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The distribution of GRB spectral lags : implications for the lag - L_{iso} relation

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A study of the spectral lags distribution of all Swift GRBs with a redshift puts in evidence the existence of negative lags, confirming recent results. The GRBs with negative lags must thus be taken into account in the study of the Lag - L_{iso} relation. Considering the entire population of GRBs with both a spectral lag and a measure of E_{po} (the peak energy of the spectrum), we find that Lag - L_{iso} relation is not a true relation, but instead a boundary in the spectral lag – L_{iso} plane. This result complicates the use of this relation for cosmological purposes.

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1. Introduction

Norris et al. [1] found an anti-correlation between the spectral lag and the isotropic luminosity (L_{iso}) within a sample of 6 BATSE GRBs with a redshift. Although limited by the sample size, this anti correlation was confirmed by several studies for BATSE GRBs [2, 3, 4], for HETE GRBs [5] and for SWIFT GRBs [6]. In these studies, the spectral lags were defined in the observer frame energy bands. With a large GRBs sample with redshifts provided by SWIFT, Ukwatta et al. [7] investigated the impact on the relation, when source frame energy bands are considered. Limited by the detector energy range of Swift and the redshift domain of his sample, the two bands corresponded to source frame energies of 100-150 keV and 200-250 keV. A better correlation was reported by the authors considering source frame bands, although the improvement of the relation was not huge.

Even so, the main problem was the exclusion of a large GRBs fraction (44 per cent) simply because their lags were consistent with zero or negative. However, recently, Bernardini et al. [8] reinvestigated this relation, showing that with these GRBs, the spectral lag - L_{iso}relation is limited to a physical boundary.

In this proceeding, we discuss this finding with a larger sample. In particular, we consider all SWIFT GRBs with redshift with the aim of drawing the spectral lag distribution and solving the question of the existence of negative spectral lags.

2. Spectral lag definition and calculation

We used the 64ms temporal binning of Swift. With this binning, we have a sufficient signal-to-noise ratio (SNR) and a sufficient temporal resolution for most GRBs in our sample. We compute the lag value in the GRBs' source frame. Indeed, Ukwatta et al. [7] have proved that we obtain a better correlation between spectral lag and isotropic luminosity in this frame. Moreover, a study of the physical origin of the lags requires a quantity defined in the source frame. The energy bands used to compute the spectral lags are 100-150 keV and 200-250 keV in the GRB rest frame.

The spectral lag corresponds to the time difference between peaks in two energy bands. It is defined as positive when high energies arrive before low energies. To compute this quantity we use the cross correlation function (hereafter CCF) that represents the degree of correlation of two temporal series. We follow Band [9] who proposed a definition of CCF without the subtraction of the mean, that is more suitable for transient events as GRBs. Thus, the CCF is defined as :

$$CCF(d,x,y) = \frac{\sum_{i=1}^{N-d} x_i y_{i+d}}{\sqrt{\sum_i x_i^2 \sum_i y_i^2}}$$

Since CCF curves are affected by background noise, we smooth them with a moving average in order to find the global maximum. We compute a weighted CCF curve to locate the region of the maximum. Then, we fit the original CCF curve around the maximum with a polynomial whose order and fitting base depend on the maximum of the CCF. These choices are a compromise to process, in the same way, GRBs that present smoothed and peaked CCF. All CCF curves are calculated over the T_{90} GRBs duration.

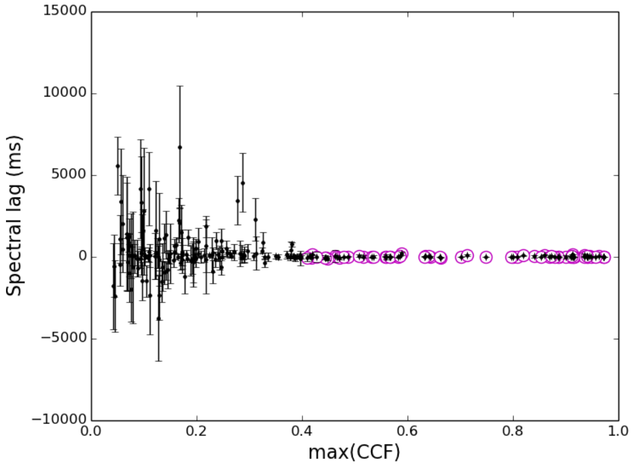

Figure 1: Spectral lag compared to CCF maximum. Magenta rounds corresponds to all GRBs with CCF maximum higher than 0.4 that is our first selection criteria.

