How Real Detector Thresholds Create False Standard Candles

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How Real Detector Thresholds Create False Standard Candles

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Abstract. GRB satellites are relatively inefficient detectors of dim hard bursts. For example, given two bursts of identical peak luminosity near the detection threshold, a dim soft burst will be preferentially detected over a dim hard burst. This means that a high E_{peak} burst will need a higher peak luminosity to be detected than a low E_{peak} GRB. This purely detector-created attribute will appear as a correlation between E_{peak} and luminosity, and should not be interpreted as a real standard candle effect. This result derives from Monte Carlo simulations utilizing a wide range of initial GRB spectra, and retriggering to create a final "detected" sample. In sum, E_{peak} is not a good standard candle, and its appearance as such in seeming correlations such as the Amati and other L_{iso} vs. E_{peak} relations is likely a ghost of real energy-related detection thresholds.

Keywords: gamma-ray bursts; detectors
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Several correlations among the spectral parameters of Long-duration Gamma-Ray Bursts (LGRBs) have been reported in the recent years. Among the most debated correlations is the Amati relation (Amati et al. 2006) that relates the cosmological rest-frame time-integrated νF_ν spectrum peak energy (E_{peak}) and the isotropic-equivalent radiated energy, $E_{iso.}$ The discovery of several outliers to these correlations however, has raised the possibility that these correlations might be totally or partially due to selection effects that happen during the detection process of GRBs. The idea is bolstered accounting for the fact that GRB detectors (in particular BATSE and SWIFT), are photon counters and GRB triggering is primarily based on the detection of a certain number of photons above the background in the detection energy range of the detector. Therefore, given an observed fluence (S_{bol}), the harder (higher E_{peak}) bursts would generally be less detectable than the softer (lower E_{peak}) bursts. The whole process of burst detection, spectral analysis and redshift measurement is so complicated that it seems impossible to find any direct evidence of selection effect (if it exists). Therefore, it is necessary to decompose the problem into subsections (i.e. Triggering, spectral analysis, redshift measurement) and look for signatures in any of these levels. The aim of this work is to investigate the existence of any selection effects during the triggering process in the observer's plane of E_{peak} vs. S_{bol}. We focus in particular on BATSE in this work, since most of the reported correlations among LGRBs parameters have been originally derived from BATSE data. We should however, mention that it is impossible to avoid the effects of spectral analysis limitations on the distribution of GRBs on this plane.

Figure (1) shows the plot of E_{peak}-S_{bol} for 320 BATSE LGRBs (analyzed by Kaneko et al. 2006, and Nava et al. 2008). There is a correlation visible in this plot ($\tau_K = 0.37, 10\sigma$). These GRBs, however, constitute only a fraction of less than $1/8$ of the whole number of GRBs detected by BATSE. In order to avoid selection effects due to spectral analysis and include as many BATSE GRBs as we can in the simulation and analysis, we move to the plane of hardness ratio $HR_{43\text{-}21}$ (which is the sum of the fluences in channel 4 and 3 divided by the sum of the fluences in channel 2 and 1) vs. S_{bol}, since there is a strong positive correlation between $HR_{43\text{-}21}$ and E_{peak} with an adjusted correlation coefficient $R^2 = 0.74$ (figure 2). We use $HR_{43\text{-}21}$ rather than any other definition of hardness ratio (such as $HR_{3\text{-}2}$), since it has the tightest correlation with E_{peak} and the residuals of E_{peak} show no trend and are normally distributed about zero. There is also a positive correlation in the plane of $HR_{43\text{-}21}$ vs. S_{bol} for the aforementioned 320 BATSE LGRBs ($\tau_K = 0.40, 11\sigma$). This way, we extend the number of BATSE GRBs to more than 1900 on the plot of hardness vs. observed bolometric fluence (regardless of their types or durations) as shown in figure (3).

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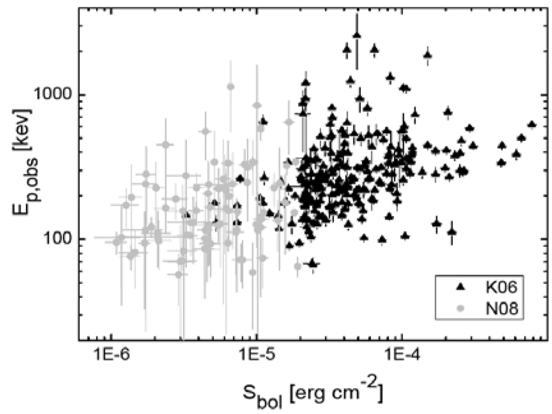

FIGURE 1. The observed E_{peak} vs. observed bolometric fluence for BATSE LGRBs analyzed by Kaneko (2006) (black triangles) and Nava (2008) (gray circles).

