Study of afterglow light curve decay indices in long GRBs

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Introduction

In this work we search for systematic relations between the luminosities L_a and the light curve decay indices α_a in the GRB afterglow phase, for 176 long bursts with known redshifts. We compare results for the two fitted models: the model proposed by Willingale et al. (2007), which provides for analysis the parameters L_a, T_a (the afterglow plateau time scale in the GRB rest frame) and α_a, and the "best" power law fit for α_a. The first one applies a functional form describing the entire GRB light curve, while the latter linear fit is applied in the selected afterglow decaying phase range, where the light curve is distinctly well fitted with a power law. We use these two models in parallel in order to check for eventual systematics due to the applied fitting. As a result we reveal systematic trends between L_a and α_a, as well as some systematic trends for both parameters in the studied earlier (L_a, T_a) distribution (Dainotti et al. 2008 and later). This analysis provides constraints for physical description of the GRB sources, but also to the issue being our driving force in the study: a search for standardization procedure for GRBs, which could allow for their application as a cosmological tool (Dainotti et al. 2013b).

Data

The analyzed GRB light curves were obtained from the Swift catalogue using the BAT and the XRT telescopes with fluxes in the range $0.3-10$ keV (Swift Catalogue website: http://swift.gsfc.nasa.gov/). Each GRB light curve has its own peculiarity thus making difficult to fit the afterglow with simple power laws (O'Brien et al. 2006). In the present analysis we use approximate fits of the total afterglow light curves, based on the approach proposed by Willingale et al. (2007), and power law fits to limited in time parts of the decaying light curve, where we consider the fit to be precise.

Analysis

Using the GRB fitting results by Dainotti et al. (2015) we obtained decay indices for each GRB and we analyzed their distributions. In addition, we studied the Luminosity-Time ($\log L_a(T_a)$, $\log T_a$) distribution (later described as the LT distribution or the related LT correlation; c.f. Dainotti et al. 2013a), and we revealed its dependence on an additional parameter, the decay index α_a .

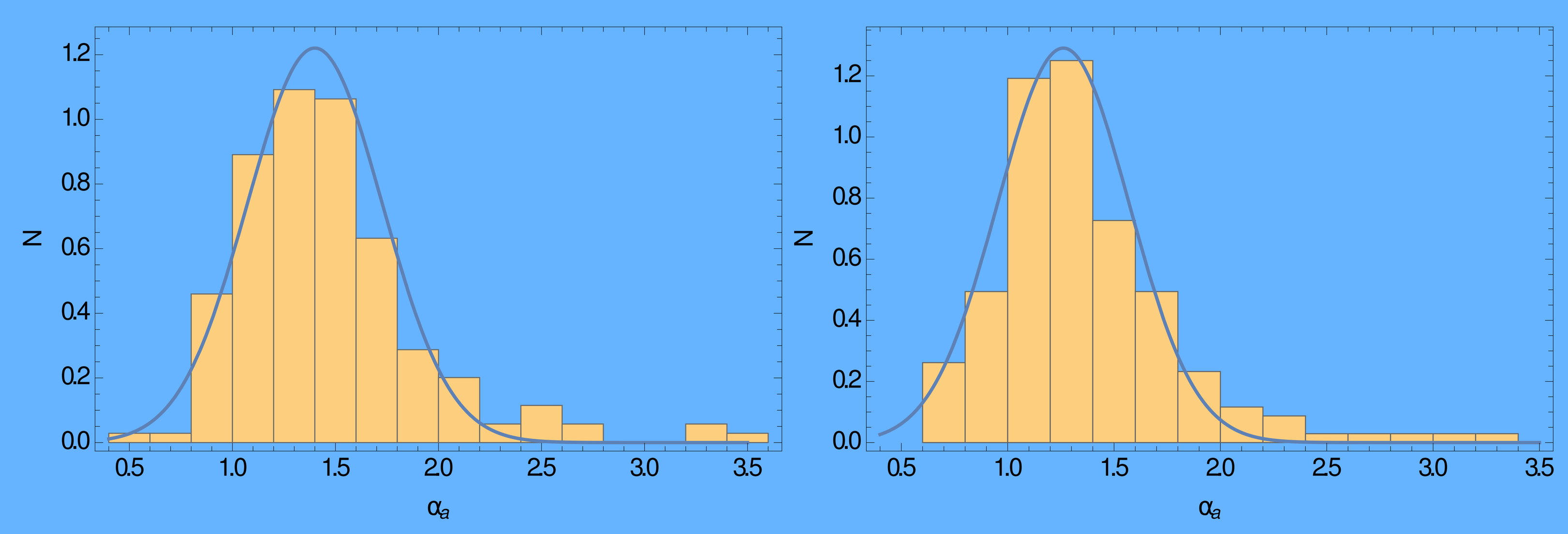

Fig. 1: Distributions of the decay indices α_a, obtained using the power law fit (left panel) and the Willingale model (right panel), with its fitted Gaussian functions.

