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LOW-ENERGY STUDY OF GAMMA-RAY BURSTS HAVING SPECTRAL LINE FEATURES

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Introduction

Gamma-ray bursts (GRBs) are energetic, short-duration emissions of gamma-rays. The Burst and Transient Source Experiment (BATSE) that was onboard NASA's Compton Gamma-Ray Observatory has done much to advance our understanding of GRBs. Perhaps foremost is to establish that GRBs originate from astronomical sources that exist well beyond our galaxy. Another area in which BATSE has been instrumental is to provide high-resolution data that can be used in spectral studies. Before BATSE, there were many reports of GRB spectra containing what appeared to be spectral absorption lines, whereas Briggs, after an extensive computer search of 117 bright BATSE GRBs, reported finding only one case that might be an absorption line and ten cases that might be emission lines [1]. None of the eleven BATSE cases were definitively identified as spectral lines, and Briggs indicated reasons as to why the pre-BATSE reports should not be taken as conclusive.

It remains an open question as to what these spectral-like features are, or if they are even real. The purpose of this work is, for the subset of the eleven BATSE GRBs for which low-energy data are available from two BATSE's Spectroscopy Detectors (SDs), to include these data in the spectral analysis. Such a study will provide additional constraints on the model spectral functions to better ascertain the reality of the line features. The spectral analysis program used was RMFIT. Of the six GRBs that met the selection criteria, the analysis was performed on only three of them due to a lack of time.

Spectral Models

The continuum portion of the GRB's spectra is fit using Band's GRB model, a product power-law and exponential function with four parameters and a break point [3]. The secondary models used in this study are a Gaussian, Optically Thin Thermal Bremsstrahlung (OTTB) model, and a Multiplicative Broken Power Law (MBPL); the first two being additive models. The Gaussian is used to model a spectral line. The OTTB model has the following form

$$f_{OTTB} = A \frac{E_P}{E} e^{-(E-E_P)/kT} \tag{1}$$

where A is an amplitude parameter, T is a temperature parameter, and E_P is known as the pivot energy. For this study E_P is constrained to 10 keV. The MBPL is unity for energies above its break point E_B. Otherwise it is given by

$$f_{MBPL} = \left(\frac{E}{E_B}\right)^b \qquad \text{for } E \le E_B, \tag{2}$$

where b is known as the low-energy index. Note that both b and E_B are free parameters.

The means by which a secondary model will be judged for improving a fit, and thus assessing the credibility of the data, is known as the Maximum Likelihood Ratio Test (MLRT). The MLRT judges the fit by considering the amount by which the χ^2 value for the fit is improved as a result of the secondary model. For example, for Briggs' study, an improvement in χ^2 of $\Delta\chi^2 = 20$ resulting from a two-parameter, secondary model corresponds to a chance occurrence of 1 in 20,000. For this study we assume that $\Delta\chi^2 = 20$ will have the same order of probability.

Results and Conclusions

Only some results and the highlights of the study will be presented here. Figure 1 shows the background-subtracted data from SD#'s 0 & 5 along with the resulting model fits (shown as solid, unmarked lines) for BATSE Trigger 3245 using just Band's GRB model. Two data types are being used, high-resolution (SHER) type and the low-energy, low-resolution (DISCSP) type. The time interval for the spectra is 7.9 to 22.5 s, which approximates the interval during which Briggs discovered the spectral feature.

