Fitting of combined Ulysses/COMPTEL GRB spectra

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We have analysed the Ulysses and COMPTEL spectral data from several strong and hard γ-ray bursts which occurred in the COMPTEL field of view. Single instrument data with their limited energy range often can be fit with single power law models. In contrast, the composite spectra obtained by a joint deconvolution of the Ulysses and COMPTEL spectra (ranging from 20 keV up to 10 MeV) need models with continuous curvature. The applicability of standard emission processes to these composite spectra is discussed.

INTRODUCTION

Historically, γ-ray burst spectra have been fitted by various models such as power law, optically thin bremsstrahlung (OTTB) or Comptonisation. During the first two years of CGRO operation burst spectra of all 4 individual instruments have been generally fitted with single power law models, whereas only in very few cases broken power laws were necessary to describe the spectral shape. A detailed investigation of BATSE SD spectra has used a generalisation (two smoothly connected power laws), the so-called "Band GRB" model (Band *et al.* 1993) which was shown to adequately fit the whole variety of GRB spectra.

While separately fitted BATSE, OSSE and COMPTEL spectra have been combined earlier into wide-band photon spectra (Schaefer *et al.* 1994, Share *et al.* 1994), the first combined fit of multi-instrument data has been performed only recently for GRB 920622 (Greiner *et al.* 1995). The continuously curved time-averaged spectrum of this burst derived from the combined Ulysses/BATSE/COMPTEL data in the 20 keV to 10 MeV range was shown to be fitted only by Band's "GRB" model whereas either OTTB or comptonisation models are too strongly curved. This work has been extended to more bursts, and the present status is given here.

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DATA SELECTION

We have analysed five γ-ray bursts detected by Ulysses and COMPTEL, namely GRB 910503, GRB 911118, GRB 920622, GRB 930131 and GRB 940217. Aboard the Ulysses spacecraft two hemispherical CsI(Tl) detectors are capable of measuring photon events in 16 energy channels covering an energy interval from 20 to 150 keV. Once triggered, the integration time is set to 1 s for 14 consecutive spectra and after that to 2 s for the following 16 spectra. Finally, another 28 spectra are accumulated over 16 s each. A part of these late data is used in the background subtraction.

The COMPTEL telescope on board the Compton Gamma-Ray Observatory (CGRO) detects high energy photons above 300 keV. COMPTEL collects spectral information either in the "telescope" mode, which is the usual imaging mode of the telescope and provides spectra between 0.75 and 30 MeV, or in the "single detector" mode using two modules with overlapping energy intervals (0.3 to 1.3 MeV, 0.6 to 10 MeV). After receiving a trigger message from BATSE, COMPTEL collects 6 spectra with 1 s accumulation time followed by 133 spectra with 6 s accumulation time. Then it returns to the background mode with 100 s accumulation. The default background spectrum for the burst analysis is the last complete background spectrum, recorded before the burst trigger. It is used for all our analysed bursts. In our investigation only the burst mode, but not the telescope data are included.

The spectral coverage of Ulysses and the COMPTEL module data leaves a small gap between 150–300 keV which is considered to be small enough to achieve reasonable fits for the burst spectra. To eliminate time dependent effects we select time intervals of each burst, which are approximately equal for both instruments. Because of the fixed accumulation times an inaccuracy of $\approx$1 s remains for bursts lasting longer than $\approx$15 s. The Ulysses detector generally triggers later than BATSE according to its lower sensitivity (even if both spacecrafts were at the same location). Therefore, some of the first spectra measured by COMPTEL had to be excluded from the joint deconvolution.