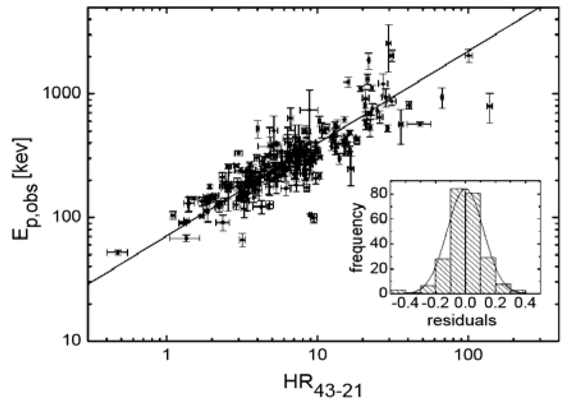

FIGURE 2. $HR_{43\text{-}21}$ vs. E_{peak} for 244 BATSE GRBs with firm E_{peak} (Kaneko, 2006). The inset graph is the frequency histogram of the residuals.

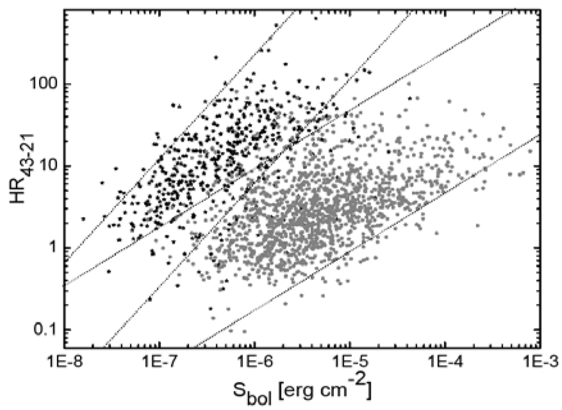

FIGURE 3. $HR_{43\text{-}21}$ vs. S_{bol} for 1904 BATSE GRBs. The dashed lines approximate the boundaries for each population of (short (black stars) and long (gray circles) duration) GRBs.

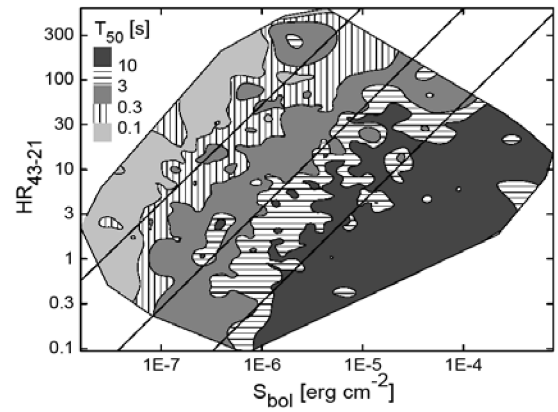

FIGURE 4. $HR_{43\text{-}21}$-S_{bol}-T_{50} contour plot for 1904 BATSE GRBs. The solid lines represent the typical slope that the boundaries for regions of different duration exhibit on this plot.

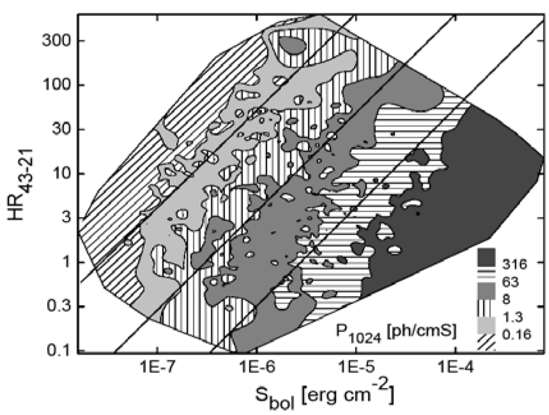

FIGURE 5. $HR_{43\text{-}21}$-S_{bol}-P_{1024} contour plot for 1904 BATSE GRBs with durations normalized to the longest duration in the sample. The solid lines are the same as the lines in figure 4, and are shown for a comparison of the typical slopes of the boundaries in the two plots of figures 4 & 5. Note that different patterns in this plot show regions of different peak fluxes (P_{1024}).

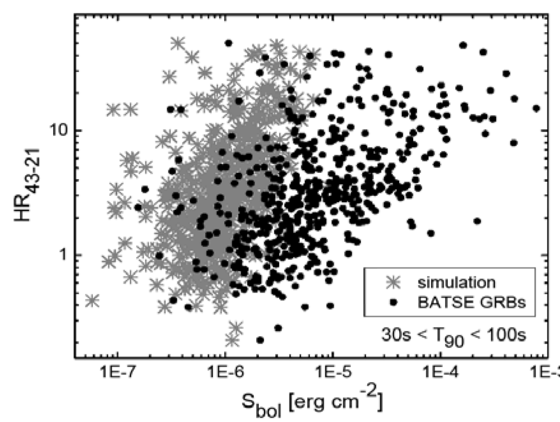

FIGURE 6. $HR_{43\text{-}21}$-S_{bol} plot of BATSE GRBs (black dots) and simulation results (gray stars) for GRBs with $30s<T_{90}<100s$. As seen, the slopes on the left and right hand side of BATSE GRBs are significantly different, while the slope on the left side resembles BATSE detection threshold (grey stars).