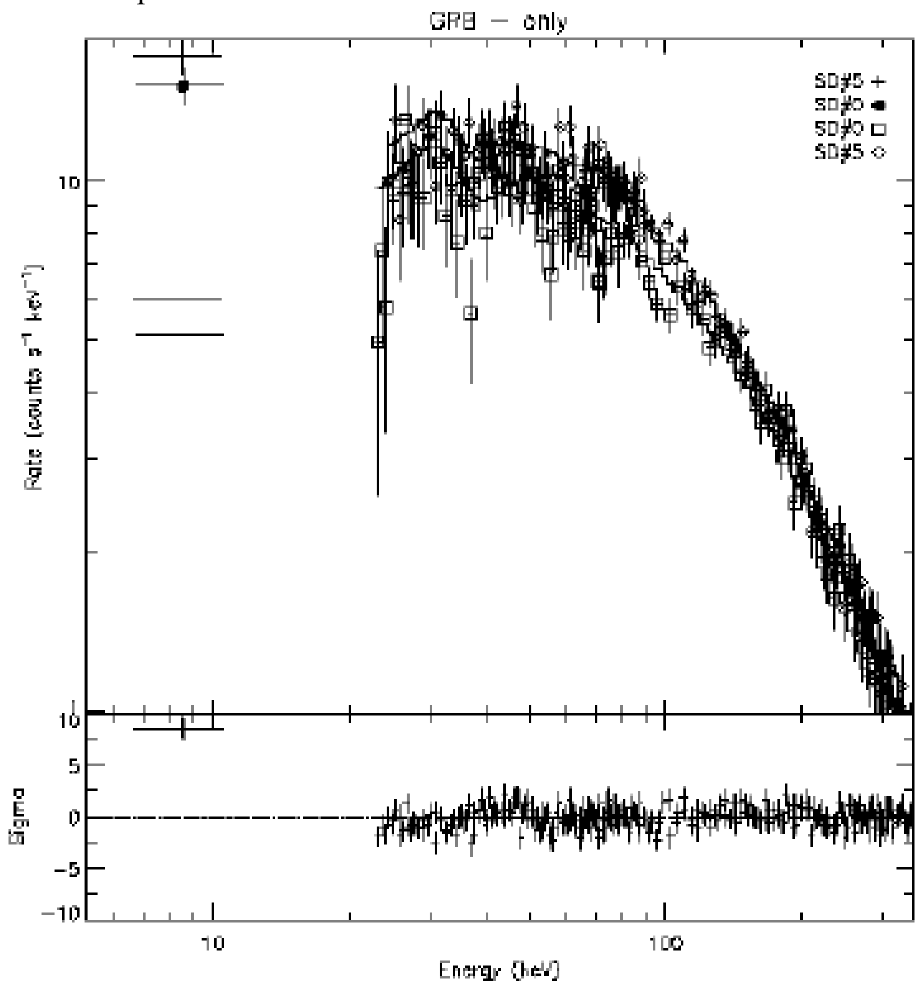

Figure 1: Joint fit of Trig 3245 from 7.9 to 22.5 s.

The lower panel in Figure 1 is a plot of the difference between the measured and model count rates expressed in units of σ. It is evident that there is a significant discrepancy (~ 9σ) at the low energy. Preece et al. [2] have studied low-energy (x-ray) discrepancies and have found significant discrepancies are present in fewer than 20% of bright GRBs.

Table 1 gives a summary of the various fitting attempts for Trig 3245. In each case, the continuum was fit with Band's GRB model. The secondary model and its fixed parameter are listed, and, in the last case, a third model (Gaussian) was also used. The number of degrees of freedom (DOF), the resulting χ^2, and the improvements on χ^2 ($\Delta\chi^2$) for each fit are also listed. Most noteworthy is that by far the greatest improvement in the fit resulted from using the OTTB model as the secondary ($\Delta\chi^2$ = 170.); however, adding in a Gaussian as a third component still yields a significant improvement ($\Delta\chi^2$ = 21). This suggests, although is not conclusive, that the feature associated with the Gaussian fit may be real. (The fit determined the energy centroid of the Gaussian to be 43.5 ± 1.3 keV.)

Table 1 Summary of Fit Results for Trig 3245

Trig: 3245	(X-Ray: Excess)				Full Resolution	
				DOF	χ^2	$\Delta\chi^2$
Main Model:	Band's GRB			390	553.47	
Secondary Model	Fixed Param.	w. Third Model	Fixed Param.			
Gaussian	Width			388	535.98	17.49
Gaussian	--			387	535.93	17.54
OTTB	E-Pivot			388	383.30	170.17
		Gaussian	Width	386	361.94	21.36

The type of low-energy discrepancy in Trig 3245 case is known as an "X-Ray Excess." The other two GRBs studied were found to have significant "X-Ray Deficits" (data count rates being lower than the model count rates). Therefore, there may be a connection between the existence of a spectral-line feature and an x-ray discrepancy.

