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The E_{iso}-L_{iso} Plane for Gamma-Ray Bursts

Walid J. Azzam, Fatima S. Jaber, Ghufran M. Ahmed

Department of Physics, College of Science, University of Bahrain, Sakhir, Bahrain
Email: wjazzam@uob.edu.bh, wjazzam@gmail.com

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Abstract

Gamma-ray bursts (GRBs) are the most intense and powerful explosions in the universe. Based on their observed duration, they are traditionally divided into long bursts whose observed duration equals or exceeds 2 s, and short bursts whose observed duration is less than 2 s. Several GRB energy and luminosity correlations have been discovered for long gamma-ray bursts. Two important correlations are the Amati relation and the Yonetoku relation. The Amati relation is a correlation between the intrinsic peak energy, $E_{p,i}$, obtained from the νF_ν spectrum and the equivalent isotropic energy, E_{iso}, while the Yonetoku relation is a correlation between $E_{p,i}$ and the peak isotropic luminosity, L_{iso}. In this paper, we use a recent data sample that includes both long and short GRBs to compare these two correlations for the two groups of bursts. We also compare the E_{iso}-L_{iso} plane for these two types of bursts. Our results indicate that both long and short bursts adhere to these two correlations but with different normalizations. We also find that the E_{iso}-L_{iso} plane is similar for both types of GRBs but is shifted to lower values of E_{iso} for short GRBs.

Keywords

Gamma-Ray Bursts, Peak Energy Correlations, Energy Indicators, Luminosity Indicators

1. Introduction

Gamma-ray bursts (GRBs) are immensely powerful stellar explosions with an equivalent isotropic energy, E_{iso}, that can exceed 10^{54} erg [1]. They exhibit a nonthermal spectrum and their light curves consist of erratic, complex, and intense pulses. Current theoretical models suggest that GRBs emanate from jets, but the precise physical mechanism behind the formation of these jets remains elusive [2].

Several GRB energy and luminosity correlations have been discovered for long

GRBs, which are bursts whose observed duration equals or exceeds 2 s. Some of these correlations were discovered through the analysis of the light curves [3] [4], while others were obtained from spectral analysis and currently include the Amati relation [5] [6] [7] [8], the Ghirlanda relation [9], the Yonetoku relation [10] [11], and the Liang-Zhang relation [12]. These correlations are important because they can be utilized as tools to probe cosmological models [12]-[18], and because they provide insight into the physics of GRBs [19] [20].

In this paper, we compare and examine the degree to which the Amati relation and the Yonetoku relation apply to both long and short bursts. We also explore and compare the E_{iso}-L_{iso} plane for both types of GRBs. Section 2 provides important background regarding the Amati and Yonetoku correlations. Our data sample, results, and analysis are presented in Section 3, and our conclusion is provided in Section 4.

2. The Amati and Yonetoku Correlations

The study by Amati *et al.* [5] in 2002 was the first examination of a correlation in the burst's rest frame. The study found that there is a positive correlation between the intrinsic peak energy, $E_{p,i}$, and the equivalent isotropic energy, E_{iso}. The study by [5] was based on 12 bursts with known redshifts, z, detected by *BeppoSAX*. The intrinsic peak energy is calculated from the observed peak energy, $E_{p,obs}$, by applying the z-correction as follows:

$$E_{p,i} = (1+z) \times E_{p,obs} \tag{1}$$

while E_{iso} can be calculated from the bolometric flux, S_{bol}, using:

$$E_{iso} = 4\pi d^2 S_{bol} / (1+z) \tag{2}$$

where d is the luminosity distance, which can be calculated from z after adopting a certain cosmological model. In Amati's original paper [5], a flat universe was assumed with $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 65\ \text{km}\cdot\text{s}^{-1}\cdot\text{Mpc}^{-1}$. The Amati relation can be expressed logarithmically as [21] [22] [23] [24] [25]:

$$\log(E_{iso}) = A + B \cdot \log\left(E_{p,i} / \langle E_{p,i} \rangle\right) \tag{3}$$

where the normalization, A, and the slope, B, are constants, and where $\langle E_{p,i} \rangle$ is the mean value of the intrinsic peak energy for the entire data sample. Early studies found that the approximate mean values for the fitting parameters are $\langle A \rangle \approx 53$ and $\langle B \rangle \approx 1$.

Another important peak-energy correlation is the Yonetoku relation, which is a correlation between the intrinsic peak energy and the peak isotropic luminosity, L_{iso}, and which can be expressed logarithmically as [26] [27] [28]:

$$\log(L_{iso}) = A + B \cdot \log\left(E_{p,i} / \langle E_{p,i} \rangle\right) \tag{4}$$

where, like before, the normalization, A, and the slope, B, are constant fitting parameters.

