GRB Variability-Luminosity Correlation Confirmed

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ABSTRACT

Recently, Guidorzi et al. (2005) expanded the size of the sample of GRBs for which variabilities and peak luminosities have been measured, from 11 to 32. They confirm the existence of a correlation, but find a dramatically different relationship between $L$ and $V$ than had originally been found. We find that this is the result of improper statistical methodology. When we fit a model to the data that accommodates both statistical variance (in two dimensions) and sample variance, we find that $L \sim V^{3.4 \pm 0.9}$ with a sample variance of $\sigma_{\log V} = 0.20^{+0.04}_{-0.04}$, which is consistent with the original finding of Reichart et al. (2001) – $L \sim V^{3.3 \pm 0.9}$ with a sample variance of $\sigma_{\log V} = 0.18^{+0.07}_{-0.05}$ – and inconsistent with the finding of Guidorzi et al. (2005): $L \propto V^{1.3^{+0.3}_{-0.4}}$ with sample variance assumed to be zero.

Subject headings: gamma-rays: bursts — methods: statistical

1. Introduction

A correlation between GRB variability and peak luminosity was first proposed by Fenimore et al. (2000). Motivated by this, Reichart et al. (2001) constructed a robust measure of GRB variability and computed variabilities for 18 GRBs with high time-resolution (64 msec) light curves and variability lower limits for two GRBs with low time-resolution (1 sec) light curves. Of the former 18 GRBs, 11 had measured redshifts and peak luminosities. A correlation between $L$ and $V$ was apparent and significant at the 3.8$\sigma$ credible level if nearby GRB 980425 was excluded and 4.9$\sigma$ credible level if GRB 980425 was included. However, we did not model the data with a power law (as Guidorzi et al. 2005 claim), because the scatter of the data around such a model is more than can be accounted for by the data’s statistical error bars alone. This scatter is called sample variance. Consequently, we instead

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modeled the data with a normal distribution around a line in the \( \log L - \log V \) plane. The width of this distribution, which can be parameterized by either \( \sigma_{\log L} \) or \( \sigma_{\log V} \), measures the sample variance, and is sometimes called the “slop” parameter (e.g., Reichart 2001; Lee et al. 2001; Galama et al. 2003; Nysewander et al. 2005). Fitting such a distribution to data with error bars in not one but two dimensions is non-trivial. However, we present a maximum-likelihood procedure for doing just this in §2.2.2 of Reichart (2001). Applying this formalism yielded \( L \sim V^{3.3^{+1.1}_{-0.9}} \) with a sample variance of \( \sigma_{\log V} = 0.18^{+0.07}_{-0.05} \).

Using the measure of variability introduced by Reichart et al. (2001), Guidorzi et al. (2005) have expanded the size of the sample of GRBs for which both variabilities and peak luminosities are known from 11 to 32, primarily with BeppoSAX GRBM data, but also with HETE-2 FREGATE, Swift BAT, CGRO BATSE, WIND Konus, and Ulysses GRB data. They confirm the existence of a correlation, using Pearson’s \( r \), Spearman’s \( r_s \), and Kendall’s \( \tau \) tests. They also find that the data are not well described by a power law (\( \chi^2 = 1167 \) or 1145, depending on how they do the fit, for only 30 degrees of freedom), but incorrectly state that Reichart et al. (2001) had found this to be the case. Although their fits are poor, they find that \( L \propto V^{1.3^{+0.8}_{-0.4}} \) or \( V^{1.2^{+0.5}_{-0.2}} \), again depending on how they do the fit, with sample variance assumed to be zero. This is significantly different than what Reichart et al. (2001) found.

Some of the effects of not modeling sample variance when it is required can be seen in Figures 1 and 2: The dashed lines mark the center and 1\( \sigma \) width of the original best-fit distribution of Reichart et al. (2001), and appear to remain an acceptable description of the data even though the sample has nearly tripled in size. We update this fit in §2. The dotted lines are the best-fit power laws of Guidorzi et al. (2005), which do not appear to acceptably describe even the trend of the data.

2. Updated Fits

We now refit the model of Reichart et al. (2001) to the expanded data set of Guidorzi et al. (2005). However, we do not include GRB 000210 in this fit: This GRB is missing high time-resolution data for 2.5 sec during the peak of this \( T_{90} = 8.1 \) sec long event and consequently should be viewed as only providing a lower limit to the variability. Indeed, this GRB is significantly less variable than all other GRBs of comparable peak luminosity, typically by an order of magnitude. Using the statistical formalism presented in Reichart (2001) for fitting distributions to data with error bars in two dimensions, we find that \( L \sim V^{3.4^{+0.9}_{-0.6}} \) with a sample variance of \( \sigma_{\log V} = 0.20^{+0.04}_{-0.04} \) if we exclude GRB 980425 from the fit and \( L \sim V^{3.5^{+0.9}_{-0.6}} \) with a sample variance of \( \sigma_{\log L} = 0.20^{+0.04}_{-0.04} \) if we include GRB 980425.
The solid lines in Figures 1 and 2 mark the centers and $1\sigma$ widths of the best-fit distributions, respectively. These distributions are in excellent agreement with our earlier work.

If we also include GRB 000210, we find that $L \sim V^{4.0^{+1.5}_{-0.9}}$. This shows that the difference between our fits and those of Guidorzi et al. (2005) are not due to our exclusion of this point, but due to their exclusion of sample variance in their model.

3. Conclusions

Using a statistical formalism that is appropriate for this data set, we fit a distribution in the $\log L$ – $\log V$ plane to the expanded data set of Guidorzi et al. (2005). Our findings are in excellent agreement with our earlier work, when the sample was approximately one-third its current size. The variability-luminosity correlation is now best described by $L \sim V^{3.4^{+0.6}_{-0.9}}$ with a sample variance of $\sigma_{\log V} = 0.20^{+0.04}_{-0.04}$.

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Fig. 1.— Variabilities $V$ and peak luminosities $L$ of all of the GRBs in the sample of Guidorzi et al. (2005) except for nearby GRB 980425. Dashed lines mark the center and $1\sigma$ width of the original best-fit distribution of Reichart et al. (2001) and solid lines mark the center and $1\sigma$ width of the updated best-fit distribution of this paper. Dotted lines are the best-fit power laws of Guidorzi et al. (2005). The variability of the unfilled circle (GRB 000210) should be treated as a lower limit and consequently we do not include it in our updated fit, though we show that including it does not significantly change our results (§2).

Fig. 2.— Same as Figure 1, except including GRB 980425.
A graph showing the relationship between $L \times 10^{50}$ erg/s and $V$. The data points are labeled as follows:

- Reichart et al. 2001
- Guidorzi et al. 2005
- Reichart & Nysewander 2005