3. Sample and selection

We retrieved Swift/BAT data from the public archive and processed them with the standard Swift analysis software included in the NASA's HEASARC software (HEASOFT,ver. 6.15.1) and the latest calibration files. For each GRB, we extracted mask-weigthed, background-subtracted light curves with the batmaskwtevt and batbinevt tasks in FTOOLS. For this study, we use the entire sample of long GRBs with a redshift detected by Swift between GRB050126 and GRB140518A. Our sample contains 221 long GRBs with a redshift.

We exclude GRBs with a maximum of the CCF smaller than 0.4. This first selection reduces the sample to 76 GRBs. Indeed, below this value, the method generally fails to find a reliable spectral lag. Figure 1 presents spectral lag values compared to the corresponding CCF maximum. We note a broadening of the spectral lag domain below 0.4. We interpret this fact as an evidence that our method fails for CCF maxima smaller than this value. More generally, for these GRBs, CCF curve are too noisy to extract cleanly a reliable spectral lag. We then check our selection by a visual inspection of each CCF curve. This inspection convinced us to remove 12 GRBs for which our method does not provide a reliable maximum. It is in particular the case for GRBs that present very smooth CCF. Finally, our sample contains 64 GRBs with spectral lags, of which 45 have also an E_{po} measurement.

4. Spectral lag distribution

Figure 2 presents the spectral lag distribution. We fit it with a Gaussian centered around 11ms and a one-sigma dispersion of 13.8ms. The existence of a non-negligible fraction of values outside this distribution may indicate that the lag distribution is not truly Gaussian.

The existence of negative lags is clearly confirmed. They represent $\approx 15\%$ of the spectral lags and cannot be simply excluded. Nevertheless, the extended tail towards positive lags indicates that spectral lags are more easily positive than negative. Indeed, most important absolute values are found for positive lags. This could be an indication of a spectral evolution that is more often hard-to-soft than soft-to-hard.

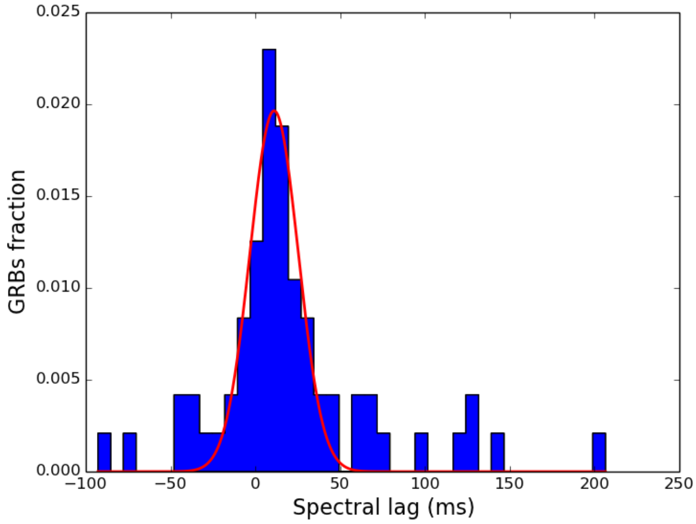

Figure 2: Spectral lags with redshift measurement in blue and gaussian fit in red centered around 11ms with a one sigma dispersion of 13.8ms.

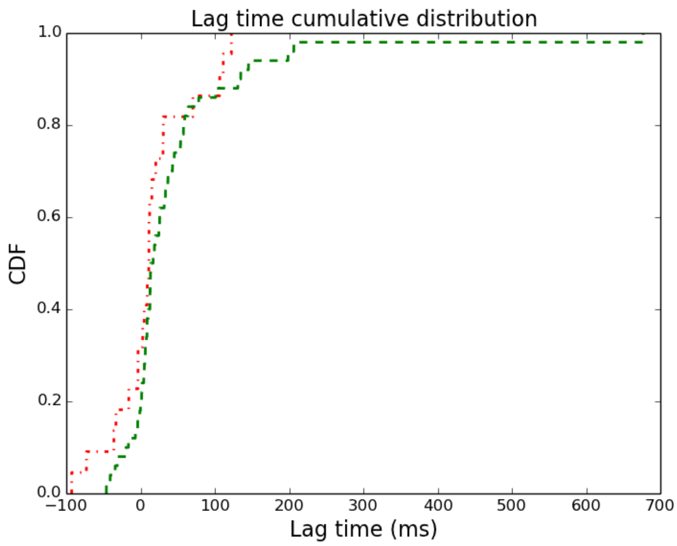

Figure 3: Lag distribution. In red GRB with redshift and in green GRBs that have also spectral parameters measurement.

Figure 3 compares the spectral lags for two different classes of GRBs. The first, in green, consists of 41 GRBs with redshift and spectral parameters measurements. The other class, in red, includes GRBs with redshift but with no spectral parameters measurement. We find no difference between the two classes, with a KS probability of 0.29. So, considering only GRBs with spectral parameters does not bias the spectral lag distribution. This point is important since we need both spectral lag and spectral parameter measurement for the study of the Lag - L_{iso} relation.