These two distributions look quite similar and the Kolmogorov-Smirnov (KS) test does not reveal any systematic difference. The best fits of the Gaussian distributions $\frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$ have: $\mu = 1.4$ and $\sigma = 0.32$ for the power law fitting and $\mu = 1.26$ and $\sigma = 0.31$ for the Willingale model fitting.

To look for any dependence of the afterglow luminosity on α_a, we split our data into three groups with equal numbers of GRBs in the luminosity ranges: low $log\ L_a < 47.65$, medium $47.65 < log\ L_a < 48.7$ and high $log\ L_a > 48.7$ (we write shortly L for $logL$ at the figure descriptions).

We also studied the distributions of burst distances $\Delta \log L$ from the whole LT distribution fit line, for the selected three luminosity groups (Fig.2). The KS test confirms reality of a significant difference visible between distributions for the low and high luminosity subsamples. This result, which at a first glance looks quite trivial, provides however some additional insight into the general LT distribution.

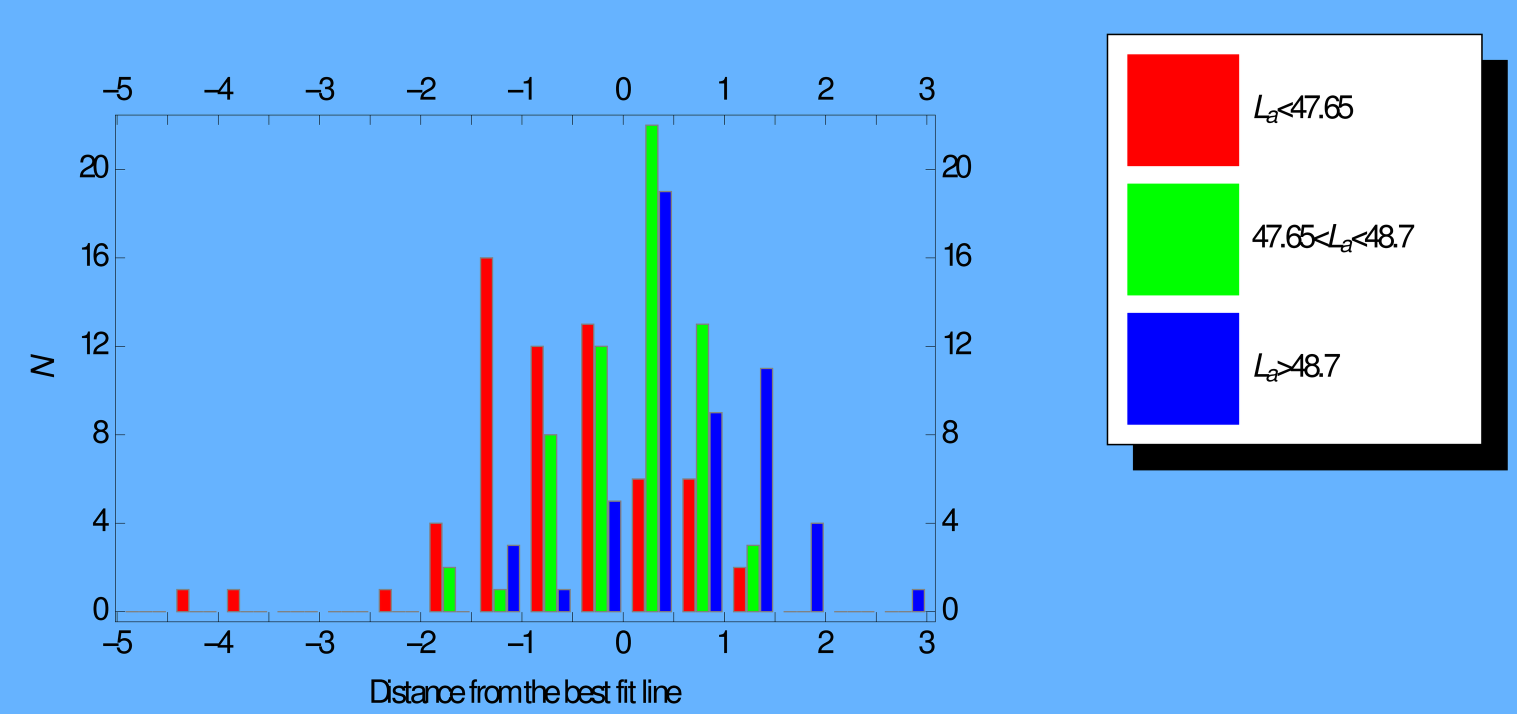

Fig. 2: Distributions of the distances from the best fit line of LT correlation for the three luminosity groups: low (red), middle (green) and high (blue).