3. Data, Analysis, and Results

The data sample that we use in this study is taken from Table 1 and Table 2 of [26] and consists of 49 long bursts and 19 short bursts. First, we calculated the intrinsic peak energies for all the bursts using Equation (1), then a maximum-likelihood fit of the form expressed in Equation (3) was applied to obtain the Amati relation. For the long bursts, the best-fit parameters that we obtained were A = 53.41 and B = 0.85, with a mean intrinsic peak energy of 2151.8 keV and a linear regression coefficient r = 0.67, while for the short bursts, the best-fit parameters that we obtained were A = 51.69 and B = 2.03, with a mean intrinsic peak energy of 1929.3 keV and a linear regression coefficient r = 0.86, as shown in **Figure 1**.

A similar procedure was applied to obtain the best-fit parameters for the Yonetoku relation. For the long bursts, the best-fit parameters that we obtained were A = 53.07 and B = 1.50, with a linear regression coefficient r = 0.86, while for the short bursts, the best-fit parameters that we obtained were A = 52.47 and B = 1.60, with a linear regression coefficient r = 0.92, as shown in **Figure 2**.

The values of the linear regression coefficient that we obtained indicate that the fits are statistically significant and that the correlations are strong. For long GRBs this is not surprising, but for short GRBs it is somewhat unexpected. However, it is important to keep in mind that the normalization parameter, A, is significantly smaller for short GRBs for both correlations, so it would be more accurate to say that the short bursts follow an Amati-like relation and a Yonetoku-like relation rather than following these relations in the strict sense.

We also investigated the E_{iso}-L_{iso} plane for the two types of bursts to explore whether there are any significant differences. As **Figure 3** shows, both types of bursts display a similar trend with a strong positive correlation between E_{iso} and

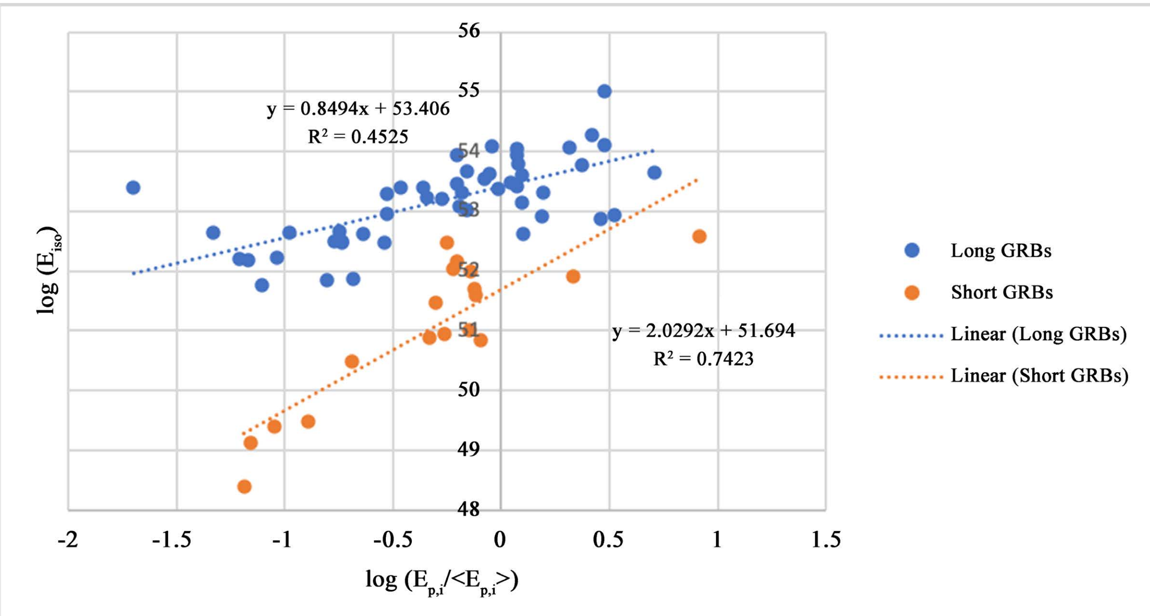

Figure 1. The best-fit Amati relation applied to a sample of 49 long bursts and 19 short bursts.