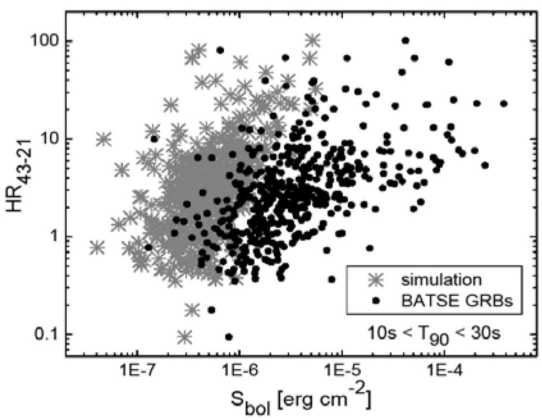

FIGURE 7. The same plot as in figure 6, but for GRBs with 10s<T_{90}<30s. The difference in the slopes of the left and right hand side of the real GRBs distribution is again visible, while the slope on the left side is very similar to the detection threshold limit (grey stars).

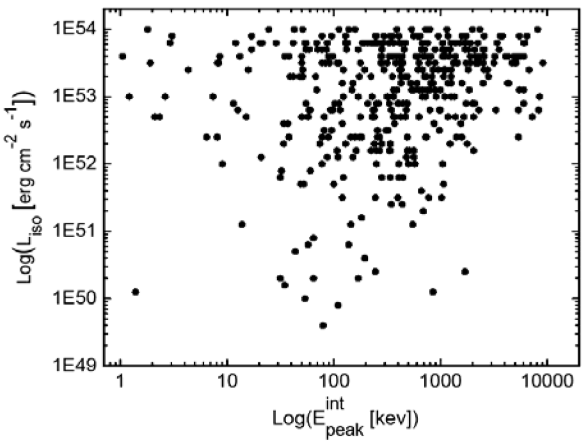

FIGURE 8. Isotropic luminosity vs. rest frame E_{peak} for simulated GRBs detected by BATSE. Note that a large fraction of GRBs on the lower right side of the plot are not detected while they might exist.

The hardness-fluence plot of figure (3) clearly shows that there are two different populations of GRBs (i.e. Short duration (SGRB, T_{90} < 3s) and long duration (LGRB, T_{90} >3s) bursts). However, both populations are showing the same slope and similar trend on their left and right boundaries, suggesting that SGRBs and LGRBs either have the same intrinsic physics or both are affected by the same triggering deficiencies. More importantly, the slopes of the two boundaries for LGRBs are significantly different ($0.69 \pm 0.02, 1.25 \pm 0.11$). It appears from the plot of figure 3 that there is no significant difference in the distribution of SGRBs and LGRBs on this plot, *except that* they happen to be in different regions of the plot due their different durations. Figure 4 shows the contour plot of $HR_{43\text{-}21}$-S_{bol} for different GRBs with different durations. We also normalize the duration of all BATSE GRBs to a fiducial T50 (i.e. the highest duration in the sample) in order to make a contour plot of $HR_{43\text{-}21}$-S_{bol} with different peak fluxes (figure 5). The slopes of the lines in these two plots are suspiciously similar to each other, which is again another indication of a truncation due to detector thresholds. Next we run Monte Carlo simulations for BATSE GRBs with different durations. The results confirm the findings of the previous lines, that is, the slopes of the boundaries obtained by simulation are very similar to those found as the slopes on the left boundaries in figures 3, 4 & 5. Parts of the simulation results are shown in figures 6 & 7. We also investigate any possible selection effects in the plot of E_{peak}-L_{iso} for SWIFT's BAT and BATSE LADs by creating a Monte Carlo universe of GRBs with totally random spectral parameters and with random redshifts. A preliminary result for BATSE is shown in figure (8).

Using the results obtained by the simulations described above in brief, we conclude that the existence of selection effects due to trigger thresholds cannot be rejected, even for BATSE GRBs. This confirms the results of previous analyses done by separate authors reporting that a large fraction of BATSE GRBs (< 1000 spectrally analyzed GRBs) are inconsistent with Amati relation (see Nakar (2005), Band (2006), and Butler (2007)). The results of the simulations suggest that the Amati relation might be in fact an inequality. Further detailed analysis of the simulation results will be given soon in a separate work (Shahmoradi & Nemiroff 2009).

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