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The Potential of GLAST in Observing Features in the High-Energy Spectra of GRBs

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Abstract: GLAST is a gamma-ray mission which will be launched end of 2007. It is equipped with the GLAST Burst Monitor (GBM) which detects Gamma-Ray Bursts (GRBs) with high reliability and provides a position and energy spectrum in the range between 10 keV and 30 MeV. The Large Area Telescope (LAT) will observe photons with energies from 20 MeV up to more than 300 GeV. With GLAST it will be possible to study the spectra of GRBs over 7 orders of magnitude in energy and for the first time in the energy band above several tens of GeV.

From the high-energy part of GRB spectra new insights into the bursts physics can be expected. Emission due to Inverse Compton scattering of electrons or due to interactions of hadrons would point to particles accelerated in the jets of the GRBs. A cut-off of the spectrum would allow to study internal absorption of gamma-rays in the burst and external attenuation in interaction with the EBL.

Here we will present the study of simulated GRBs, in particular with respect to features in the high-energy spectrum. We will discuss the performance of GLAST of detecting cut-offs and additional high-energy emission.

Introduction

GLAST [1] (Gamma-ray Large Area Space Telescope) is dedicated to the observation of the gamma-ray sky in the energy range from several keV up to several hundred GeV. It will be launched end of 2007. It comprises two separate instruments, the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM) [2].

With its large field of view the LAT sees $\approx 20\%$ of the sky at any time. In the first year GLAST will operate in scanning mode, covering the entire sky every three hours. GLAST can perform pointed observations, which will be important to follow the emission of GRBs. The LAT observes photons at energies between 20 MeV and 300 GeV with a sensitivity about 30 times higher than EGRET's. It will observe the sky with unprecedented sensitivity and in the currently unobservable GeV energy band.

In order to correlate the high-energy emission from GRBs with the better known low energy emission, GLAST is equipped with the GBM. The GBM comprises 12 NaI and 2 BGO scintillation detectors. With its field of view of about 9 sr it will detect GRBs with high reliability in the energy range between 10 keV and 30 MeV. The GBM provides a position and a trigger time of the GRB for further LAT observations.

High-energy gamma-rays from Gamma-Ray Bursts (GRBs) with energies up to 20 GeV were observed by EGRET [3]. Features in the GeV band provide insight into the physics of GRBs. A break in the spectrum would allow the estimation of the bulk Lorentz factor in the jet. Additional high-energy components would point to inverse Compton emission of relativistic electrons or to hadronic interaction of accelerated protons. Due to the large distance of GRBs the gamma-rays produced in the bursts suffer from absorption at the Extra-Galactic Background Light (EBL), producing a cut-off of the spectrum.

Simulations and Analysis

In order to perform systematic studies GLAST observations of 1 year were simulated. After simulating the entire gamma-ray sky parameterised ef-

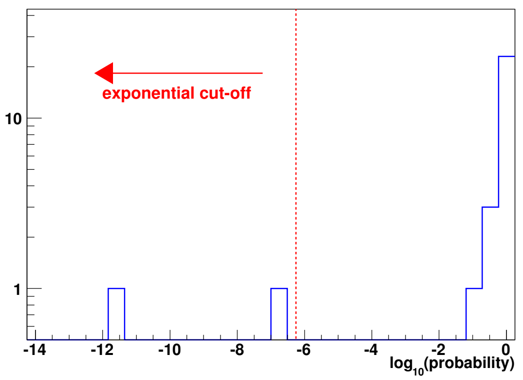

Figure 1: χ^2-probability of the difference of the likelihoods of fits of a power law with and without an exponential cut-off. A probability of $< 5.7 \times 10^{-7}$ corresponds to a $5\,\sigma$ detection of a cut-off.

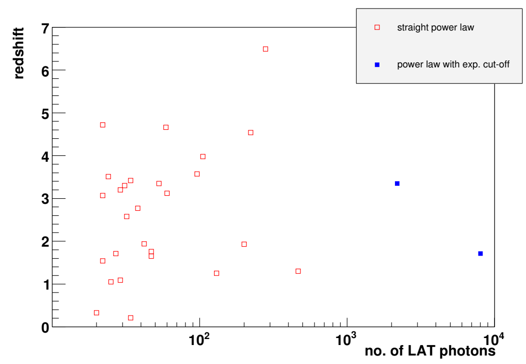

Figure 2: Distribution of the GRBs with respect to the number of detected events and the simulated redshift. Open symbols represent bursts with a power law spectrum, filled symbols denote bursts with a cut-off.

fective areas were used to calculate the response of GLAST. These simulations include 430 GRBs. The GRB simulations were performed based on a phenomenological or physical model [4]. The simulations include synchrotron emission, inverse Compton emission and absorption due to EBL.

