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SPECTRAL CHARACTERISATION OF GAMMA-RAY BURSTS WITH COMPTEL AND BATSE

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Abstract. Although the earliest observed gamma-ray burst spectra were well described by thermal bremsstrahlung models, subsequent observations above 1 MeV showed the existence of high energy power law tails in ~60% of events. In order to accurately characterise burst spectra, both the low energy turnover and the high energy tail must be accounted for. We have addressed this issue by jointly deconvolving spectra obtained by the BATSE and COMPTEL instruments onboard the *Compton* Observatory. We present preliminary results obtained by application of this method to the gamma-ray burst of February 17, 1994.

Key words: Gamma-ray bursts - spectra

1. Introduction

Since the discovery by BATSE of the isotropic and inhomogeneous distribution of gamma-ray bursts (GRBs) [1] there has been an upsurge of theoretical activity placing these sources at cosmological distances . One consequence of such models is that the existence of a highly relativistic outflow must be invoked to raise the threshold for pair production, thereby enabling the observed high energy emission to escape without appreciable attenuation. Possibilities include baryon-loaded fireballs [2] or jets in cocooned AGN [3]. The observation by BATSE that most GRBs have their peak luminosities at ~200 keV has provided a starting point for modelling GRB spectra in terms of the Compton attenuation of an input power law spectrum in the interstellar medium around the source [4].

As such models increase in complexity, concomitant improvements in our ability to accurately characterise burst spectra are required in order to impose additional observational constraints which models must satisfy. The motivation for the work described here has been to exploit the complementary gamma-ray burst detection capabilities of BATSE and COMPTEL in order to improve the accuracy with which spectral parameters can be determined. The merit of this joint analysis approach is that the lever arm in the spectral fitting is extended beyond BATSE's nominal limit of ~2 MeV, to 10.6 MeV, thereby improving the constraints on the fit parameters.

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2. Analysis method

	Effective area	Energy range
SD	127 cm^2@100 keV 55 cm^2@2 MeV	0.015–110 MeV
LAD	2025 cm^2@100 keV 350 cm^2@1.9 MeV	30–1900 keV
D2-14	220 cm^2@1 MeV	300–1700 keV
D2-7	125 cm^2@8 MeV	0.6–10.6 MeV

Table I
BATSE and COMPTEL detector characteristics

The relative merits of BATSE [5] and the COMPTEL burst modules [6] in terms of detection efficiency and energy coverage are given in Table I.

The BATSE and COMPTEL data are jointly deconvolved, using the forward-folding method, with the XSPEC spectral analysis package. The Band GRB model [7] has been implemented to characterise the spectrum over the required broad energy range. Although a power law model is in most cases sufficient to describe GRBs within COMPTEL's energy range [8] it is not adequate to describe the turnovers seen at around 200 keV in the BATSE data [7]. Conversely, an exponential cut-off model is often an acceptable fit up to ~1 MeV, but is incompatible with COMPTEL observations. The GRB model characterises both of these components in a functional form with a turnover energy E_b and spectral slopes (α, β) below and above E_b respectively. XSPEC was chosen for this work because it was designed to do complex, multi-instrument spectral analysis. It also corrects for normalisation differences between different detectors. The individual instruments' analysis packages are used to provide important consistency cross-checks.

3. Application to GRB 940217

GRB 940217 was an event of extraordinary spectral hardness and duration [9] which occurred within COMPTEL's field of view [10]. The time profile (Fig. 2) consisted of 6 well-defined peaks and the burst had a total duration of ~ 160 s. The time intervals used in the BATSE and BATSE+COMPTEL analysis match those used in [10]. The BATSE data were from Spectroscopy Detector 0 (~ 40 keV – 3000 keV), this being the only detector with full temporal coverage of the event. A response matrix, taking earth scattering into account, was generated at the best COMPTEL location. The response matrix for the COMPTEL burst modules was also generated for a source at the GRB position [10].

The deconvolved photon spectrum for the entire burst (162 s) is shown in Figure 1 and shows the Band model to be a reasonable approximation to the GRB spectral shape. The parameter E_b shows strong variation over the burst event. From Figure 1 it appears that the joint instrument fitting produces slightly softer values of E_b than the BATSE-only results, except in the case of Peaks #2 and #6, the softest intervals.