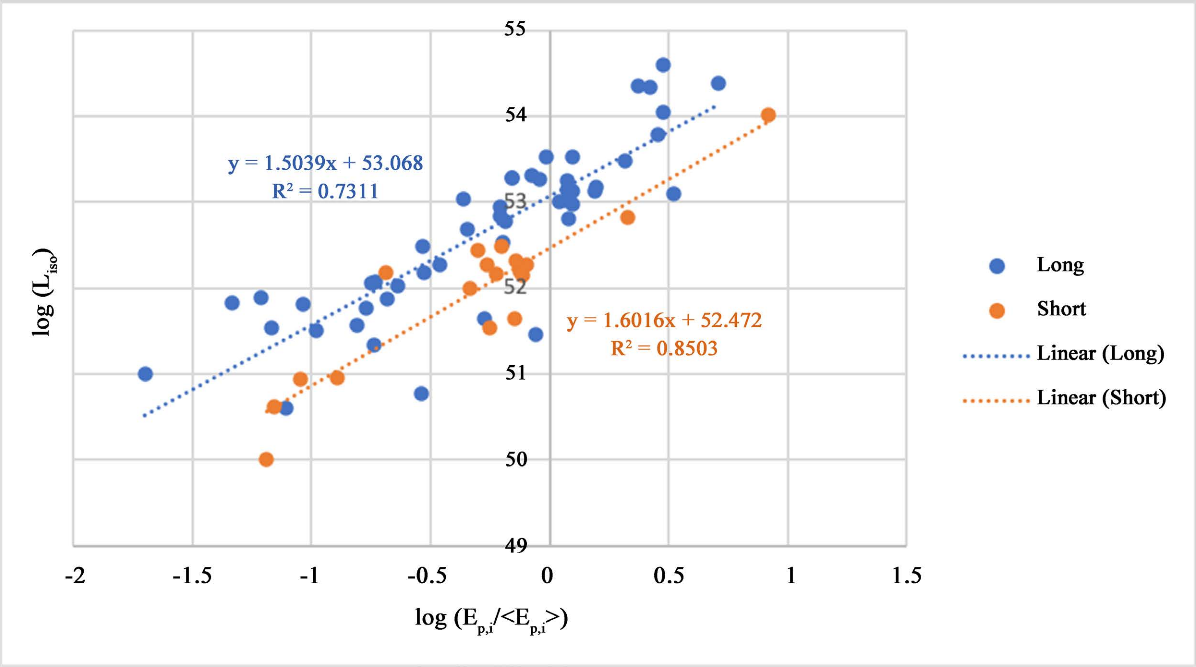

Figure 2. The best-fit Yonetoku relation applied to a sample of 49 long bursts and 19 short bursts.

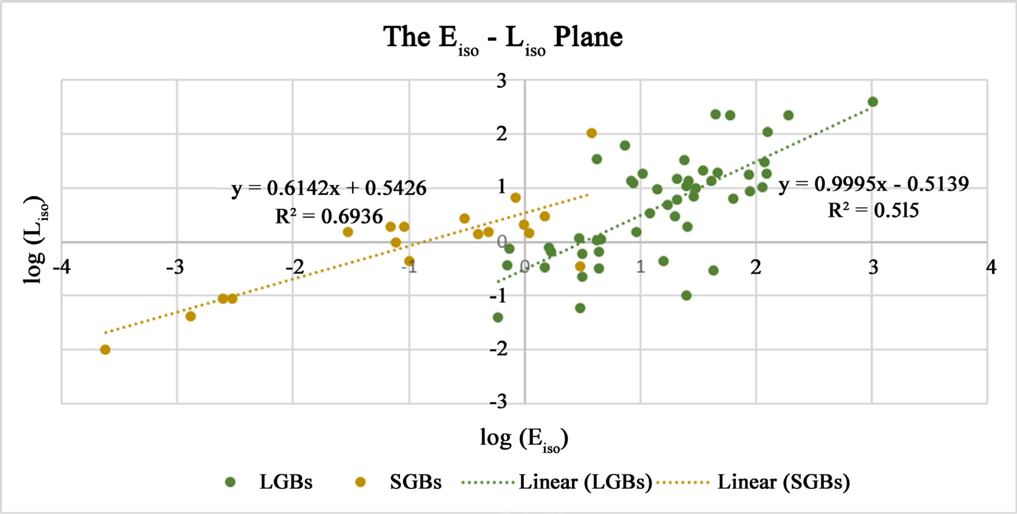

Figure 3. The E_{iso}-L_{iso} plane for the sample of 49 long bursts and 19 short bursts.

L_{iso}, as indicated by the values of the linear regression coefficient, $r = 0.71$ for long GRBs and $r = 0.83$ for short GRBs. However, it is important to note that in the case of the short GRBs, the correlation is shifted appreciably to lower values of E_{iso}, which is not surprising since the energy budget involved in the formation mechanism of short bursts is less than that for long bursts.

4. Conclusion

The peak energy correlations of GRBs are important relations that provide insight into the physics of GRBs. The Amati relation is an important correlation between the intrinsic peak energy and E_{iso}. Our results indicate that it applies to both long and short bursts, albeit with different fitting parameters. Another important peak energy correlation is the Yonetoku relation, which correlates the intrinsic peak energy and L_{iso}, and our results confirm that this correlation applies to both short and long bursts but with different normalizations. Our study also finds evidence that there is a significant correlation between E_{iso} and L_{iso} for both types of bursts. As more data become available, it is important to confirm these results because they have important implications regarding the underlying physics of both long and short gamma-ray bursts.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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