GRB Spectral Hardness and Afterglow Properties

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Abstract. A possible relationship between the presence of a radio afterglow and gamma-ray burst spectral hardness is discussed. The correlation is marginally significant; the spectral hardness of the bursts with radio afterglows apparently results from a combination of the break energy $E_{\text{break}}$ and the high-energy spectral index $\beta$. If valid, this relationship would indicate that the afterglow does carry information pertaining to the GRB central engine.

INTRODUCTION

Early observations of gamma-ray bursts (GRBs) with afterglows led us to hypothesize that GRBs with afterglows are spectrally harder than those without. However, the heterogeneous nature of GRB observations, coupled with the multi-wavelength nature of afterglow observations, has led us to a number of concerns:

1. Afterglow observations are heterogeneous: observational biases for detecting radio afterglows are different than those for detecting optical and/or x-ray afterglows.

2. A GRB might have no intrinsic afterglow, or inadequate search conditions might result in no afterglow being detected.

3. Spectral hardness measures are biased by instrument performance: One instrumental dataset should be used.

Our solutions to these concerns are as follows:

1. We require GRBs to either have detected radio afterglows or moderately-complete radio afterglow searches. This condition satisfies the first and second concerns.

2. We require that GRBs be observed by BATSE. This satisfies the third concern.
Our resulting database is shown in Table 1.

GRB 980425 may or may not have a radio afterglow, depending on its association with supernova SN 1998bw. If there is an association with SN 1998bw, then GRB 980425 has x-ray, optical, and radio afterglows. If there is no association with SN 1998bw, then this GRB has only an x-ray afterglow, with no optical or radio afterglow. The SAX team [1] lists two possible x-ray afterglow sources for GRB 980425; the first one is consistent with SN 1998bw, the second one is not.

The SAX Team indicates that the second afterglow source might have “re-bursted”, making its classification as a GRB counterpart questionable (this is not standard GRB behavior). However, it should be noted that the flux measurement of the second observation of this source represents less than a 3σ detection, placing the rebursting claim in doubt.

If the first afterglow source is associated with SN 1998bw, then GRB 980425 is significantly less luminous than typical GRBs. As discussed elsewhere in the literature [2], very few BATSE GRBs can have luminosities this small in typical spatial distribution models.

It appears to us that the afterglow source of GRB 980425 is still in question. Because of these doubts, we consider independently the cases where GRB 980425 has and does not have a radio afterglow.

**ARE GRBS WITH RADIO AFTERGLOWS DIFFERENT FROM THOSE WITHOUT?**

Figure 1 demonstrates that GRBs with radio afterglows appear to be harder than those without. The hardness ratio HR(43/21) (100-1000 keV energy fluence divided by 25-100 keV energy fluence) has been used in this analysis, because it has the largest signal-to-noise ratio available in BATSE 4-channel data and spans...
the largest spectral range. However, similar results can be obtained from other hardness ratios.

![Graph](image)

**FIGURE 1.** HR(43/21) vs. Radio Afterglow Type.

In Table 2 we summarize Student’s t-test probabilities that the log[HR(43/21)] distributions of bursts without radio afterglows and bursts with radio afterglows have different means. The significance of a correlation depends strongly on the status of GRB 980425 due to small number statistics. If GRB 980425 is not associated with SN 1998bw, then the correlation between spectral hardness and radio afterglow is more likely.

**TABLE 2.** Probability that GRBs With and Without Radio Afterglows Have Different Distributional Means.

| Status of SN 1998bw                  | t-Test Probability |
|-------------------------------------|--------------------|
| GRB980425 NOT associated with SN 1998bw | 0.963              |
| GRB980425 associated with SN 1998bw    | 0.781              |

**DISCUSSION**

To determine why this difference in hardness might exist, we checked other hardness ratios in the four-channel data. Hardness ratios involving channels 3 and 4 indicate similar results as obtained in Figure 1. Thus, any spectral differences dependent on radio afterglow type appear to result from the distribution of high energy photons. This is supported by Figure 2, which indicates no correlation of radio afterglow type with hardness ratio HR21.
This is also supported by Figure 3, which compares the GRB function spectral parameters $E_{\text{break}}$ and $\beta$ for the bursts in question (GRBs 980425 and 980519 are not plotted due to large $\beta$ errors). Large values of $E_{\text{break}}$, large values of $\beta$, or both produce conditions indicating many high-energy photons. GRBs with radio afterglows tend to occupy a different diagram region than GRBs without radio afterglows. Since $E_{\text{break}}$ and $\beta$ are obtained from time-averaged spectra, we suspect that the diagram regions might be even more distinct if signal-to-noise were better for faint BATSE GRBs.

The possible correlation between GRB spectral hardness and afterglow type can be clarified with additional observations in the future. Resolution of the status of GRB 980425 would also help clarify this issue.

If GRB spectral hardness is an indicator of radio afterglow type, then a direct link between the central engine and the delayed emission is established. Such a link could be very important to the understanding of GRB physics. The Lorentz factor of the expanding external shock could be constrained by this correlation. For this reason, it is as important to determine upper flux limits on afterglow non-detections as it is to provide information on detections.

**CONCLUSIONS**

There is evidence that GRBs with radio afterglows have harder gamma-ray burst emission than those without. Due to small number statistics, the significance of this correlation depends at present time on whether or not GRB 980425 is associated with supernova SN 1998bw. There is evidence of a similar correlation between
bursts with optical afterglows, but this is more difficult to document because the literature is less clear on conditions under which an optical search failed to yield an afterglow.

If we assume that a relationship exists between spectral hardness and radio afterglow type, then GRBs with radio afterglows appear to have more high-energy photons ($E \geq 100$ keV) than those without radio afterglows, as determined from the spectral parameters $E_{\text{break}}$ and $\beta$. Also, roughly $2/3$ of BATSE-detected GRBs should produce radio afterglows based on the overall distributions of $E_{\text{break}}$ and $\beta$. It should be noted that all GRBs producing afterglows of any type belong to the long, bright, soft GRB class.

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