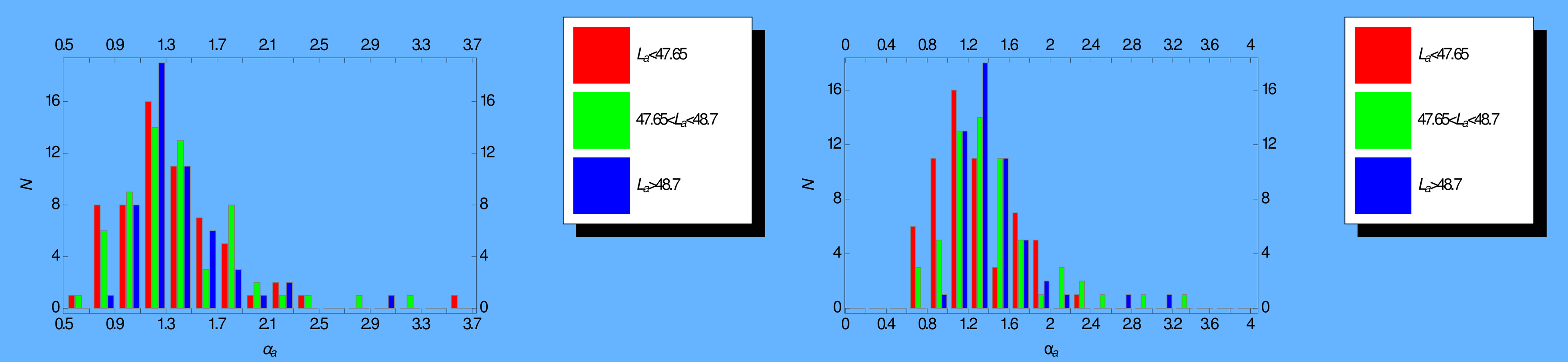

Fig. 3: Distributions of the decay indices α_a for low, medium and high luminosity subsamples obtained using a power law fits (left panel) and the Willingale model fits (right panel) .

Now, let us plot the LT distribution using α_a as a third parameter. To proceed we split each of the two considered α_a samples into three α_a ranges, with the same number of elements (Fig. 4).

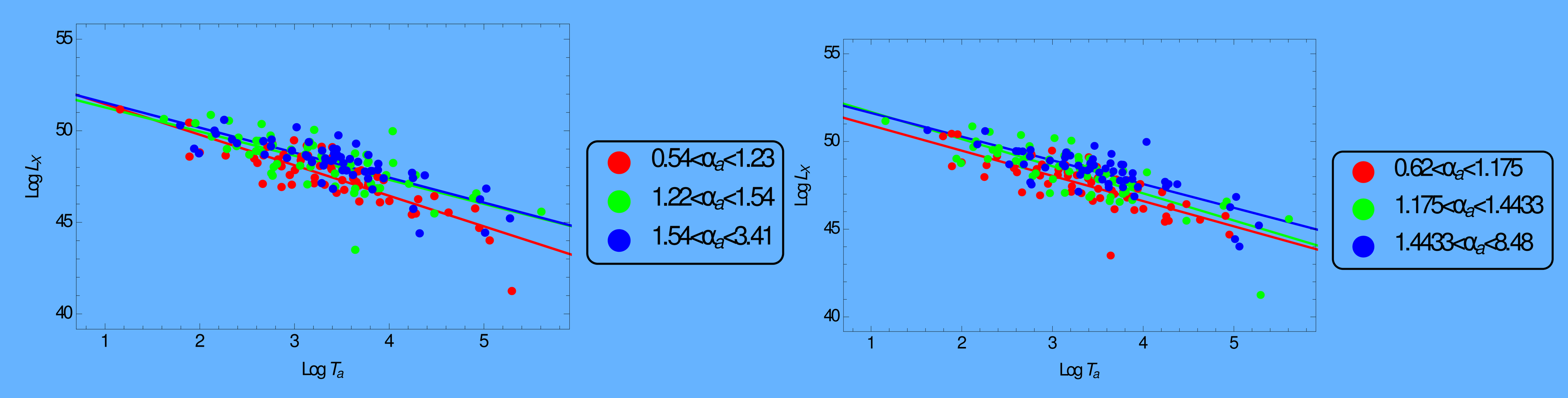

Fig. 4: The LT distribution with indicated the α_a subsamples in colors. For each α_a subsample the best fit line is presented.

Using the fit of the LT correlation for the full GRB sample we calculated distances from the derived fit line for each α_a subsample (Fig. 5).

