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Statistical Connection between the prompt and X-ray afterglow emission of Swift detected GRBs

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I report on tight relationships between the GRB prompt and X-ray afterglow emission of the 651 Swift-detected GRBs (March 2012) from BAT and XRT observation. There are very strong correlations between the BAT T_{90} and the break times before and after the X-ray afterglow plateau phase in the observed as well as in the rest-frame. The break times before and after the plateau phase also strongly anti-correlate with the luminosity in the 15-150 keV band. A Principal Component Analysis shows that the main driver of the properties in GRBs is the luminosity/energy of the burst.

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1. Introduction

The Swift mission revolutionized the study of Gamma-Ray Burst (GRB) afterglows. With Swift it was possible for the first time to access the early data of X-ray afterglows (e.g. [3, 10]). The rapid response of Swift to GRB triggers also allows to localize the position of the bursts with arcsec accuracy within minutes which enables ground-based observers to obtain redshift for these bursts. Of the 651 onboard detected GRBs until March 2012, 184 had spectroscopic redshift measurements which allow us to compare physical and not just observed parameters. In our study here we are interested in statistical connections between the GRB prompt and X-ray afterglow emission. Some correlations found in GRBs are well-know, such as the relations between $E_{\rm peak}$ and the isotropic and the collimation corrected energies ([1, 5]), but also a link between the energetics in the prompt and afterglow emission has been found ([8, 2], see also their contributions in these proceedings).

Swift with its fast slewing capacity did not only gave access to early data of the X-ray afterglow but also discovered the presence of violent flaring activity in X-rays (e.g. [7, 4] and that GRBs often follow 'canonical' light curves ([9, 12]). Roughly 40% of all bursts with X-ray observations follow this behavior [3]. In the study presented here we follow the definitions of the phases in the X-ray afterglow light curves given in [9] and [12] who denoted the decay slope during the plateau phase as α_2 and that of the 'normal' decay phase after the plateau phase as α_3. Our initial sample consists of all onboard detected Swift BAT bursts.

For the BAT data we used the values published in the BAT refined GCN Circular, and for XRT we used the light curve fits available at the public page are Leicester ([3]). For the X-ray afterglow spectra we used the spectra available at Leicester (www.swift.ac.uk) and fitted the spectra within XSPEC. Our approach here is to look a large parameter space and study the relations with bi-variate and multivariate statistical tools (Grupe et al. 2012, in prep).

2. Simple Statistical Analysis

For any multivariate analysis the first step is to check the parameters for any bivariate correlations. We found several (anti)-correlations between GRB prompt and afterglow emission properties. These correlations become apparent in the Swift GRB sample due to the large number GRBs. Correlations which are very strong are between T_{90} and the break times before and after the plateau phase (left panel Figure 1). We also noticed that there is a correlations between the spectral slopes in the 15-150 keV and 0.3-10 keV bands and that the break time after the plateau phase anti-correlates with the luminosity in the 15-150 keV band (right panel Figure 1). Although the detector properties of the Swift BAT can introduce selection effects, the relations shown in Figure 1 appear to be real and not a results of a selection bias. We will discuss selection biases in the Swift GRB sample in Grupe et al. 2012 (in prep).

3. Multivariate Statistical Analysis

While simple Correlation analysis gives some information about the data set, only multi-variate analysis methods access the full parameter space. For our GRB sample we applied a Principal Component Analysis (PCA, e.g. Pearson 1901). All multi-variate analysis has been performed in R (http://www.r-project.org/ , [11]).

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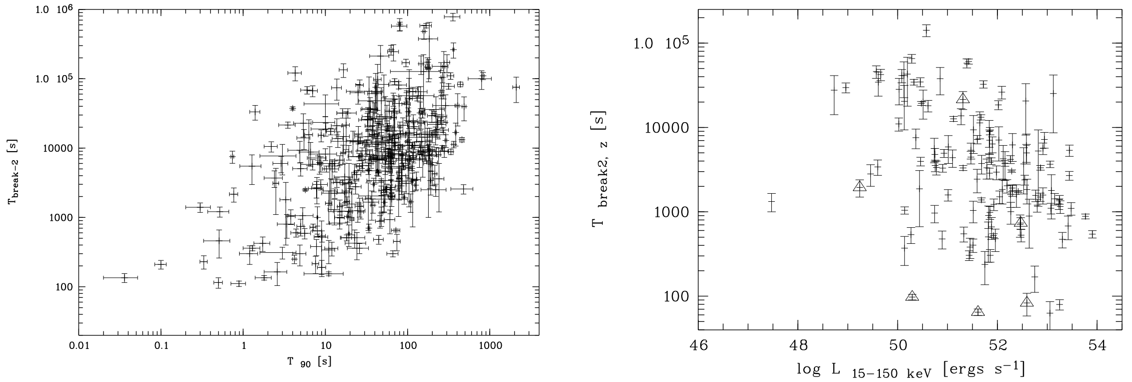

