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Chasing the association of single-pulse gamma-ray bursts and supernovae

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Abstract. We explore the hypothesis, similar to one recently suggested by Bloom and colleagues, that some nearby supernovae are associated with smooth, single-pulse gamma-ray bursts, possibly having no emission above 300 keV. We examine BATSE bursts with durations longer than 2 s, fitting those which can be visually characterized as single-pulse events with a lognormal pulse model. The fraction of events that can be reliably ascertained to be temporally and spectrally similar to the exemplar, GRB 980425 – possibly associated with SN 1998bw – is 4/1573 or 0.25%. This fraction could be as high as 8/1573 (0.5%) if the dimmest bursts are included. Approximately 2% of bursts are morphologically similar to GRB 980425 but have emission above 300 keV. A search of supernova catalogs containing 630 detections during BATSE's lifetime reveals only one burst (GRB 980425) within a 3-month time window and within the total 3 σ BATSE error radius that could be associated with a type Ib/c supernova. Thus we find no further evidence to support a single-pulse GRB and SN Ib/c connection. We also find no tendency for any set of single-pulse GRBs to fall near the Supergalactic Plane, whereas SNe of type Ib/c do show this tendency – evidence that the two phenomena are not related.

Key words: gamma-rays: bursts — stars: supernovae, general

1. Introduction

GRB 980425 was located inside the BeppoSAX Wide Field Camera (WFC) error circle, along with two weak X-ray sources, one of which faded away $2-3$ days after the gamma-ray burst, as observed by the BeppoSAX Narrow Field Instruments (Pian et al. 1998a). An unusual supernova (SN), apparently of type Ic, was also detected within the WFC error circle (Galama et al. 1998). This supernova, SN1998bw, was not positionally coincident with the fading X-ray source – a candidate for the typical GRB X-ray afterglow.

A radio source, detected by Wieringa (1998) three days after the burst, brightened to become approximately two orders of magnitude more luminous than any previously studied radio source associated with a type Ic SN and was inferred to be expanding relativistically (Kulkarni et al. 1998). Modeling of the optical light curve implies an explosion energy of $2-5$ 10^{52} ergs, and core collapse within about 1 day of GRB 980425 (Iwamoto et al. 1998). These observations and deductions have led many investigators to examine the possibility that GRB 980425 and onset of SN 1998bw are one and the same event: The combined positional and temporal chance probability has been estimated as 10^{-4} (Galama et al. 1998), and the explosion dynamics and energetics could possibly power an observable gamma-ray at the distance to SN 1998bw (38 Mpc). This interpretation requires that the fading X-ray source is not associated with the GRB.

We have further examined the hypothesis discussed by Bloom et al. (1998) that GRBs with time profiles resembling that of GRB 980425 (BATSE trigger 6707) may be associated in general with SNe type Ib or Ic. Bloom et al. detail the criteria for inclusion in a supernova-GRB (S-GRB) class, including: prompt radio emission with high brightness temperature; no long-lived X-ray afterglow; broad line emission and high optical luminosity; and a gamma-ray profile consisting of a single, relatively smooth, broad pulse. The single shock expected in a SN core collapse would be expected to give rise to a single gamma-ray pulse.

2. Single-pulse gamma-ray bursts

The pulse in GRB 980425 exhibited the dominant GRB spectral evolutionary mode: At lower energies pulses tend to peak later and exhibit longer decay timescales (Norris 1995; Norris et al. 1996). Since this behavior is observed in most GRBs, it is not a constraining

