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Redshift Independence of the Amati and Yonetoku Relations for Gamma-Ray Bursts

Walid J. Azzam, Mohamed J. Alothman

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

ABSTRACT

The Amati and Yonetoku relations are two of the main energy and luminosity correlations that currently exist for gamma-ray bursts (GRBs). The Amati relation is a correlation between the intrinsic peak energy, E_{peak}, in the νF_ν spectrum of a burst and its equivalent isotropic energy, E_{iso}. The Yonetoku relation is a correlation between E_{peak} and the isotropic peak luminosity, L_{iso}. In this paper, we use a recent data sample of 65 GRBs to investigate whether these two relations evolve with redshift, z. The z-correction and the k-correction are both taken into account. Our method consists of binning the data in redshift, z, then applying (for each bin) a fit of the form: $\log(E_{iso}) = A + B\log\left(E_{peak}\big/\langle E_{peak}\rangle\right)$ for the Amati relation, and of the form: $\log(L_{iso}) = A + B\log\left(E_{peak}\big/\langle E_{peak}\rangle\right)$ for the Yonetoku relation, where $\langle E_{peak}\rangle$ is the mean value of the peak energy for the entire sample. The objective is to see whether the two fitting parameters, A and B, evolve systematically with z. Good least-squares fits were obtained with reasonable values for the linear regression coefficient, r. Our results indicate that the normalization, A, and the slope, B, do not evolve with redshift, and hence the Amati and Yonetoku relations seem to be redshift independent.

Keywords: Gamma-Ray Bursts; Energy Correlations; Luminosity Indicators; Redshift Evolution

1. Introduction

There are currently several energy and luminosity correlations for gamma-ray bursts (GRBs). Some were obtained from the light curves, like the lag-luminosity and variability relations [1,2], while others were obtained from the spectra and included the Amati relation [3-6], the Ghirlanda relation [7], the Yonetoku relation [8,9], and the Liang-Zhang relation [10]. The importance of these correlations resides in their potential use as cosmological probes that might help constrain cosmological models [11-15], and also as tools that might help probe the physics of GRBs.

On the other hand, some studies have looked at possible inherent problems that these relations might suffer from, like the circularity problem and selection effects [16-20]. However, less attention has been given to the possible redshift evolution of these correlations as evidenced by the few studies dedicated specifically to this issue [21-26]. But since these relations are typically calibrated over a wide range in redshift (roughly $0.1 < z < 8$),

it becomes incumbent to study their possible dependence on z, if they are to be utilized as cosmological probes.

The purpose of this paper is to investigate the possible redshift evolution of two well-known GRB energy and luminosity correlations—namely, the Amati and Yonetoku relations. The Amati relation is a correlation between the intrinsic (*i.e.*, rest-frame) peak energy, E_{peak}, in a burst's νF_ν spectrum and its equivalent isotropic energy, E_{iso}. The Yonetoku relation, on the other hand, is a correlation between E_{peak} and a burst's isotropic peak luminosity, L_{iso}.

In this paper we study the possible redshift evolution of these two relations by making use of a recent data sample consisting of 65 GRBs. The data, analysis, and results are presented in Section 2, which is followed by a discussion and summary in Section 3.

2. Data, Analysis, and Results

The data sample used in this study is taken from Geng and Huang [27], who were able to fit the time-averaged

spectra of 65 GRBs using the Band function and to extract the relevant spectrum parameters. The data sample includes bursts that were observed by *Swift*, *Konus/Wind*, or *Fermi*. The values for E_{iso} and L_{iso} were obtained by integrating over the energy range 1 keV to 10^4 keV in the burst's rest frame and applying the appropriate *k*-correction. Although the entire data sample consists of 65 GRBs, only 53 bursts have both E_{peak} and E_{iso} values available and so these are the bursts that we used in our analysis of the Amati relation; similarly, only 47 bursts have both E_{peak} and L_{iso} values available and thus these are the bursts that we used in our analysis of the Yonetoku relation.

