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# BATSE data support the multicomponent model for Gamma Ray Bursts prompt emission

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**Abstract.** Observations of the prompt emission of several Gamma Ray Bursts (GRBs) detected with the instruments on-board the Fermi Gamma ray Space Telescope (hereafter *Fermi*) as well with the Burst and Transient Source Experiment (BATSE) on-board the Compton Gamma Ray Observatory (*CGRO*) reveal deviations from the Band function to describe their spectra in the keV-MeV energy range. Analysis of *Fermi* data conclude that GRB prompt emission is adequately fitted with the simultaneous combination of three emission components: a thermal-like component interpreted as the jet photosphere, a non-thermal component interpreted as synchrotron radiation from particles within the jet and an additional non-thermal power-law (PL) function extending from low to high energies in gamma-rays, interpreted as Inverse Compton emission. In this work we present new analysis of three BATSE Bursts, namely GRBs 941017, 970111 and 990123. We show that the BATSE data are fully consistent with the model derived from *Fermi* data and that these three BATSE bursts also exhibit the three different components as reported from *Fermi*, noticing that they present similar spectral behaviour. In addition, the analysis using this three-component model during the prompt emission results in a strong correlation between the time-resolved luminosity and the corresponding rest-frame $\nu F\nu$ spectral peak energy ($\mathrm{L}_i^{nTh}$-$\mathrm{E}_{p,i}^{nTh,rest}$ relation). When fitted with a power law the relation have similar indices for all three bursts and these values are also in perfect agreement with the *Fermi* results. This points toward a possible universal emission process intrinsic to the non-thermal component of GRB prompt emission. Using this correlation we estimated the redshift for GRBs 941017 and 970111 using GRB990123 (with known redshift) as reference. The estimated redshifts for these bursts are typical values for long GRBs.

## 1. Introduction

The spectra of Gamma Ray Bursts prompt emission in the keV-MeV energy range are usually considered as adequately fitted with the empirical Band function (Band et al 1993) -a smoothly broken power law-. Recently multiple component models seem to be favoured compared to single component ones for GRBs prompt emission. In some cases (González et al. 2003, Ackermann et al. 2011) an additional PL was required to account for spectral deviations at high energies. Recently a thermal like component ($C_{Th}$) among with a non-thermal ($C_{nTh}$) one have been discovered in the prompt phase of some bursts observed with *Fermi* (Guiriec et a. 2011, Axelsson et al. 2012). When this thermal component is present the non thermal one is adequately described with a Band function but with different spectral values compared when fitting the Band function alone, making them consistent with the synchrotron emission scenarios. The observed $C_{Th}$ is usually energetically sub dominant compared to the $C_{nTh}$ one which favours highly magnetized jet models.

Guirec et al. (2015) identified simultaneously the three known components in the prompt emission of bright GRBs detected by *Fermi*, namely GRBs 080916C and 090926A. The analysis changed the view of GRB080916C which was considered before as adequately fitted with a single Band function alone (Abdo et al. 2009). While the spectral and temporal behaviour was completely different for the two GRBs, both become similar within the context of the $C_{nTh}$+$C_{Th}$+PL model. A strong correlation between the time-resolved luminosity and the corresponding rest-frame $\nu F\nu$ spectral peak energy ($L_i^{nTh}$-$E_{p,i}^{nTh,rest}$ relation, where "i" counts time intervals) was noted, interestingly these relations for all GRBs are properly described using PLs with very similar index. This relation points towards a possible universal physical mechanism intrinsic to all GRBs, which could be used to measure distances using prompt phase data.

When fitting either $C_{nTh}$+$C_{Th}$ or $C_{nTh}$+$C_{Th}$+PL to the data the indices of these components do not vary much in the same burst or from burst to burst (Guirec et al. 2013, 2015). Indeed $\alpha_{nTh}$ indices present values ∼0.7 or ∼-1.2 depending on the burst, $\alpha_{Th}$ value is usually ∼0.6 and $\alpha_{PL}$ ∼-1.5. Therefore the number of free parameters of these models can be reduced by freezing some of them in order to become statistically competitive with the Band function in therms of free parameters.

## 2. Data Selection

We focus on a limited sample of three famous bright long GRBs detected with BATSE. These GRBs are of particular interest because they have often been and still are cited to support or discard theoretical interpretations for GRB prompt emission. GRB941017 was the first burst of the pre *Fermi* era for which a strong deviation at high energy from the Band function was reported (González et al. 2003). GRB970111 was considered as adequately fitted to a Band function but with positive values of the lower energy index of the Band function at early times (Gorosabel et al. 1998). The photometric redshift of this burst was estimated to be $0.2<z<1.4$ based on its probable association with host galaxies. GRB990123 was an extremely bright GRB considered, so far, as adequately fitted to a Band function alone (Akerlof et al. 1999). It was the first burst to be simultaneously detected during its prompt phase in $\gamma$-ray and optical bands. A 1.61 redshift estimate was reported for this burst (Kelson et al. 1999, Hjorth et al. 1999).