For the spectral analysis we selected those bursts with more than 20 photons detected by the LAT within a radius of 20° around the burst position. The selection and binning of the photons were performed using the standard GLAST analysis software, and spectral fits using XSPEC [5] with Cash Statistics [6].

Search for High-Energy Cut-Offs

The search for high-energy cut-offs was performed using only LAT data. Based on the Monte Carlo truth of the simulation we selected only bursts without an inverse Compton component, in order to avoid misinterpretation of the data. Each spectrum was fitted by a straight power law, $dN/dE = N_0(E/10\,\mathrm{MeV})^{-\Gamma}$, and a power law with exponential cut-off, $dN/dE = N_0(E/10\,\mathrm{MeV})^{-\Gamma}\exp(E/E_\mathrm{c})$.

The Likelihoods of the fits were examined to evaluate the improvement of the fit by adding the cut-off energy as additional parameter. The difference of the Likelihoods follows a χ^2-distribution with one degree of freedom. A χ^2-probability of less than 5.7×10^{-7} corresponds to a $5\,\sigma$ detection of a cut-off. The distribution of the probabilities is shown in Fig. 1. We found two bursts with a significant high-energy cut-off.

The simulated GRB spectra do not have an intrinsic cut-off. Therefore, all detected cut-offs are due to EBL absorption, and are expected for high redshifts only. Fig. 2 shows the distribution of the bursts with respect to their redshift and number of detected photons. It can be seen that the bursts with a detected cut-off have average redshifts with respect to the redshifts of the full sample, yet they are very bright (with more than 1000 photons detected).

For the two bursts with significant cut-off we performed a second fit using the parameterisation of the EBL cut-off proposed by [7]: $\exp(-\tau)$, with $\tau = 1 + (E - E_1)/P$ for $E > E_1 - P$, 0 otherwise. Figure 3 shows the fitted spectrum for one of the two bursts and Fig. 4 the two fitted values of E_1 as compared to the true value of the model used for the simulation.

Synchrotron Peak

In order to analyse the synchrotron peak we use the NaI detectors (energy range 10 keV to 1 MeV) and the LAT (more than 100 MeV). The synchrotron

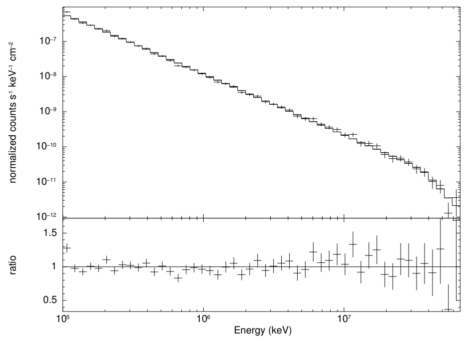

Figure 3: Spectrum of a GRB with cut-off due to EBL.

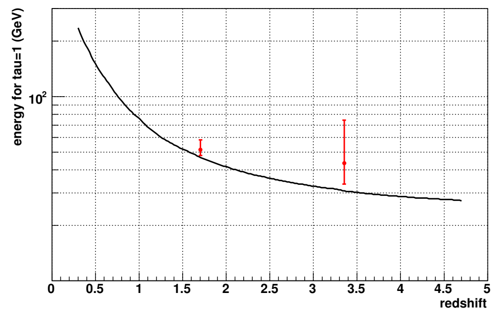

Figure 4: Fitted energy for which the EBL optical depth is unity (E_1), for the two bursts with cut-off. The line denotes the model used in the simulation.

spectrum of GRBs can be described by a phenomenological GRB-Model, the so-called Band function [8], two smoothly connected power laws. The parameters of this model are the spectral indices in the low and high-energy part, α and β respectively, and the peak energy. In case of the two GRBs showing a high-energy cut-off as described above, the data is described by a Band function with an additional exponential cut-off.

As can be seen from the comparison of the fit result with the simulated value in Fig. 5, the low-energy photon index can be well reproduced.

