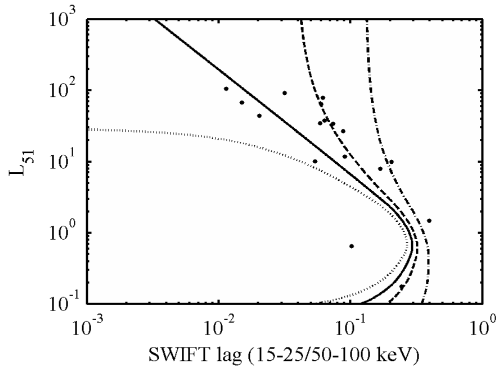

Figure 2: Our model in the Gehrels context, where points show Swift burst, which we put in our diagram.

In Fig. 2 we put several points representing Gehrels bursts and draw our theoretic curves. We can notice once more:

1. Lag is proportional to pulse duration, so short GRBs have small lags
2. Moderate variations of a, b can accommodate most of the Swift bursts
3. There is a departure from the power-law at low L
4. Our curves fit even some GRBs considered before as outliers

Based on these conclusions, lately we are asking for a new parameter characterising the spectral evolution instead of the lag, the so called reduced lag $\frac{\Delta t}{t}$.

References

Band, D. L. et al.: 1993, *Astrophys. J.*, **413**, 281.
Crider, A. et al.: 1997, *Astrophys. J.*, **479**, L39.
Donaghy, T. Q. et al.: 2006, *arxiv: astro-ph/0605570.*
Gehrels, N. et al.: 2006, *Nature*, **444**, 1044.
Ghirlanda, G. et al.: 2005, *MNRAS*, **360**, L45.
Hafizi, M., Mochkovitch, R.: 2007, *Astronomy and Astrophysics*, **465**, 6.
Hakkila, J. and Cumbee, R. S.: 2009, *AIP Conf. Proc.*, **1133**, 479.
Hakkila, J. et al.: 2008, *Astrophys. J.*, **677**, L81.
Kocevski, D., Liang, E.: 2003, *Astrophys. J.*, **594**, 385.
Norris, J. P. and Bonnell, J. T.: 2006, *Astrophys. J.*, **643**, 266.
Norris, J. P. et al.: 2000, *Astrophys. J.*, **534**, 248.
Preece, R. et al.: 1998, *Astrophys. J.*, **496**, 849.
Ryde, F.: 2005, *Astronomy and Astrophysics*, **429**, 869.