## 3. Analysis

We first performed a time integrated spectral analysis of the bursts (for GRB941017 see table No.1) to identify the main spectral components of the prompt emission -for details about the procedure of the analysis go to Guiriec et al. (2015)-. It is clear from the Cstat values that a Band function alone is not a good description and that $C_{nTh}+C_{Th}$ and $C_{nTh}+C_{Th}$+PL significantly improve the Band fits.

| Models | Base Component CPL or Band | | | Additional Component | | Cstat/DOF |
|---|---|---|---|---|---|---|
| | | | | BB | PL | |
| | Ep (keV) | $\alpha$ | $\beta$ | kT (keV) | $\gamma$ | |
| GRB941017 from $T_0$-4.096 s to $T_0$+118.784 | | | | | | |
| Band | 330±5 | -0.78±0.01 | -2.35±0.03 | | | 205.8/9 |
| $C_{nTh}$+PL | 270±4 | +0.12±0.07 | | | -1.62±0.01 | 75.3/8 |
| $C_{nTh}$+PL | 272±9 | +0.01±0.25 | | | -1.99±0.33 | 28.2/7 |
| $C_{nTh}+C_{Th}$ | 784±44 | -1.33±0.02 | | 56.0±0.66 | | 25.1/8 |
| $C_{nTh}+C_{Th}$ | 674±75 | -1.30±0.03 | -2.41±0.22 | 56.3±0.73 | | 23.6/7 |
| $C_{nTh}+C_{Th}$+PL | 451±52 | -0.62±0.27 | | 51.8±2.3 | -1.7±0.03 | 18.3/6 |

Table 1. Time integrated analysis of GRB941017 with their 1-$\sigma$ uncertainties

Then we analysed every burst on fine time scales to follow the evolution of the various components and to verify that the observed spectral features are not merely artefacts due, for instance, to strong spectral evolution. We discuss only the most relevant models for the time-resolved analysis, namely Band, $C_{nTh}+C_{Th}$ and $C_{nTh}+C_{Th}$+PL. We froze $\alpha_{nTh}$ to -0.7 and $\alpha_{PL}$ to -1.5 when fitting the $C_{nTh}+C_{Th}$+PL model as proposed in Guiriec et al. (2015). Although these parameter estimates may not be completely accurate they are good enough in the context of the present analysis.

The similarities of BATSE and *Fermi* results are notorious when comparing Band and $C_{nTh}+C_{Th}$: $\alpha_i^{nTh}$ is systematically lower than $\alpha_i^{Band}$ and conversely to the Band case the indices $\alpha_i^{nTh}$ are always compatible with the synchrotron scenario. For $E_{peak,i}^{nTh}$ the value is systematically higher than $E_{peak,i}^{Band}$. For the temperature associated to the thermal component a less notorious variation is observed when compared to $E_{peak,i}^{Band}$ and is usually lower. Fitting the $C_{nTh}+C_{Th}$+PL model give that the values of $E_{peak,i}^{nTh}$ is usually lower that those resulting from the $C_{nTh}+C_{Th}$ fits which is also in total agreement with the *Fermi* analysis.

It was noted from the analysis that in the central engine frame the $L_i^{nTh}$-$E_{p,i}^{nTh,rest}$ relation present extremely similar indices for all GRBs ($\sim$1.4, $\sim$1.33, $\sim$1.28 for GRBs 941017, 970111 and 990123 respectively), and similar to the ones obtained with *Fermi*, which points out to a possible universal relation. Taking into account the redshift measurement for GRB990123 and using this relation in this BATSE sample we were able to estimate the distances to GRBs 941017 $\sim$1.79 and 970111 $\sim$1.18.

## 4. Results and Conclusions

We show that the BATSE data are fully consistent with the model derived from *Fermi* data and that these three BATSE bursts also exhibit the three different components.

The $C_{nTh}$ component overall overpowers the other components in the BATSE energy range from 20 keV to 2 MeV in all three bursts. Its contribution is usually higher than 50% of the total energy released in this range of energy. This component is interpreted as either synchrotron emission from charged particles propagating and accelerated within the GRB jet or a strongly reprocessed photospheric emission.

The $C_{Th}$ contribution is lower, $\leq$ 20% of the total emission. It is more intense at early times and it is interpreted as emission from the jet photosphere as predicted by the fireball model, but with lower energy contribution than expected.

The PL component energy contribution is roughly few tens of percent although it can be >70% at early and late times. Because of the limited energy range of BATSE, the additional PL is mostly subdominant compared to $C_{nTh}$ over the whole observed energy range, and it only starts to be dominant at the very high energy of the spectrum. This component is most likely to have inverse Compton origin.

Finally assuming that $L_i^{nTh}$-$E_{p,i}^{nTh,rest}$ relation is universal as suggested in Guiriec et al (2013, 2015), and using GRB990123 -which has a measured redshift z$\sim$1.61- as reference, the redshift for GRBs 941017 and 970111 was estimated (z=1.79$\pm$0.07 and z=1.18$\pm$0.06 respectively). These values are in consistence with typical ones for long GRBs and for the case of GRB970111 it is in the range of the predicted value considering possible host galaxies (0.2$\leq$z$\leq$1.4) as reported by Gorosabel et al. (1998).

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