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THE PROMPT X-RAY EMISSION OF GAMMA-RAY BURST 980519
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ABSTRACT

The prompt X-ray emission from gamma-ray burst (GRB) 980519, as measured with the Wide Field Cameras on board BeppoSAX, is characterized by a strong soft-to-hard-to-soft evolution. An analysis of the evolution of the X-ray spectrum in terms of a single power-law model shows that the photon index evolved from 2.0 to 1.58 over 256 ms, would place it in the brightest 14% of all bursts in the 4B catalog (Meegan et al. 1998). Simultaneously, the X-ray counterpart to the burst was detected in WFC unit number 2 at an off-axis angle of 7° and localized with an error circle radius of 3′ ( Muller et al. 1998). Jaunsen et al. (1998) detected a fading optical counterpart in the WFC error box in V- and I-band observations that started 8.8 hr after the burst (see also Djorgovski et al. 1998a). A fading X-ray afterglow was detected 9.7 hr after the burst with the narrow-field instruments on BeppoSAX (Nicastro et al. 1998a). Frail et al. (1998) report the detection of a brightening 8.3 GHz radio counterpart coincident with the optical counterpart from observations on May 19.8, 20.6, and 22.3. Sakolov et al. (1998) report the detection of an R = 26.05 ± 0.22 extended source that may be the host galaxy. This was confirmed by Bloom et al. (1998).

GRB 980519 is of particular interest because there appears to be X-ray activity prior to the gamma-ray event. In the past, there have been sporadic reports of such activity in other GRBs. The best-documented case is GRB 900126, which was detected with the Ginga GRB detectors with 1–370 keV coverage. Murakami et al. (1991) found these data to exhibit clear X-ray emission in the 2–10 keV band about 10 s prior to the onset of the gamma-ray event. It could be modeled by blackbody radiation of temperature \( kT = 1.58 \pm 0.26 \) keV. Other (less documented) cases of bursts with preburst X-ray activity have been found in P78-I data (Laros et al. 1984) and WATCH data (Sazonov et al. 1998). In the WATCH database of 95 GRBs, six appear to have preburst activity. In the Ginga database of 121 GRBs, there is the one convincing case and two possible cases (Murakami et al. 1992). This suggests that preburst \( \leq 20 \) keV activity occurs in only a few percent of the GRBs. Preburst activity in any wavelength regime is considered to be important in constraining the nature of the central engine of the GRBs. For instance, in a recent study, Paczyński (1998) proposes that the preburst X-ray activity in GRB 900126 supports the hypernova scenario for the GRB central engine. In this scenario, rotational energy is extracted from a freshly formed black hole through a torus around it. The preburst blackbody radiation could be due to thermal radiation from this torus.

In this Letter, we study the prompt X-ray emission of GRB 980519. We discuss the question of whether truly preburst X-ray activity is present, and we consider the relationship of the prompt X-ray emission with the X-ray afterglow.
2. OBSERVATIONS AND ANALYSIS

The WFC instrument (Jager et al. 1997) consists of two coded aperture cameras, each with a field of view of 40° by 40° FWZ and an angular resolution of about 5°. The bandpass is 2–27 keV. The spectral resolution is approximately constant over the bandpass at 20% FWHM. The field of WFC unit 2, in which GRB 980519 was detected, was void of other point-source detections. Therefore, the sensitivity of the observation was dominated by the background, which is an optimum situation. Proper spectral analyses of WFC data are limited to within 2–20 keV because the response function is not yet sufficiently well determined outside that range. Furthermore, a systematic error of ~7% applies per channel. In the case of GRB 980519, the systematic error does not degrade the analysis because the X-ray fluence is so small that statistical errors dominate.

The gamma-ray measurements presented here were obtained from the publicly available archive of BATSE large area detector (LAD; Fishman et al. 1989) data. Specifically, we used the “DISCSC” data product that contains the combined photon count rates of the two LADs (out of eight) that were most favorably oriented toward GRB 980519, in four photon energy channels and with 1.024 s time resolution or better.

2.1. The 2 keV to Greater than 325 keV Time Profile

Figure 1 presents the time profile of the WFC and BATSE data in seven different photon energy bands. These profiles are obtained from photon count rates on detectors, without a correction for the projected area. A number of characteristics catch the eye. First, there is X-ray activity up to several tens of keV preceding the onset of ~107 keV gamma-ray emission by about 70 s. This pre-gamma activity has a quick rise at about \( T = -50 \) s (\( T \) is the time relative to the BATSE trigger time) and continues into the main peak. It is discernible in all WFC channels, as well as the first BATSE channel, up to 58 keV. Second, there is an X-ray tail present that contains a double-peaked feature that is almost completely separated from the soft emission around the main gamma-ray peak. It continues for another 80 s after the ~107 keV emission has ended. In the following, we will employ the terms “nose” and “tail” to refer to the 2–27 keV X-ray emission before \( (T = -85/-5) \) s and after \( (T = 46/120) \) s the main gamma-ray event as measured above ~107 keV.

2.2. The X-Ray Spectrum

To study the X-ray spectrum, the data were resolved in 10 time intervals. Spectra were generated by cross-correlating the position information of the detected photons with the aperture mask (see, e.g., Jager et al. 1997). This ensures that the information obtained pertains uniquely to the emission from the GRB position. We stress this because in GRB research it is customary to determine spectra directly from background-subtracted time profiles, such as those shown in Figure 1. Our procedure has a number of advantages with respect to this. It guarantees that source confusion is not an issue, nor scattering effects from within the instrument, spacecraft, or Earth. It makes the generation of the response matrix straightforward, and it keeps the analysis independent from background variation models.

