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PHYSICAL DIFFERENCE BETWEEN THE SHORT AND LONG GAMMA-RAY BURSTS

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Abstract. We provided separate bivariate log-normal distribution fits to the BATSE short and long burst samples using the durations and fluences. We show that these fits present evidence for a power-law dependence between the fluence and the duration, with statistically significant different indexes for the long and short subgroups. We argue that the effect is probably real, and the two subgroups are different physical phenomena. This may provide a potentially useful constraint for models of long and short bursts.

Key words: gamma rays: bursts

1. INTRODUCTION

The simplest grouping of gamma-ray bursts (GRBs) divides bursts into long ($T_{90} > 2$ s) and short ($T_{90} < 2$ s) duration subgroups. Here we analyze (see also Balázs et al. 2003) the distribution of the observed fluences and durations, and present arguments indicating that the intrinsic fluences and durations are well represented by log-normal distributions within these subgroups. We calculate the power-law exponent for the two subgroups of bursts and briefly discuss the possible implications for GRB models. A statistically significant difference between the two subgroups of GRBs is found.

2. ANALYSIS OF THE DURATION DISTRIBUTION

Our GRB sample is selected from the current BATSE *Gamma-Ray Burst Catalog* (Meegan et al. 2001). The bimodal distribution of the observed T_{90} can be well fitted by means of two Gaussian distributions in the logarithmic durations (Horváth 1998). The T_{90} observed duration of GRBs (which may be subject to cosmological time dilatation) relates to t_{90}, the duration which would be measured by a comoving observer by

$$T_{90} = t_{90}\, f(z), \tag{1}$$

where z is the redshift and $f(z)$ measures the time dilatation. Taking the logarithms of both sides of the equation one obtains the logarithmic duration as a sum of two independent stochastic variables. According to Cramer's theorem (Cramér 1937), if a variable ζ which has a Gaussian distribution is given by the sum of two independent variables, e.g., $\zeta = \xi + \eta$, then both ξ and η have Gaussian distributions. The Gaussian distribution of $\log T_{90}$ implies that the same type of distribution exists for the variables $\log t_{90}$ and $\log f(z)$. The distribution of $\log f(z)$ cannot be Gaussian which means that the Gaussian nature of the distribution of $\log T_{90}$ must be dominated by the distribution of $\log t_{90}$.

3. DISTRIBUTION OF THE ENERGY FLUENCES

The fluences are given in four different energy channels, F_1, F_2, F_3, F_4, whose energy bands correspond to 25–50 keV, 50–100 keV, 100–300 keV and >300 keV. The total fluence is defined as $F_{\rm tot} = F_1 + F_2 + F_3 + F_4$. The observed total fluence $F_{\rm tot}$ can be expressed as

$$F_{\rm tot} = \frac{(1+z)}{4\pi d_l^2(z)} E_{\rm tot} = c(z) E_{\rm tot}. \tag{2}$$

Here $E_{\rm tot}$ is the total emitted energy of the GRB at the source in ergs, the total fluence has a dimension of erg/cm^2, and $d_l(z)$ is the luminosity distance corresponding to redshift z. Accepting the hypothesis of a Gaussian distribution within the short and the long subgroup, one can apply again Cramer's theorem which leads to the conclusion that either both the distribution of $\log c(z)$ and the distribution of $\log E_{\rm tot}$ are Gaussian, or else the variance of one of these quantities is negligible compared to the other, which then must be mainly responsible for the Gaussian behavior. Calculating the variance of $\log c(z)$ for the GRBs with known redshifts one obtains $\sigma_{\log c(z)} = 0.43$. The

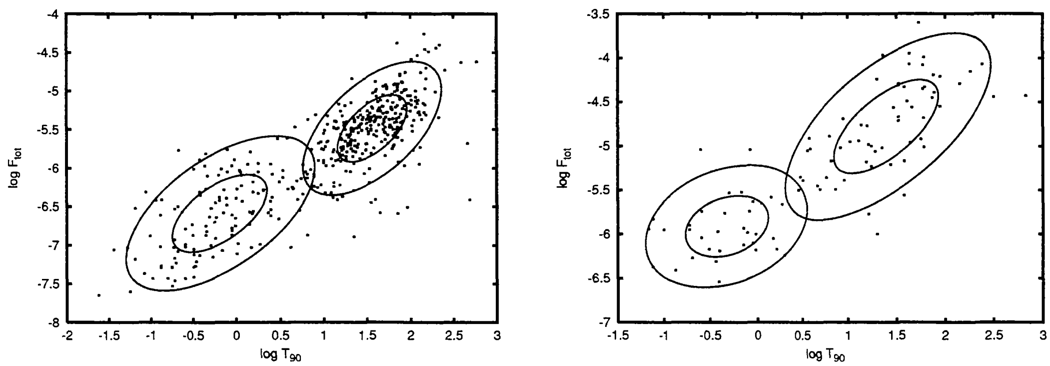

Fig. 1. The maximum likelihood fits of the two log-Gaussian distributions for the faintest and brightest subsample. The 1σ and 2σ error ellipses of the two components are indicated.

total observed variance is $\sigma(\log F_{\rm tot}) = 0.66$. Hence, the variance of $c(z)$ gives roughly a $(0.43/0.66)^2 \approx 43\,\%$ contribution to the entire variance, so its significant fraction is also intrinsic.

4. RELATIONSHIP BETWEEN FLUENCE AND DURATION

We observe only those bursts which fulfil some triggering criteria and whose observed quantities are suffering from some type of bias depending on the process of detection. The detection proceeds on three time scales: on 64, 256 and 1024 ms resolution. We have shown in a previous paper (Bagoly et al. 1998) that the duration and the peak intensity are independent stochastic variables:

$$\log F_{\rm tot} = a_1 \log T_{90} + a_2 \log P + \varepsilon, \tag{3}$$

where a_1 and a_2 are constants and ε is some noise term. By fixing the P peak intensity we get the relationship between the fluence and duration. To ensure the best time resolution, we used P_{64} in our calculations. In order to fit the $[\log T_{90}, \log F_{\rm tot}]$ data pairs with the superposition of two two-dimensional Gaussian bivariate distributions we splitted the Catalog into subsamples with respect to 64 ms peak fluxes.

The strata were obtained by taking 0.2 wide strips in the logarithmic peak fluxes in the $0.0 < \log P_{64} < 1.0$ range. With this choice we avoided the incompleteness among the faint bursts and get enough objects for statistics within the strips investigated. The calculated weighted mean of the slopes resulted in $a_1 = 0.81 \pm 0.06$ for the short bursts and $a_1 = 1.11 \pm 0.03$ for the long bursts. The difference is significant at the 99.998 % level. Figure 1 shows the results obtained for the faintest and brightest subsamples of our calculations.

5. CONCLUSIONS

We have presented evidence indicating that there is a power-law relationship between the logarithmic fluences and the T_{90} durations. An intriguing corollary of these results is that the exponents in the power-law dependence between the fluence and duration differ significantly for the subgroups of short ($T_{90} < 2$ s) and long ($T_{90} > 2$ s) bursts. This also means that the same power law relations hold between the total energy emitted ($E_{\rm tot}$) and the intrinsic durations (t_{90}) of the two subgroups. In summary, we have presented quantitative arguments that there is a power law relation between the fluence and duration of GRBs, and this relation is significantly different for the two subgroups of bursts. This may indicate that two different types of central engines are at work, or perhaps two different types of progenitor systems are involved.

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