Application of the Variability $\rightarrow$ Luminosity Indicator to X-Ray Flashes

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Abstract. We have applied the proposed variability $\rightarrow$ luminosity indicator to ten “X-Ray Flashes” (XRFs) observed by the Wide-Field Cameras on BeppoSAX for which BATSE survey data exists. Our results suggest that the variability $\rightarrow$ luminosity indicator probably works for XRFs. Assuming this to be so, we find that the luminosity and redshift distributions of XRFs are consistent with those of long-duration gamma-ray bursts (GRBs), and therefore most XRFs are probably not very high redshift GRBs. The fact that XRFs and GRBs have similar luminosity and redshift distributions suggests that XRFs and long-duration GRBs are produced by a similar mechanism.

1. Introduction

X-ray flashes (XRFs) are a new type of fast transient source observed with the BeppoSAX Wide Field Cameras (WFCs) at a rate of about four per year (Heise et al. 2001). The rate for XRFs is thus $\approx 40\%$ of the rate for gamma-ray bursts (GRBs).

XRFs are distinguished from Galactic transient sources by their isotropic spatial distribution and short ($\sim 10$-100 sec) durations. Furthermore, they are distinguished from GRBs based on the fact that they are not detected above 40 keV by the BeppoSAX GRB Monitor – implying much larger $L_x/L_\gamma$ ratios than GRBs. Actually, the distribution of $L_x/L_\gamma$ ratios overlaps considerably with that of GRBs (Heise et al. 2001). In other respects, such as duration, temporal structure, spectrum and spectral evolution, XRFs exhibit properties that are qualitatively similar to the X-ray properties of GRBs. These similarities have led to the suggestion that the XRFs are in fact very “X-ray rich” GRBs (Heise et al. 2001).

However, no host galaxy nor redshift has yet been reported for an XRF. Therefore, it is not known whether XRFs are very high redshift GRBs, normal GRBs viewed off the axis of the jet, or GRBs that have unusually small energies.
2. Results

A possible Cepheid-like luminosity estimator for GRBs was suggested by Ramirez-Ruiz and Fenimore (2000) and has been developed further by Reichart et al. (2000; see also Reichart & Lamb 2001a,b). These authors have shown that there exists a correlation between a measure \( V \) of the variability of the burst time history and the intrinsic isotropic-equivalent peak photon energy luminosity \( L \) of the burst for the 19 GRBs for which some redshift information (either a redshift measurement or a redshift limit) exists. We show this correlation in Figure 1.

In this paper, we use the possible Cepheid-like luminosity estimator for the long-duration GRBs developed by Reichart et al. (2001) to estimate the intrinsic isotropic-equivalent peak photon energy luminosity \( L \), and thus the redshift \( z \), of 10 XRFs detected by the BeppoSAX WFCs (Heise et al. 2001) and the Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory (Kippen et al. 2002). There is a significant limitation to what we can say, since these XRFs did not trigger BATSE and therefore we must use BATSE survey data for these ten events. The BATSE survey data is 1024 msec time resolution data, whereas all previous applications of our proposed variability measure have used 64 msec time resolution data. This means that,
technically, we can only establish lower limits on the luminosities, and therefore the redshifts, of the ten XRFs. However, our experience applying our variability measure to \( \approx 900 \) GRBs in the BATSE 4B catalog (Paciesas et al. 1999) suggests that this may not be a severe limitation.

| Burst    | Variability | Luminosity  | Redshift |
|----------|-------------|-------------|----------|
| 971019   | > 0.15      | \( > 5 \times 10^{52} \) | > 12     |
| 971024   | > 0.1       | \( > 1 \times 10^{52} \) | > 5      |
| 980128   | > 0.025     | \( > 1 \times 10^{50} \) | > 1.0    |
| 980306   | > 0.025     | \( > 1 \times 10^{50} \) | > 0.8    |
| 990520   | > 0.075     | \( > 5 \times 10^{51} \) | > 4      |
| 990526   | > 0.075     | \( > 5 \times 10^{51} \) | > 4      |
| 991106   | > 0         | > 0         | > 0      |
| 000206   | > 0.025     | \( > 1 \times 10^{50} \) | > 0.7    |
| 000208   | > 0.05      | \( > 1 \times 10^{51} \) | > 1.5    |
| 000416   | > 0.1       | \( > 1 \times 10^{52} \) | > 8      |

Table 1. Lower Limits on the Variability, Luminosity, and Redshift of Ten XRFs.

Table 1 lists our results. Figure 2 compares the distribution in the \((z, L)\)-plane of the lower limits in luminosity \( L \) and redshift \( z \) for the ten XRFs with the distribution in the \((z, L)\)-plane of the luminosities and redshifts of \( \approx 900 \) GRBs from the BATSE 4B catalog (Paciesas et al. 1999) estimated (Reichart & Lamb 2001a,b) using the variability measure \( V \) of Reichart et al. (2001). The diagonal solid line shows the approximate BATSE detection threshold. Figure 2 shows that the distribution of the lower limits for the XRFs is indistinguishable from the distribution of the estimates for the GRBs.

The fact that all ten XRFs lie below but near the BATSE detection threshold is expected because none of the ten events triggered the BATSE instrument. This fact also indicates that the variability measures \( V \) (and therefore the estimates of the luminosities \( L \) and redshifts \( z \)) which we would obtain for the ten XRFs, using 64 msec time resolution data, would not differ much from the lower bounds which we have obtained using BATSE survey data, which has 1024 msec time resolution. Otherwise, the ten XRFs would lie above the BATSE detection threshold, contradicting the fact that they did not trigger the BATSE instrument.

These results suggest that the variability \( \rightarrow \) luminosity indicator probably works for XRFs, and that the lower bounds on the luminosities \( L \) and redshifts \( z \) that we have obtained for the ten XRFs do not differ much from the estimates of these quantities that we would find using higher time resolution data.

Figure 3 compares the cumulative distribution of the lower limits on \( z \) for the XRFs with the cumulative distribution of the estimates of \( z \) for the GRBs. The two distributions appear similar, and a KS test confirms that there is no significant difference between them.


3. Conclusions

Our results suggest that the variability → luminosity indicator probably works for XRFs. Assuming this to be so, we find that the luminosity and redshift distributions of XRFs are consistent with those of long-duration gamma-ray bursts (GRBs), and therefore most XRFs are probably not very high redshift GRBs. The fact that XRFs and GRBs have similar luminosity and redshift distributions suggests that XRFs and long-duration GRBs are produced by a similar mechanism.

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