The reconstruction of the high-energy photon index turns out to be more difficult. As the LAT is the most important sub-detector for this part of the spectrum, the spectral fit has been performed as a fit of a power law to the LAT data only. From Fig. 6 can be seen that the agreement with the simulation is quite good, with rather large statistical uncertainties.

Search for Inverse Compton Emission

In order to search for an additional high-energy component we selected the bursts which were simulated with a strong inverse Compton (IC) component. The inverse Compton peak was simulated using the same spectral parameters as the synchrotron peak, but shifted to higher energies.

For the spectral analysis we used the data of GBM and LAT, covering an energy range from 10 keV up to several hundred GeV. An example spectrum is shown in Fig. 7. We performed a fit of two Band functions in order to describe the two peaks. This model describes the data points reasonably, and the spectral parameters of the high energy peak can be well reproduced.

Conclusion

We performed systematic studies of simulated GRB spectra with several models. High-energy cut-offs can be detected with a statistical approach evaluating the different spectral fits. Bursts with a cut-off can be used to test the EBL model, it is found to be in good agreement with the simulations.

In order to analyse the overall synchrotron spectrum of the GRBs the energy spectrum in all subdetectors is used. The low-energy spectral index of the Band model can be well reconstructed. This fit depends mainly on the data in the NaI detectors of the GBM. The fit of the high-energy spectral index depends mainly on the data of the LAT. A fit of a power law to the LAT data yields results in good agreement with the simulations.

We also searched for additional high-energy emission, based on simulated bursts with an inverse Compton component. The energy spectrum can be reproduced, showing both, the synchrotron and the inverse Compton peak. In order to study the accuracy of the fits further systematic studies are necessary.

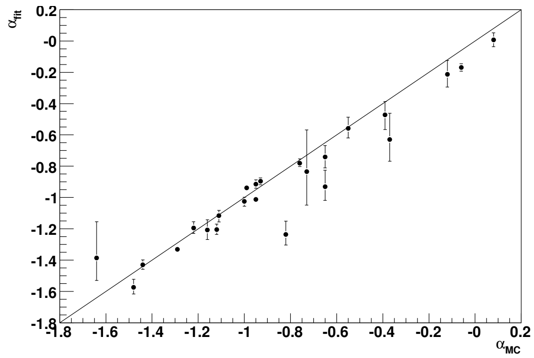

Figure 5: Low-energy spectral index α. Shown is the fit result in dependence on the simulated value.

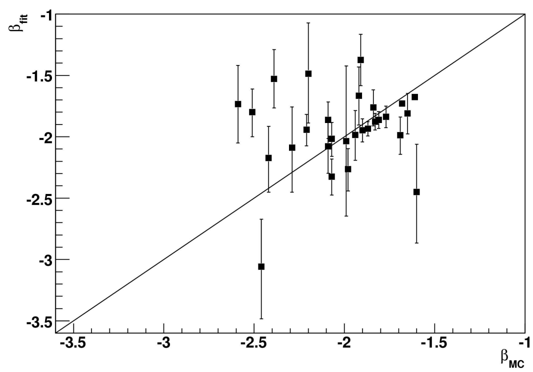

Figure 6: High-energy spectral index β. Shown is the fit result in dependence on the simulated value.

Several physical models of high-energy GRB spectra could be well reproduced. This demonstrates the high performance to be expected from GLAST GRB observations.

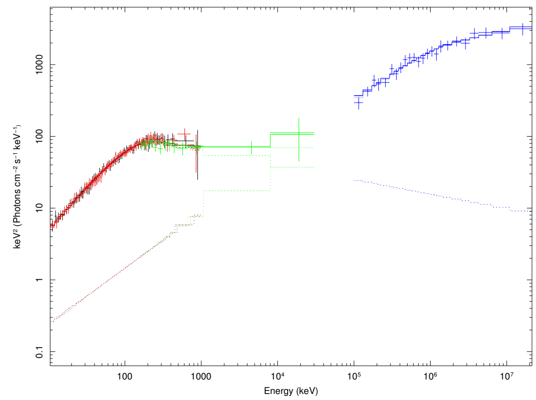

Figure 7: Unfolded $E^2 f(E)$ spectrum and model of a simulated gamma-ray burst with inverse Compton component. Shown in red and black are the GBM/NaI detectors, in green the GBM/BGO detector and in blue the LAT.

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