Time histories of the fit parameters of the three GRBs were examined to look for commonalities or correlations. Examination of Trig 3245 shows that there are two peaks in the Gaussian feature that seem to precede two corresponding peaks in the x-ray component; however, the uncertainties in the parameters are too large to make a convincing case for the entire GRB duration. The third case studied (referred to as Case C) was exceptional in two ways. One was that a Gaussian is significant is only about 0.5 s out of 20 s of significant activity. The other exceptional point to make regarding Case C is illustrated in Figure 2, which is the time history of the low-energy MBPL index (holding E_B fixed to 18.1 keV) plotted along with the corresponding reduced χ^2 value for each time interval. (Note that there is one interval for which χ^2 did not converge. This interval is indicated by a negative value for χ^2.) From Figure 2, it is seen that MBPL low-energy index is notably close to zero in the same narrow interval that the Gaussian line is most prominent.

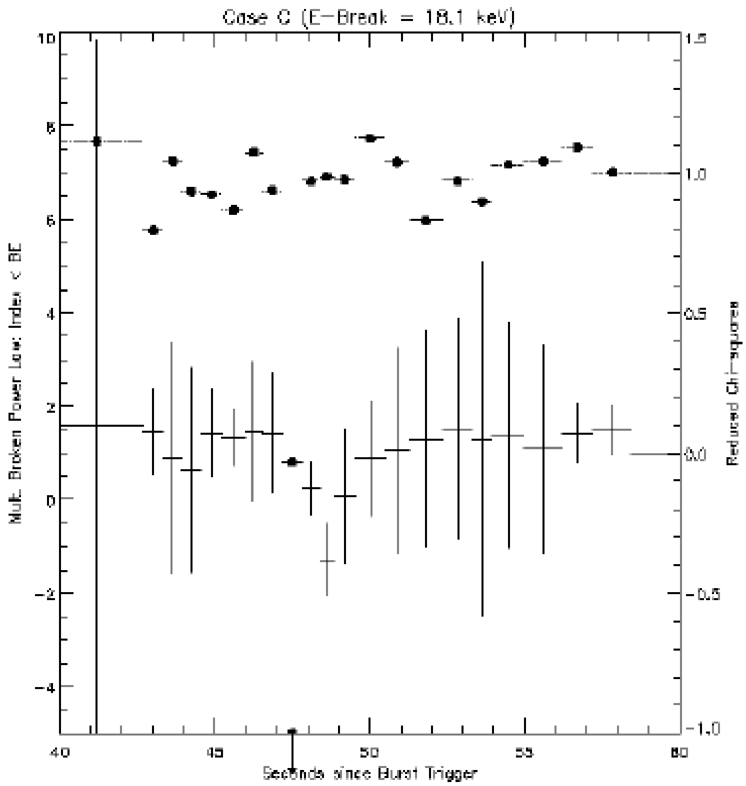

Figure 2 Time History of the MBPL Low Energy Index and Reduced Chi-Squared for Case C.

In conclusion, three of eleven GRBs from Briggs' spectral-line study were analyzed including low-energy SD data from two detectors. The major finding is that these cases were found to have significant x-ray discrepancies. Trig 3245, even after considerably improving the fit using the OTTB model, still had a spectral feature that might be significant ($\Delta\chi^2 = 21$). Case C showed a possible anti-correlation between its x-ray deficit and its spectral feature.

References

[1] Briggs, M. S. (1999) "Low-Energy Spectral Features in GRBs," *ASP Conference Series,* v. 190, pp. 133-149.

[2] Preece, R. D., et al. (1996), "BATSE Observations of Gamma-Ray Burst Spectra. III. Low-Energy Behavior of Time-Averaged Spectra," *The Astrophysical Journal*, v. 473, p. 310-321.

[3] Preece, R. D., et al. (2000), "The BATSE Gamma-Ray Burst Spectral Catalog. I. High Time Resolution Spectroscopy of Bright Burst using High Energy Resolution Data," *The Astrophysical Journal Supplement Series*, v.126, pp. 19-36.