Search for the Gamma-Ray Burst Groups with the Fermi Satellite

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Abstract. A sample of 488 gamma-ray bursts (GRBs), measured by the Fermi satellite, is studied statistically with respect to the durations. Standard statistical tests are used, such as the F-test and the maximum likelihood ratio test, in order to ask for the number of components in a Gaussian mixture model of the GRB duration probability density in this database. Using the durations T_{90} and T_{50}, the F-test and also the maximum likelihood test, did not find any statistically significant intermediate group.

Introduction

At the last years several different tests, probing the separation of gamma-ray bursts (GRBs) into subgroups were provided. A mixture of three components was found (Hakkila et al. 2000, Horváth 2002, Hakkila et al. 2004, Horváth et al. 2006, Horváth 2009, Horváth et al. 2010, Veres et al. 2010, Řípa et al. 2012).

Models of GRBs are still not fully clear, especially for the short and intermediate GRBs. We do not know, how many astrophysically different groups are in the log-normal distribution of durations.

Observations

We use the Fermi GRB Catalog (http://heasarc.gsfc.nasa.gov/) that contains 488 GRBs having well measured durations. Two values of GRB duration are used in this study, T_{90} and T_{50}. T_{90} (T_{50}) is the duration of a GRB, during which time 90% (50%) of the total time-integrated flux is received. We proceed similarly to earlier papers (Horváth et al. 1998, Horváth et al. 2004, Huja et al. 2009, Řípa et al. 2009, Řípa et al. 2012), which applied standard statistical tests on the durations of other datasets. Fermi Catalog contains first two years of observations.

Case 1

First method is the χ^2 test. Data set of 488 GRBs is binned by the duration into 17 bins. Every bin contains minimally five GRBs. Then we try to fit the distribution of duration with the sum of log-normal functions. The fit T_{90} distribution with one Gaussian curve gave $\chi^2 = 129.99$ for 14 degree-of-freedom (dof). The fit is very bad. The significance is far below 0.01%. We can reject the fit with one Gaussian curve. The fit with two and three log-normal functions are shown in Fig. 1 and Fig. 2. The parameters of the fits, the values of χ^2, the degrees of freedom and the goodness-of-fits are listed in Table 1.

The assumption of two groups for T_{90} distribution duration, being represented by two log-normal fits, is still acceptable ($\chi^2 = 20.10$ for dof = 11 gives 4.39% significance—i.e., still an acceptable fit), the fit with three log-normal functions is already wrong ($\chi^2 = 18.21$ for dof = 8 gives a 1.97% significance). This shows that the introduction of the third group is hardly necessary.

The question is whether the improvement—coming from the introduction of third group—in χ^2 is statistically significant. To answer this question, we used the F-test (Band et al. 1997, see also Protassov et al. 2002). The F-test gives a significance 96.8% for $F(3, 8) = 0.277$. The improvement in χ^2 can well be accidental. Hence, this value from the F-test, and also the χ^2 tests, both for the sum of two (three) log-normal functions, show that here two log-normal curves are enough to describe the observed duration distribution.

The fit T_{50} distribution duration with one Gaussian curve gave $\chi^2 = 113.47$, which for 20 degree-of-freedom (dof) is a very bad fit. The significance is far below 0.01%. Data set of 488 GRBs is binned by the duration into 23 bins. We can reject the fit with one Gaussian curve. The fit with two log-normal

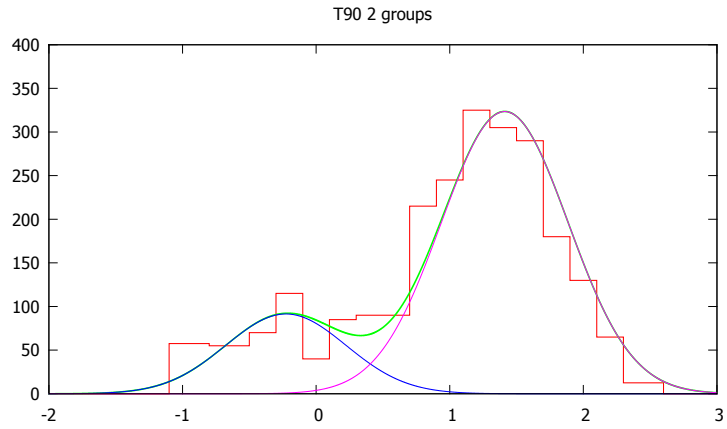

Figure 1. Distribution of duration T_{90} of Fermi 488 GRBs fitted with 2 log-normal functions. On the horizontal axis there is log T_{90} in seconds and on the vertical axis is the number density.