The spectrum can be modeled by a simple power-law function with a low-energy cutoff. In what way exactly the low-energy cutoff is modeled is ambiguous. The following two (commonly used) models are equally successful in describing the data:

1. A power-law function with absorption due to cold interstellar or circumstellar gas of cosmic abundances:

\[
N(E) = K \exp \left[ -N_H \sigma(E) \right] \frac{E}{E^*}
\]

photons s\(^{-1}\) cm\(^{-2}\) keV\(^{-1}\), where \( E \) is the photon energy, \( \Gamma \) is the photon index, \( \sigma(E) \) is the cross section (in units of cm\(^2\)) per H atom (following Morrison & McCammon 1983), and \( N_H \) is the hydrogen column density in units of cm\(^{-2}\).

2. The empirical GRB model spectrum as defined by Band et al. (1993):

\[
N(E) = \frac{AE^\alpha \exp \left( -E/E_0 \right)}{BE^\alpha}, \quad \text{for } E \leq (\alpha - \beta)E_0,
\]

\[
\frac{1}{BE^\alpha}, \quad \text{for } E \geq (\alpha - \beta)E_0
\]

photons s\(^{-1}\) cm\(^{-2}\) keV\(^{-1}\), where \( A \) and \( B \) are coupled constants.

We fitted both models. In our pursuit to describe the spectral evolution with as simple a model as possible, we found that the data allow us to fit all 10 temporal samples with a single value for the low-energy parameter (i.e., the low-energy parameters are “tied” over the 10 samples, while the high-energy power-law index is left free). The reduced \( \chi^2 \), \( \chi^2_r \), is 0.91 for
We note that there is yet another difference between GRB 980519 and GRB 900126, which relates to the variability of the initial X-ray emission. In GRB 900126, this emission increases smoothly until the peak, while in GRB 980519, there is more structure in the initial X-ray phase.

How does the spectrum of the nose of the GRB 980519 compare with that of other GRBs? Systematic spectral measurements of GRBs that include data below ~10 keV have so far only been performed with the Ginga-GBD and the BeppoSAX-WFC. The total number of bursts detected is 121 for Ginga-GBD and 17 for BeppoSAX-WFC. Strommayer et al. (1998) studied the overall spectra of the 22 brightest Ginga bursts in terms of model B. Seven of these bursts have break energies \((\alpha - \beta)E_b\) below 10 keV (it is ~5 keV for GRB 980519). Among these seven bursts, the softest spectrum has \(\beta = -2.26 \pm 0.14\) [and \(\alpha = 0.22\) and \((\alpha - \beta)E_b = 9.1\) keV]. This is, within the error margins, equal to what is seen in the nose of GRB 980519. Therefore, the second criterion for pre-burst X-ray activity also does not hold for GRB 980519.

We conclude that, despite the suggestive time profiles, there is no strong evidence for preburst X-ray activity in GRB 980519. In our opinion, reports on preburst X-ray activity or X-ray precursors in other bursts based on time profiles alone should be interpreted carefully. This has also been concluded from a systematic study of precursors based solely on BATSE data (Koshut et al. 1995).

4. The Relationship to the X-ray Afterglow

The photon index during the tail is, within the error margins, identical to that of the X-ray afterglow of GRB 980519 of \(-2.8^{+0.6}_{-0.5}\) (Nicastro et al. 1998b). In fact, this applies in a more general sense as well. First, this index is quite common for many tail spectra of GRBs: BATSE data reveal that for 22 GRBs that were followed up in X-rays, the tail spectra have an average low-energy photon index of \(-1.9 \pm 0.4\) (Koshut et al. 1999). Second, the index is common to what is observed on average in seven cases of X-ray afterglows \((-2.2 \pm 0.4\);
Owens et al. 1998). The X-ray spectrum of the tail is also quite similar to that of the nose and in contrast to the gamma-ray phase.

The similarity of the spectra in the nose, tail, and X-ray afterglow may lead one to suggest that the nose and tail emission have the same origin as the X-ray afterglow and a different one than that of the main gamma-ray event; in other words, that the X-ray afterglow started before the burst. An explanation would have to be searched in terms of the very successful fireball model (for a recent review and list of references, see Piran 1998). This model infers that the afterglow is due to external shocks (which result from the interaction of the fireball with the surrounding medium) and that the burst is due to internal shocks (which result from the interaction between different parts of the fireball). An early start of the X-ray afterglow would involve particularities of the fireball in GRB 980519 that make external shocks set in prior to internal shocks. However, the considerable structure in the time profile of the nose and tail is unlike that expected for external shocks (as has been argued in general for GRB time profiles by Fenimore, Madras, & Nayakshin 1996), and an interpretation in terms of an X-ray afterglow preceding the gamma-ray burst must currently be considered speculative at best.

5. CONCLUSIONS

We have presented the intriguing characteristics of the prompt X-ray emission from GRB 980519 and briefly speculated on the implications. GRB 980519 is characterized by a strong soft-to-hard-to-soft evolution, each of these three stages lasts between 50 and 80 s. Although suggestive of preburst X-ray activity, the soft start of the burst evolves smoothly into the main gamma-ray event through variations of the parameters of a single spectral model. Thus, there is no reason to assume that the emission mechanism is fundamentally different during the soft start. Furthermore, the similarity of nose, tail, and X-ray afterglow spectra suggests that they have a common origin. However, the type of variability of these soft stages does not support such a far-reaching conclusion.

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