Several models have been applied to the burst spectra: a single power law, OTTB, Comptonisation (Sunyaev & Titarchuk, 1980), and Band's "GRB" model (Band *et al.* 1993) which smoothly connects two power law models:

$$N_E(E) = A\left[\frac{E}{(100keV)}\right]^{\alpha}\exp\left[-\frac{E}{E_o}\right], \qquad (\alpha-\beta)E_o \geq E$$

$$= A\left[\frac{(\alpha-\beta)E_o}{(100keV)}\right]^{\alpha-\beta}\exp(\beta-\alpha)\left[\frac{E}{(100keV)}\right]^{\beta} \qquad (\alpha-\beta)E_o \leq E$$

GRB 910503: This burst shows a complex time structure with two different peaks: the intense first one lasts about 10 s while the second occurs $\approx$45 s after the BATSE trigger. Only the first bright peak is included in this investigation. The common interval selected starts 1 s after the BATSE trigger and extends for 11 s. Due to discriminator thresholds the three lowest energy channels of Ulysses were omitted. The dead time correction for Ulysses is

26%. The COMPTEL energy channels are combined to ensure $\geq 3\sigma$ detection significance above background in each bin. The spectrum is consistent with Band's GRB model fit ($\chi^2/\nu = 2.2$). The other spectral models give unacceptable fits ($\chi^2/\nu = 4.7$ for OTTB, 6.1 for Comptonisation and 6.9 for a power law).

The BATSE data of this burst had been fit earlier with Band's GRB model (Band *et al.* 1993). A comparison the the results obtained here shows that the well determined high-energy part (above 1 MeV) reduces the error in the estimate of β, and the inclusion of the low-energy part shifts the break energy to higher values.

GRB 911118: With a trigger delay of 1 s, the selected time intervals are 1 to 24 s for COMPTEL and 0 to 22 s for Ulysses (both relative to the corresponding trigger times). The two lower energy channels of Ulysses were rejected. Unfortunately, from mid-1991 to mid-1992 the low range detector module of COMPTEL was switched off due to increased high-voltage noise leading to a wider energy gap between the Ulysses and the COMPTEL data, and thus to increased systematic errors. The energy channels of the COMPTEL high range detector are rebinned to ensure $\geq 1\sigma$ detection significance above background in each bin. The Ulysses deadtime correction fraction is estimated to 24%. Though all models give acceptable fits (see Tab. 1), Band's GRB model turns out to give the lowest χ^2/ν of 0.6 (due to the low number of photons).

Also for this burst, the BATSE data have been fit earlier (Band *et al.* 1993). Despite the large gap between the Ulysses and COMPTEL data due to the missing low-energy COMPTEL module the results of our fit and that of the BATSE data are in surprising agreement (<10% difference in best fit values).

GRB 920622: The trigger delay of Ulysses is 4 s. The included time intervals are 4 to 24 s for COMPTEL and 0 to 20 s for Ulysses (relative to corresponding trigger times). The three lowest Ulysses energy bins were rejected. A deadtime correction of 20% has been applied to the Ulysses data. Also this spectrum is best fit by Band's GRB model (Tab. 1). The reduced χ^2 values are 1.6 (Band's GRB), 3.0 (OTTB), 4.6 (Comptonisation) and 7.3 (power law).

A combined deconvolution including the BATSE data (Greiner *et al.* 1995) resulted in fit parameters being consistent with those derived from the Ulysses/COMPTEL data. The shift of the break energy towards lower energies by about 20% and a corresponding flatter α is due to the fact that the fit down to about 100 keV is completely determined by the BATSE data as compared to the Ulysses data with its lower statistics.

GRB 930131: This burst, known as the superbowl burst, had a duration of two seconds with the emission separated in two peaks. The first peak lasted only 0.3 s, while the second started about 0.7 s later. The included time intervals are 0 to 2 s for COMPTEL and for Ulysses (relative to corresponding trigger times). Due to a 0.57 s trigger delay of Ulysses there is an about 20% uncertainty in the flux calibration. The three lowest Ulysses energy bins were excluded from the fitting. A deadtime correction of 24% has been applied to the Ulysses data. Based on the reduced χ^2 values only Band's GRB model provides an acceptable fit (Tab. 1).