Our method consists of binning the data by redshift, then writing the Amati relation as:

$$\log\left(E_{iso}\right) = A + B\log\left(E_{peak}\Big/\left\langle E_{peak}\right\rangle\right) \qquad (1)$$

and the Yonetoku relation as:

$$\log\left(L_{iso}\right) = A + B\log\left(E_{peak}\Big/\left\langle E_{peak}\right\rangle\right) \qquad (2)$$

and then extracting the fit parameters A and B for each bin; the objective is to see whether A and B vary systematically with z. Note that we normalized E_{peak} to the corresponding mean value for the entire sample, $\langle E_{peak}\rangle$, in order to avoid introducing any spurious correlations between the two fit parameters.

The binning was done by fixing the number of bursts per redshift bin, and a different number of bins was tried in order to check that the binning itself does not affect our conclusions. **Table 1** shows our results for the Amati relation when a least-squares fit was used with 5 bins. The first two columns show, respectively, the bin number and the mean redshift for that particular bin. Columns 3 and 4 show the best-fit values for A and B, respectively, along with their 1σ errors. The values for the linear regression coefficient, r, and its corresponding chance probability, P, were also calculated and are shown in columns 5 and 6, respectively. **Table 2** is similar to **Table 1** but shows our results for the Yonetoku relation. Both tables show that the goodness of the fits varied

from bin to bin, with some bins having very good fits while others have acceptable fits, which is probably due to the paucity of data points. A quick examination of the two tables shows that neither shows any systematic trend between the fitting parameters, A and B, and the redshift.

Figure 1 shows the best-fit lines for the Amati relation and **Figure 2** shows how the corresponding values for A

Table 2. The best-fit values for the normalization, A, and the slope, B, along with their 1 σ errors, obtained for the Yonetoku relation. The linear regression coefficient, r, and its corresponding chance probability, P, are also shown.

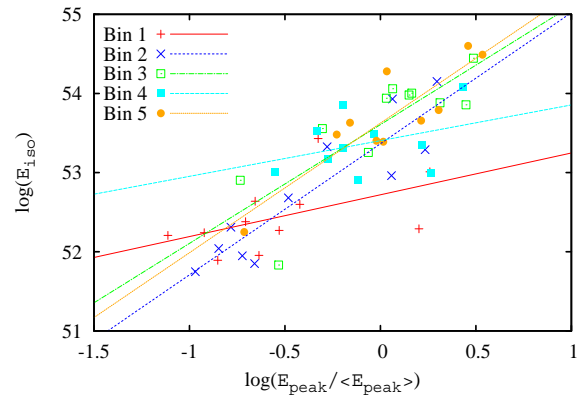| Bin	Mean Redshift	A	B	r	P
1	0.471	51.58 ± 0.29	0.15 ± 0.43	0.12	0.74
2	0.877	52.52 ± 0.07	1.01 ± 0.14	0.93	0.000090
3	1.222	52.40 ± 0.15	1.31 ± 0.39	0.79	0.012
4	1.816	52.74 ± 0.13	1.90 ± 0.43	0.86	0.0029
5	3.041	53.07 ± 0.10	2.01 ± 0.33	0.92	0.00050

Figure 1. The equivalent isotropic energy, E_{iso}, plotted versus the normalized rest-frame peak energy (the Amati relation) for different redshift bins, where Bin 1 represents the lowest redshift range.
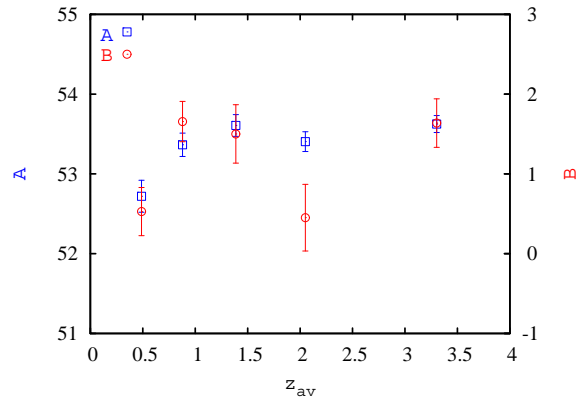

Figure 2. The normalization, A, and the slope, B, plotted versus the mean redshift for the least-squares fits shown in Figure 1. The vertical bars refer to 1 σ errors.

Table 1. The best-fit values for the normalization, A, and the slope, B, along with their 1 σ errors, obtained for the Amati relation. The linear regression coefficient, r, and its corresponding chance probability, P, are also shown.