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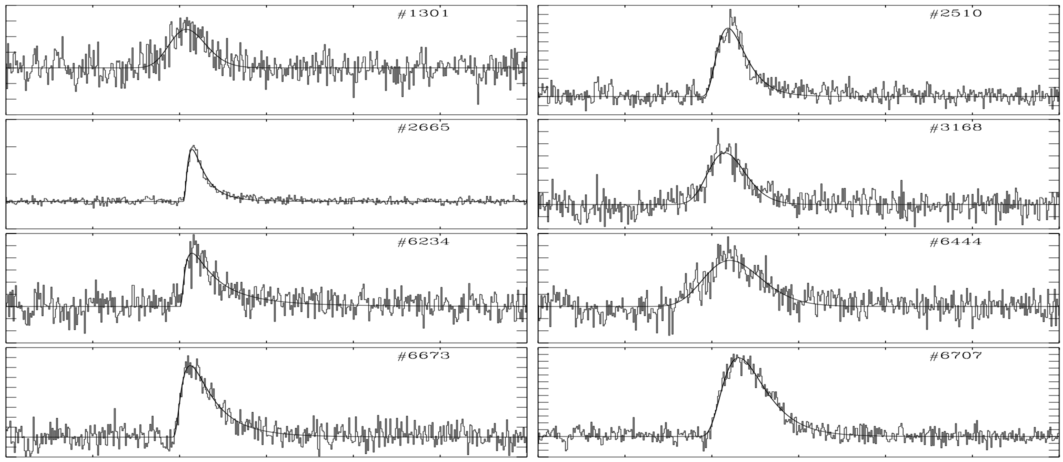

Fig. 1. Time profiles in the energy range $50 - 300$ keV for the eight bursts categorized as single-pulse, NHE events. The abscissa range for all plots is 120 s. BATSE trigger numbers are indicated

diagnostic. Also, as noted by Wang & Wheeler (1998), GRB 980425 had no high-energy (NHE) emission above 300 keV (see Pendleton et al. 1998). Most bursts exhibit significant high energy (HE) emission, but approximately one-third, mostly dim bursts, do not. In fact, it is likely that the apparent NHE class results from brightness bias effects (Bonnell & Norris 1999). Nevertheless, for the putative S-GRB class, the NHE characteristic may be a distinguishing signature. Thus if gamma-ray diagnostics are of any value in recognizing S-GRB events, the salient feature is a solitary smooth, broad pulse, and possibly NHE.

We have culled single-pulse GRBs from a total sample of 1573 BATSE GRBs with four energy channel LAD data presently available at the Compton GRO Science Support Center archive. The background fitting and sample selection are described in detail in Norris et al. (1999). Discrimination between single and multiple pulse bursts was based on statistical fits to a single, lognormal pulse model (Brock et al. 1994) using data binned at a 256-ms timescale. Signal to noise equalized profiles were also examined for statistically significant HE emission as described in Norris et al.

3. Results and discussion

We identify 68 bursts in our sample as apparently consisting of a single pulse. Of these, 30 are NHE bursts and eight of these NHE bursts have profiles similar to the broad profile of GRB 980425. The BATSE time profiles for the eight bursts are shown in Fig. 1. We judge only four of the eight to have sufficiently high s/n to make the statistical determination of a single-pulse structure reliable. Their BATSE trigger numbers are 2510, 2665, 6673, and 6707 itself. Thus the proportion of events in our sample that fit the two distinguishing criteria of the putative S-GRB class as defined by their exemplar GRB 980425 smooth, single-pulse, and NHE is 4/1573 (0.25%). This fraction is possibly as high as 8/1573 (0.5%).

Attempts to match positions and times of occurrence of these eight bursts with those of SNe have yielded no matches other than already reported for GRB 980425 and SN1998bw. Further, no subset of our single-pulse GRBs shows a tendency to cluster near the Supergalactic Plane, which one might expect if the sources of such bursts lie within the nearby supercluster (Norris et al. 1999).

Follow-up observations (Pian et al. 1998b) of the original BeppoSax WFC error circle have also failed to detect a recurrence of the fading X-ray source (1SAXJ1935.3-5252) indicating that the X-ray decay signature for GRB 980425 remains similar to that for other GRBs if in fact it was the true counterpart. In that case, of the more than twenty bursts detected by BeppoSAX with X-ray or optical afterglows, none besides GRB 980425 has single-pulse morphology in its prompt emission. Future BeppoSAX detections of X-ray afterglows of broad single-pulse, NHE events like this would clearly constitute additional evidence against the putative S-GRB class.

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