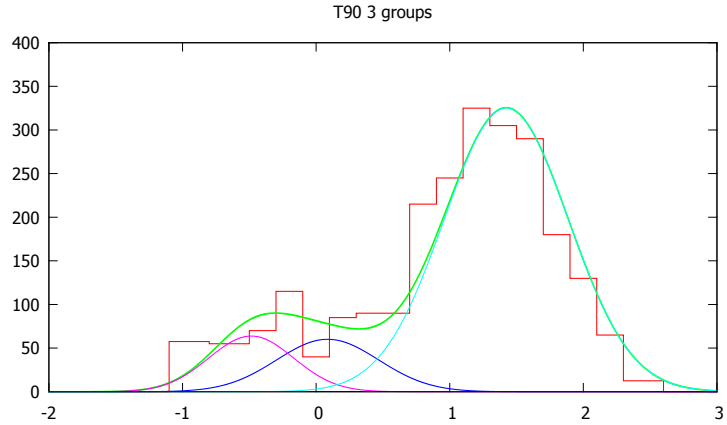

Figure 2. Distribution of duration T_{90} of Fermi 488 GRBs fitted with 3 log-normal functions. On the horizontal axis there is log T_{90} in seconds and on the vertical axis is the number density.

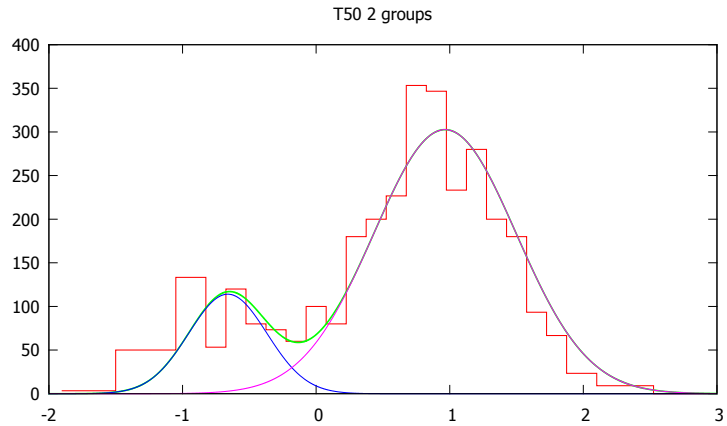

Figure 3. Distribution of duration T_{50} of Fermi 488 GRBs fitted with 2 log-normal functions. On the horizontal axis there is log T_{50} in seconds and on the vertical axis is the number density.

functions is shown in Fig. 3 and the fit with three log-normal functions in Fig. 4. The parameters of the fits, the values of χ^2, the degrees of freedom and the goodness-of-fits are listed in Table 2.

The assumption of two groups for T_{50} distribution duration being represented by two log-normal fits is still acceptable ($\chi^2 = 19.10$ for dof = 17 gives 32.28% significance—i.e., still an acceptable fit), the fit with three log-normal functions is similar ($\chi^2 = 17.37$ for dof = 14 gives a 23.69% significance). The F-test gives a significance 92.5% for $F(3, 14) = 0, 465$. The improvement in χ^2 can well be again