Bin	Mean Redshift	A	B	r	P
1	0.488	52.72 ± 0.20	0.53 ± 0.30	0.50	0.11
2	0.879	53.37 ± 0.15	1.66 ± 0.25	0.91	0.00011
3	1.387	53.61 ± 0.14	1.50 ± 0.37	0.81	0.0027
4	2.050	53.40 ± 0.12	0.45 ± 0.42	0.36	0.31
5	3.302	53.63 ± 0.11	1.64 ± 0.30	0.89	0.00066

and *B* vary with redshift. In **Figure 2**, the vertical bars refer to 1σ errors, and the exact horizontal location of the points was set at the mean redshift value for each bin. **Figures 3** and **4** are similar to **Figures 1** and **2**, respectively, but for the Yonetoku relation. **Figure 4** shows an initial rise in the values of *A* and *B*, but this is not significant since the values soon "saturate" and are consistent with one another to within 1 σ. Therefore, the figures reinforce what is seen in the two tables—namely, the best-fit lines, and hence the fitting parameters, *A* and *B*, do not vary systematically with *z*.
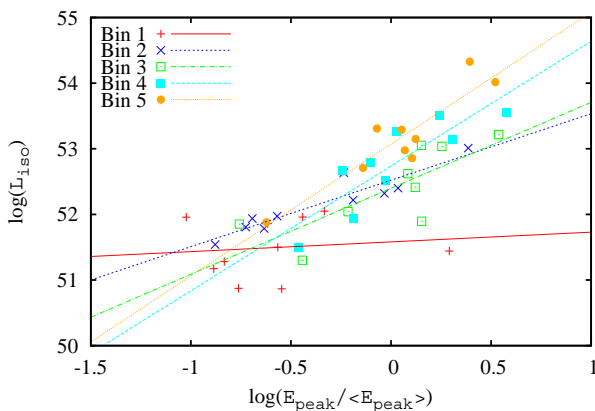

Figure 3. The isotropic peak luminosity, L_{iso}, plotted versus the normalized rest-frame peak energy (the Yonetoku relation) for different redshift bins, where Bin 1 represents the lowest redshift range.
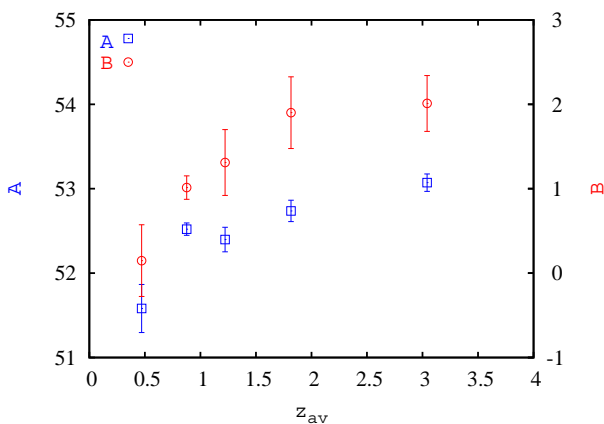

Figure 4. The normalization, *A*, and the slope, *B*, plotted versus the mean redshift for the least-squares fits shown in Figure 3. The vertical bars refer to 1 σ errors.

3. Discussion and Summary

In this section we would like to put our study in proper context by comparing it to what has been done by others. As mentioned earlier, although many recent studies have looked at different aspects of GRB energy and luminosity relations [27-29], only a few have specifically considered the issue of redshift evolution of these relations.

One of the earliest studies to look at this issue is the paper by [21] in which a sample of 48 GRBs was used to investigate the possible redshift evolution of the Amati relation. The author of that paper found evidence that this relation gets steeper with redshift, and thus concluded that the Amati relation seems to evolve with redshift. However, a subsequent investigation by [18] extended the study done by [21] by enlarging the data sample to 76 bursts. Although they confirmed the results found by [21] for the 48 bursts, when all 76 bursts were used the redshift evolution disappeared, and so their conclusion was that what [21] had found was probably due to low statistics. Our results are in agreement with what was found by [18] since no redshift evolution was found for either the Amati relation or the Yonetoku relation.

In conclusion, a data sample of 65 gamma-ray bursts was used to investigate the possible redshift evolution of the Amati and Yonetoku relations. Our analysis indicates that the normalization, *A*, and the slope, *B*, do not vary in a systematic way with *z*. Therefore, these two GRB relations seem to be redshift independent, and are thus robust in this regard.

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