5. Spectral lag - L_{iso}relation

We can now evaluate the Lag - L_{iso} relation. This relation, originated from Norris et al. [1] can be used to standardize GRBs for cosmological purpose. This relation was used to constrain cosmological parameters inter alia by Schaefer et al. [3], nevertheless, the reality of this relation is

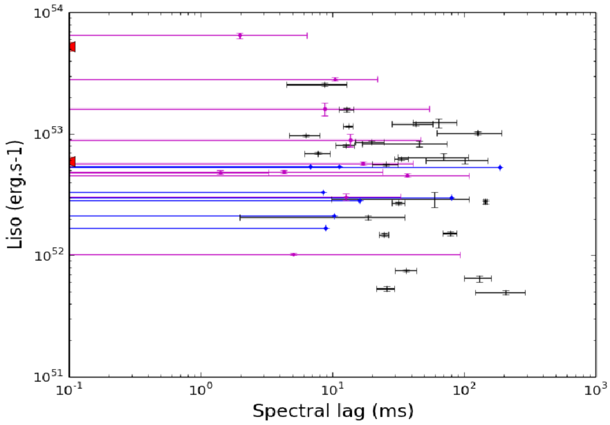

Figure 4: Lag - L_{iso} relation for the 45 GRBs with spectral parameters measurement. In dark, strictly positive spectral lags. In blue and magenta, spectral lags respectively negative and positive but consistent with zero. Red triangle, negative spectral lags.

being discussed. Also, Ukwatta et al. [6], for observer frame energy bands, and Ukawatta et al. [7], for source frame ones, found some evidences for a correlation between $L_{iso}$and spectral lag, but this correlation was obtained by considering only positive spectral lags. Bernardini et al. [8] found no evidence for a correlation between these two quantities taking into account the full GRBs spectral lag sample. We have seen previously that the spectral lag distribution confirms the existence of a non negligible part of GRBs with negative spectral lag. These GRBs cannot be simply removed of our sample and ignored.

Figure 4 presents Lag - L_{iso} relation that we obtain with 45 GRBs. Among them, 25 have strictly positive lags (in black), 10 positive lags consistent with zero (in magenta), 8 negative lags consistent with zero (in blue) and 2 strictly negative lags (in red). These numbers are close to those found by Bernardini et al. [8] invalidating the existence of Lag - L_{iso} relation considering the entire GRBs sample.

Existence of a large fraction of spectral lags consistent with zero could be an indication that we are not able to measure small lags correctly. Indeed, to obtain the lowest spectral lags values, we need a temporal resolution sufficiently high to resolve these lags in the CCF. Nevertheless, GRBs in this part of spectral lag – L_{iso} plane could have not enough photons to perform this analysis. It could be difficult to measure low spectral lag values for GRBs with low L_{iso}.

We observe a lack of GRBs with both long spectral lags and high L_{iso}. It could be an indication that a true physical limit exists and limits the GRBs repartition in the spectral lag – L_{iso} plane . Existence of selection effects in this part of the spectral lag – L_{iso} plane cannot be advocated to explain this point. Indeed, it corresponds to GRBs with high L_{iso}that send us a larger number of photons than other GRBs. Moreover, spectral lags are more easily detected than small lags as we are not limited by the temporal binning of the light curve. Thus, we expect that this kind of GRBs could have been seen if they existed.

6. Conclusions and discussions

The existence of negative spectral lags cannot be excluded by the measured spectral lag distribution. Thus, these spectral lags must be taken into account in the Lag - L_{iso}relation. In the same way, spectral lags compatible with zeros form a non negligible part of the total spectral lag distribution. As shown by Bernardini et al. [8], these results put into doubt the existence of Lag - L_{iso}relation. Thus, part of the plane is populated by GRBs with spectral lags compatible with zero reducing the relation at a physical boundary. Indeed, no long lag with low isotropic luminosity has been found. This feature is similar to the spectral relations, like $E_{peak} - E_{iso}$ relation , for which selection effects prevent using them for cosmological purpose [10]. In the same way, Lag - L_{iso}relation cannot be used directly for this aim. Introduction of a third parameter to identify GRBs close to this boundary could be a solution. Some examples are the three parameters correlations that combine both spectral and temporal parameters [11]. Existence of long lag GRBs is not confirmed ([2],[12]) but a more detailed study using more broadly separated energy bands must be done to validate or not this point. A more detailed analysis is also needed to understand the distribution of spectral lags and its impact on our understanding of GRB physics [13].

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