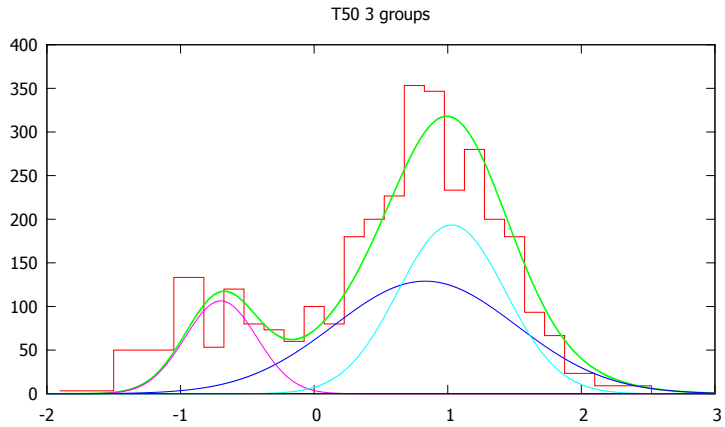

Figure 4. Distribution of duration T_{50} of Fermi 488 GRBs fitted with 3 log-normal functions. On the horizontal axis there is log T_{50} in seconds and on the vertical axis is the number density.

Table 1. Parameters of the best χ^2 fits of two and three log-normal functions with T_{90}. μ are the means, σ are the standard deviations and w are the weights of the distribution.

parameter	2 log-normal	3 log-normal
μ_{short}	-0.22	-0.48
σ_{short}	0.45	0.31
w_{short}	0.21	0.10
μ_{long}	1.41	1.42
σ_{long}	0.47	0.46
w_{long}	0.79	0.78
μ_{middle}		0.09
σ_{middle}		0.38
w_{middle}		0.12
dof	11	8
χ^2	20.1	18.2
goodness[%]	4.4	2.0
F_0	0.277	
$P(F > F_0)[\%]$	97.4	

accidental. Hence, this value from the F-test, and also the χ^2 tests for both the sum of two (three) log-normal functions, show that here only two log-normal curves are enough to describe the observed duration distribution.

Hence, the values from the F-test, and also the χ^2 tests, show that for the Fermi 488 GRBs two log-normal Gaussian curves are curves are enough. Fit with three log-normal Gaussian curves do not bring statistically significant improvement.

Case 2

We also used the maximum likelihood method (Koen & Bere 2012). We fit the log-normal distribution with two and three Gaussian curves on the Fermi 488 GRBs dataset.

For distribution duration of T_{90}, we obtained $\ln L_2 = -520.21$ and $\ln L_3 = -519.31$, respectively. The doubled difference gives an $\approx 40\%$ probability that the third group is still a random fluctuation. For distribution duration of T_{50}, we obtained $\ln L_2 = -540.19$ and $\ln L_3 = -539.41$, respectively. The doubled difference gives an $\approx 30\%$ probability that the third group is still a random fluctuation. The results are similar like results from χ^2 test. The best parameters obtained for the sum of two log-normal fits and values are similar to the values from χ^2 method.

Table 2. Parameters of the best χ^2 fits of two and three log-normal functions with T_{50}. μ are the means, σ are the standard deviations and w are the weights of the distribution.

parameter	2 log-normal	3 log-normal
μ_{short}	-0.66	-0.70
σ_{short}	0.29	0.30
w_{short}	0.17	0.15
μ_{long}	0.96	1.03
σ_{long}	0.53	0.40
w_{long}	0.81	0.40
μ_{middle}		0.83
σ_{middle}		0.68
w_{middle}		0.45
dof	17	14
χ^2	19.1	17.4
goodness[%]	32.3	23.7
F_0	0.465	
$P(F > F_0)[\%]$	93.2	

Discussion

Both the χ^2 test and maximum likelihood test show that the best fit of log-normal distribution is the sum of two Gaussian curves. One Gaussian curve is a very bad fit and the sum of three Gaussian curves curves do not bring statistical significant improvement. We did several other binning in the fits, but we did not obtain statistically significant improvement. In the log-normal distribution of T_{50} duration we also obtained a fit with three components. The third component was a narrow Gaussian curve. Maximum of the third Gaussian curve is near to the maximum of the Gaussian curve for long GRBs. It is a highly strange effect. We do not think that this behaviour really represents the third group.

Conclusion

The distribution of durations of the Fermi GRBs can well be fitted with two log-normal functions. Fit with the one Gaussian curve is very bad and the probability is far below 0.01%. Fit with three or more Gaussian curves do not bring statistical significant improvement.

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