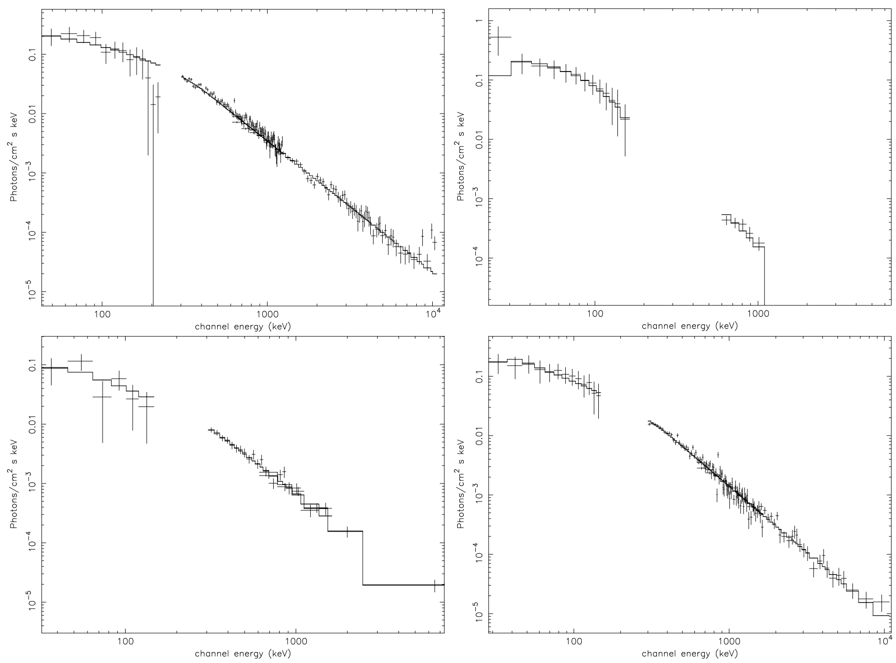

FIG. 1. Joint deconvolution of Ulysses and COMPTEL spectra with Band's GRB model: GRB 910503 (top left), 911118 (top right), 930131 (bottom left) and 940217.

GRB 940217: This burst, famous for its long-lasting high-energy emission detected with EGRET, has a rather long duration with the main peak starting only 110 s after the BATSE trigger. The Ulysses instrument triggered on the second main peak which occurred about 86 s after the BATSE trigger. Since this peak was short and the internal Ulysses trigger delay was 0.88 s, only the third main peak was used for the joint fitting. A dead time correction of 27% was applied to the Ulysses data, and the three lowest Ulysses channels were again excluded from the fit. As in the case of the other bursts, also GRB 940217 (i.e. third peak) is best fit with Band's GRB model (Tab. 1).

TABLE 1. Band's GRB model fits to combined Ulysses/COMPTEL data

GRB	Norm ph/(cm^2 s keV)	E_p (keV)	α	β	Energy range (keV)
910503	0.21±0.02	405±25	−0.27±0.19	−2.21±0.19	42–10600
911118	1.15±1.00	105±30	+0.42±0.43	−2.76±0.18	20–10400
920622	0.11±0.03	315±25	−0.27±0.26	−2.54±0.15	29–10600
930131	0.06±0.05	370±150	−0.77±0.75	−2.20±0.13	28–10600
940217	0.11±0.02	390±50	−0.78±0.23	−2.23±0.04	28–10800

DISCUSSION

GRB spectra measured in the pre-BATSE era have often been successfully fit with thermal bremsstrahlung or comptonisation models. Observations with COMPTEL and EGRET have demonstrated that many bursts exhibit high-energy power law tails, excluding these emission processes as viable models of GRB spectra. This result is confirmed with our joint fits of Ulysses and COMPTEL data: the GRB spectra are much less curved than these models. However, the broad energy coverage achieved in our analysis also convincingly shows that GRB spectra are continuously curved, and that single or broken power laws do not adequately fit the composite Ulysses/COMPTEL spectra.

While Band's GRB model gives satisfactory fits to the combined Ulysses/-COMPTEL spectra of all five bursts investigated so far, it would be more interesting if physical models could be tested against the data. In addition, looking at the residuals of these fits suggests that the burst spectra might be continuously curved in contrast to this model of combined power laws. The blast wave model of Meszaros and Rees (1993) is still too crude to be usable for detailed spectral fitting. The Compton attenuation model proposed by Brainerd (1994) seems to provide the right curvature and shall be applied as the next step. Also, the proposed shock emission model (Tavani 1995) with only two free parameters is predictive enough to be tested.

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