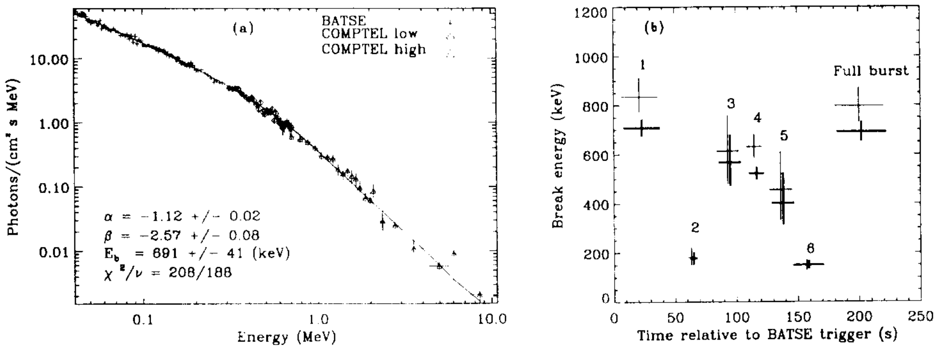

Fig. 1. GRB 940217: (a) Deconvolved photon spectrum for the full 162 s of the burst. (b) E_b values obtained for the individual peaks of the burst using BATSE (thin lines) and BATSE+COMPTEL (bold lines)

Systematic differences between the instruments are accounted for by rescaling the COMPTEL data in the fit procedure. Furthermore, a 10% systematic uncertainty on the COMPTEL data points is included due to uncertainties in the absolute detector calibration. To exclude the possibility that residual uncertainties could produce the observed softening effect, a series of simulations of Peak #4 (the most affected interval) were carried out. The results (Table II) show that both methods retrieve the correct model parameters but β is more tightly constrained at a harder value in the joint fit, thereby pushing E_b to softer values. The conclusion is that the softening of E_b is a real, albeit small effect, arising from the additional constraint which COMPTEL can impose on the upper power law slope, β.

The physical hardness of the burst can be quantified in terms of E_p ($= (2 + \alpha) \times E_b$, $\beta \leq -2$), the energy at which the GRB radiates its maximum flux [11]. The trend seen is common to many multi-peak events seen by BATSE [11]. The maximum in E_p occurs in coincidence with the first pulse, with subsequent pulses being softer (Figure 2). A small increase in E_p in coincidence with the intense peak #4 is also a commonly observed characteristic. The observed softening also agrees with the COMPTEL-only results [10]. The reduction in the error on E_p in the joint fitting procedure relative to BATSE-only ranges from 20 to 46 %, dependent on spectral hardness of the peak.

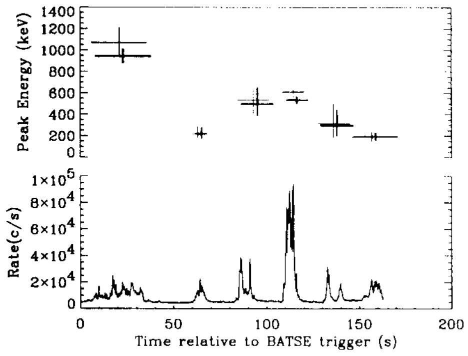

Fig. 2. Evolution of peak energy with time

	SIM	BATSE	B+C
α	-1.03	-1.04±0.02	-1.03±0.01
β	-2.61	-2.79±0.15	-2.65±0.03
E_b	631	659±33	620±20

Table II

'SIM' values were used to create fake burst data. The errors on the BATSE and BATSE+COMPTEL values are the averaged errors from a run of 10 simulations

4. Conclusions

Multi–instrument spectral fitting is a commonly used tool in the x–ray regime, but its application in the study of sources at γ–ray energies to date has been limited. The preliminary results reported here demonstrate the potential importance of this method in the attempt to accurately determine GRB spectral parameters. Further improvements may be possible using the COMPTEL telescope (30 MeV) or even the EGRET telescope (30 GeV).

Acknowledgements

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