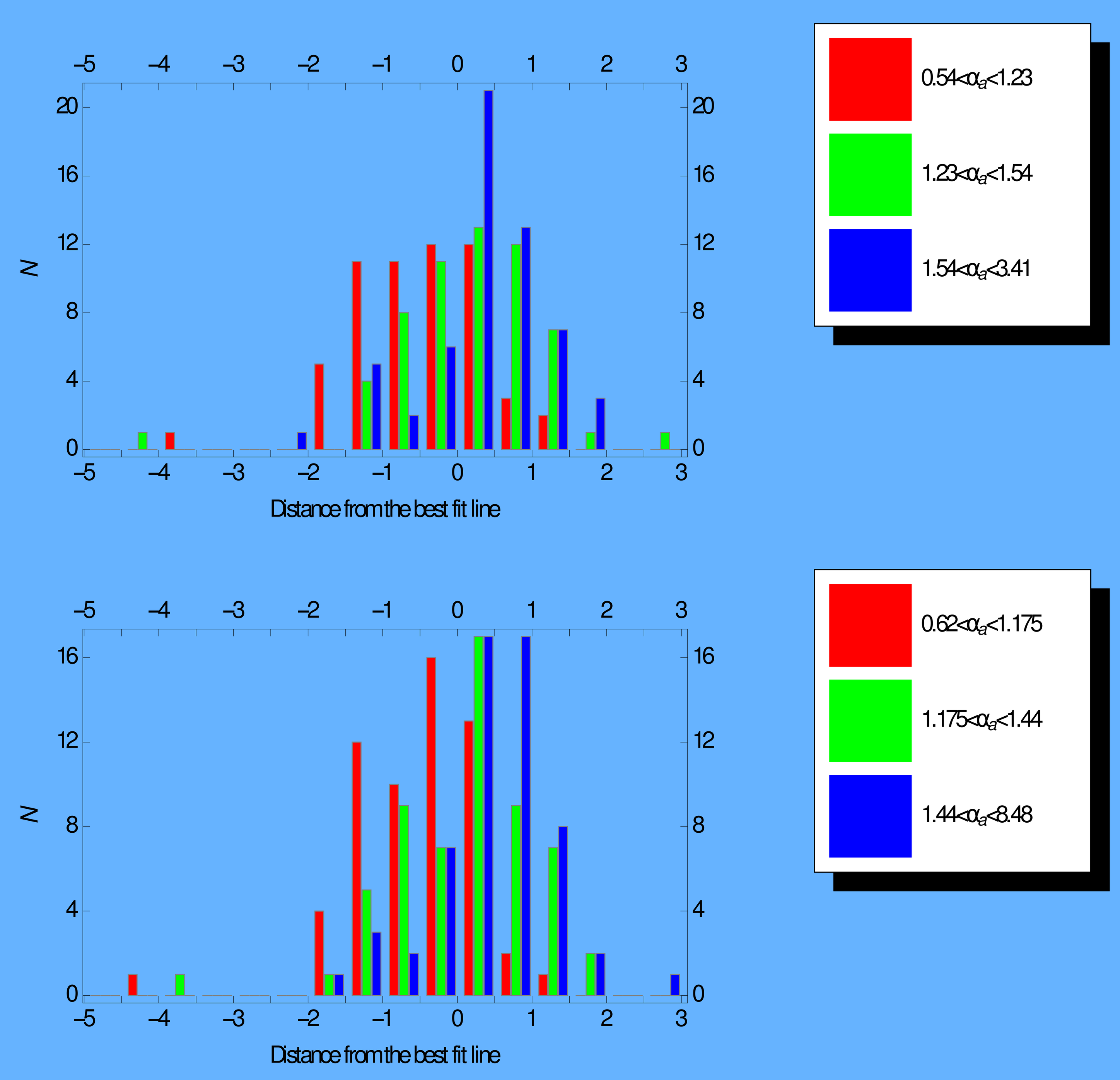

Fig. 5: Distributions of the GRB distances from the best fit LT correlation with α_a as a third parameter. The samples for a power law fit line and the Willingale model are presented at the upper and bottom panel, respectively.

Here again we observe a systematic distribution shifts from the low, through the medium, till the high α_a samples, a strongly confirmed by the KS test for low and high α_a subsamples.

Conclusions

1.) To study the afterglow light curve decay rate one can use each of the analyzed by us samples, we do not observe any systematic difference between the Willingale et al. (2007) model fits and the simple power law fits to the selected limited light curve time ranges.
2.) We discovered that there is a systematic difference of the α_a index distributions between the low, medium and high luminosity subsamples.
3.) When analyzing the LT distribution we discovered a feature (related to the above one) of systematic shifts of low, medium and high α_a range subsamples with respect to the LT correlation line.
4.) The work is still in progress and we plan to perform more detailed analysis of the discovered dependence of GRB parameters on the afterglow light curve decay rate in next weeks.

Acknowledgements

This work was supported by the Polish National Science Centre through the grant DEC-2012/04/A/ST9/00083.

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