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The conspicuous gamma-ray burst of 30 May 1996(*)

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Summary. — The spectra of the majority of bursts exhibit a low-energy power law index, α, that is either a constant or becomes softer with time. However, in the burst of 30 May 1996 α becomes harder. Here we show that this behavior can be explained by a hybrid model consisting of a thermal and a non-thermal component. In this burst the power law index of the non-thermal component changes drastically from $s \sim -1.5$ to $s \sim -0.67$ at approximately 5 seconds after the trigger, thereby revealing, at low energies, the thermal component with its hard Rayleigh-Jeans tail. This leads to the large α-values that are found if the Band function is fitted to the spectra. We suggest that the change in s could be due to a transition from fast to slow cooling of the electrons emitting in the BATSE range. This could be due to the fact that the magnetic field strength becomes weaker.

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1. – Introduction

Despite the presence of a rich observational material and great theoretical efforts, the prompt gamma-ray emission has defied any simple explanation. This is in contrast to the afterglow emission which is successfully described by synchrotron emission from a shock moving at great speed into the surrounding medium. However, recently Ryde [1] showed that the prompt emission can indeed be described by a hybrid model of a thermal and a non-thermal component and that the thermal component is the key emission process determining the spectral evolution in GRBs. Even though individual bursts appear to have complex and varying spectral evolutions the behavior of the two separate components is remarkably similar for all bursts, with the temperature describing a broken power law in time and with the non-thermal component being consistent with emission from a population of fast cooling electrons.

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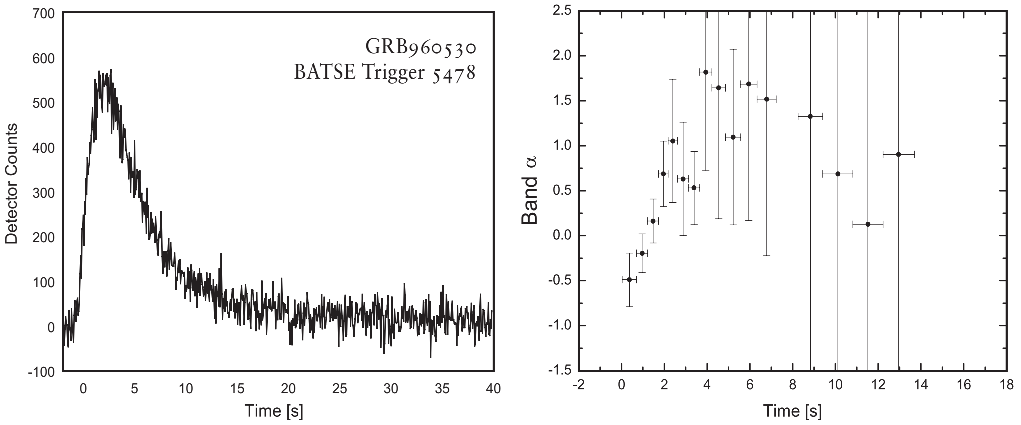

Fig. 1. – Left panel: Count light curve of the burst of 30 May 1996 as observed by the BATSE instruments on the *Compton Gamma-Ray Observatory.* Right panel: Fitting the time-resolved data with the empirical Band function the low-energy, power law index, α becomes harder at the end of the burst. This is the opposite behavior to most bursts with strong spectral evolutions.

The spectral evolution found by using the empirical Band function [2] in the data analysis, exhibits a low-energy power law which becomes softer with time in more than half of all cases [3,4]. Here we reanalyze the burst of 30 May 1996 which is shown in fig. 1. This burst displays the opposite trend, that is, the low-energy power law becoming harder with time. Ryde [1] interprets this power law evolution as an artifact of the empirical fit, reflecting the underlying variation in the thermal and the non-thermal components and their relative strengths. In most cases the thermal component is dominant during the beginning of the evolution and thus gives rise to the initially hard power law fit.

2. – Analysis

The time-resolved spectra of GRB 960530 (BATSE trigger 5478) were modelled with the Band function [2] as well as the hybrid model [1]. XSPEC version 11.3.1 was used

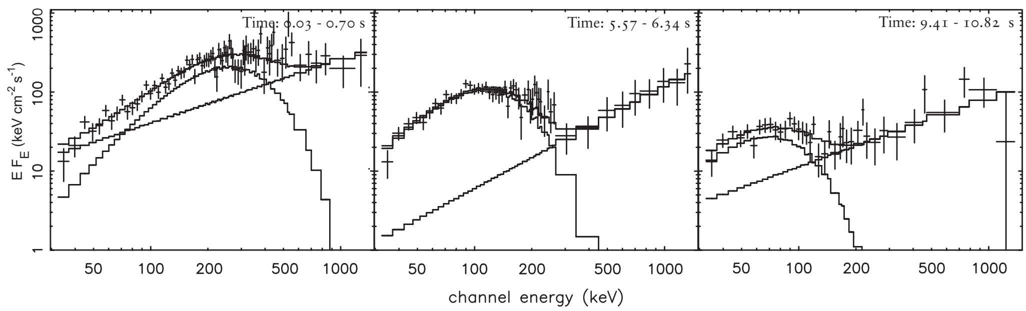

Fig. 2. – Three time-resolved spectra of GRB 960530 fitted with the hybrid model of Ryde [1]. The time intervals that are used for the fits are given in the upper right-hand corner of each panel. The non-thermal spectral component is important in determining the spectrum at the end of the pulse.