Figure 1: Correlations between the observed break time after the plateau phase in X-ray afterglow light curves and the 15-150 keV BAT T_{90} and and the rest-frame break time after the plateau phase with the K-corrected 15-150 keV luminosity (left and right panel, respectively)

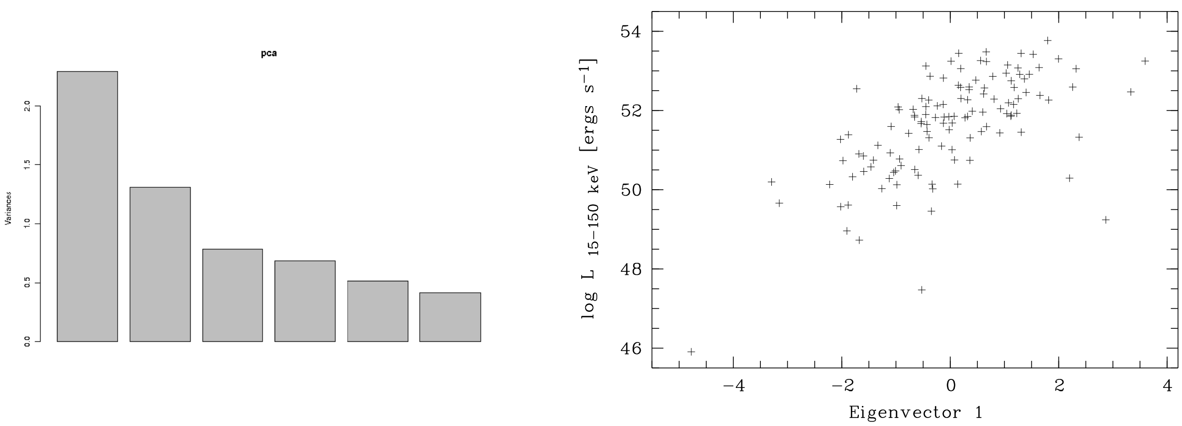

Figure 2: Results of the principal Component Analysis of the Swift sample of 125 GRBs for which the following PCA input parameters were available: rest frame T_{90} and $T_{\rm break2}$, X-ray light curve decay slopes α_2 and α_3, and the spectral slopes Γ and $\beta_{\rm x}$. The left panel displays the strength of the eigenvectors. The right panel shows the correlation between eigenvector 1 and the K-corrected 15-150 keV luminosity.

Figure 2 displays the strengths of the eigenvectors in the PCA of the sample of 125 GRB for which we have all input parameters: rest-frame T_{90} and $T_{\rm break2}$, decay slopes α_2 and α_3, and the spectral slopes Γ and $\beta_{\rm x}$. The first two eigenvectors account already for 60% of the variance in the sample. A strong eigenvector 1 results in flatter X-ray spectra and longer T_{90} and break times after the plateau phase $T_{\rm break2}$.

What do the eigenvectors mean? Because the PCA is a purely mathematical tool the results may not be physically meaningful. However, the results from the PCA and the simple correlation analysis suggest that eigenvector 1 can be interpreted as the luminosity in the 15-150 keV band. In order to test this hypothesis we calculated eigenvector 1 for each GRB and plotted eigenvector 1 vs. the 15-150 keV luminosity as shown in the right panel of Figure 2. Clearly eigenvector 1 can represent the 15-150 keV luminosity.

While the first results of the correlation analysis and the PCA are encouraging and will be

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published soon (Grupe et al. 2012, in prep) they only probe the tip of the iceberg. In order to examine the full data set we need continue working on the statistical analysis by applying advanced statistical tool such as clustering and data visualization in an n-dimensional parameter space (e.g [6]). The goal here is to isolate group and classes of GRB and classify these classes based on physical properties.

Acknowledgments

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