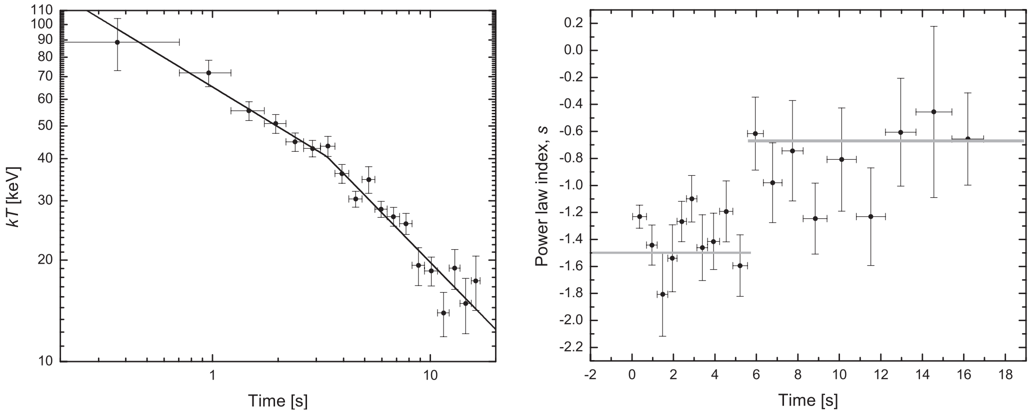

Fig. 3. – Left panel: The temperature of the thermal fit evolves as a power law in time. Right panel: The non-thermal power law index, s makes a jump from ~ -1.5 to ~ -0.67 at approximately 5 s. The grey lines indicate these theoretical values.

for the spectral analysis together with FTOOLS version 5.3.1. HERB data from the detector with the highest rank for this burst, LAD 2, were chosen. A background spectrum was extracted from the LAD data using *bcmppha* from the FTOOLS package. Seventeen spectra corresponding to approximately the 14 first seconds after the trigger were extracted using the same tool. Data from energy channels 1-8 and 114-128 were not included in the fitting procedure. A fit was performed on each spectrum with the critical delta fit 10^{-5} for convergence. After the fitting procedure the 1σ confidence region for each free parameter of the model was determined. Figure 2 shows three time-resolved spectra to which the hybrid model was fitted. In the last two spectra, the high-energy component is important in determining the spectral shape within the BATSE window.

To get a statistical estimate of how well a model fits the total set of time-resolved spectra, the sum of the χ^2 and the number of degrees of freedom (d.o.f.) were calculated. The probability that the sum of the χ^2-values could exceed the calculated $\chi^2_{\rm tot}$, if the model is correct, is then estimated by determining the Q-value, $Q_{\rm tot}$. This is the complement to the χ^2-probability function. The results for both models for the three spectra shown in fig. 2 are presented in table I.

The hybrid model ($\chi^2_\nu = 0.975, Q = 0.79$) gives a slightly better fit to all the spectra compared to the Band model ($\chi^2_\nu = 0.999, Q = 0.51$). This is in part due to the high-energy component that is not caught by the Band model, see fig. 2. Figure 3 shows the results of these fits to the hybrid model. The temperature decays as a broken power law with slopes ~ -0.4 and ~ -0.7. The thermal flux is indeed dominant initially [5],

Table I. – *Analysis of the three time-resolved spectra shown in fig.* 2.

Time interval [s]	$\chi^2_{\rm hybrid}$	Q-value (hybrid)	$\chi^2_{\rm band}$	Q-value (Band)	d.o.f.
0.03–0.70	1.113	0.205	1.067	0.304	101
5.57–6.34	0.921	0.703	1.058	0.326	101
9.41–10.82	0.887	0.887	0.992	0.503	101

however the power law index, s, behaves differently from other bursts [1] in that it becomes harder with time, thus allowing the thermal component be dominant at low energies. We further note that s makes a jump from ~ -1.5 to -0.67 at approximately 5 seconds after the trigger.

3. – Discussion

We argue that the peculiarity of this burst, namely that α becomes harder with time, is due to the fact that the non-thermal spectral component becomes harder, letting the thermal component dominate at low energies. This allows its Rayleigh-Jeans portion to be exposed. The change in s from ~ -1.5 to $\sim -2/3$ can be interpreted as the synchrotron cooling frequency of the electrons passing through the band-width, towards higher energies, at around 5 s. For a population of fast cooling electrons the spectrum below the frequency corresponding to the minimum Lorentz factor of the injected electrons, will have a power law index of -1.5, down to the cooling frequency at which the electrons cool on dynamical timescale. Below the cooling frequency the power law slope is expected to have an index of $-2/3$ [6]. Such a scenario can be imagined if the amount of the dissipated energy going into the magnetic fields decreases with time. The thermal component, on the other hand, behaves similarly to other bursts with a broken power law decay in time (fig. 3 left). It should also be noted here that for a pure synchrotron model, instead of the hybrid model, the observed behavior of GRB 960530 would be difficult to explain.

The above investigation has shown that the hybrid model [1] can give a satisfactory explanation of the spectra and spectral evolution of GRB 960530. In addition, this burst illustrated that the non-thermal component of the hybrid model can play an important rôle in determining the spectral evolution. This component should be most important at energies beyond the BATSE window ($\sim$ 20–2000 keV) studied here. Furthermore, the few super-MeV detections made to date indicate the possible presence of additional emission components at these energies [7-9]. The GLAST satellite will be able to address this issue in detail with its broad spectral coverage ($\sim$ 10 keV–200 GeV) and the improved sensitivity that it provides.

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