Gamma-Ray Burst Physics with GLAST

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The Gamma-ray Large Area Space Telescope (GLAST), scheduled to be launched in late of 2007, is the next generation satellite for high-energy gamma-ray astronomy. The Large Area Telescope (LAT), the main instrument of GLAST, will survey the sky in the energy range between 20 MeV to more than 300 GeV, shedding light on many issues left open by its highly successful predecessor EGRET (Energetic Gamma Ray Experiment Telescope). The Gamma-Ray Bursts (GRBs) are one of the most exciting science topic for the LAT, which will open a new window, exploring these sources in a energy range never observed before. Even if little is know at high energy, we would like to address, in this contribution, some of the features of the GRB spectrum that theories predict and that LAT can observe. Finally we would like to present some results about the study of the sensitivity of the LAT to GRBs.

Keywords: Gamma-ray:bursts; Gamma-ray:telescopes

1. Introduction

GLAST\(^1\) is an international mission that will study the gamma-ray Universe. It will be launched aboard a Delta 2920H-10 from Cape Canaveral, on a 565 km circular orbit at 25.3° inclination. The heart of GLAST is the LAT, a pair production telescope sensitive to gamma rays in the energy range between 20 MeV-300 GeV and above. The LAT’s energy range, effective area, field-of-view (FoV) and angular resolution are vastly improved in comparison with those of its highly successful predecessor EGRET (1991-2000), so that the LAT will provide a factor 30 or more advance in sensitivity\(^a\). This improvement should enable the detection of several thousands new high-energy sources and allow the study of GRBs and other transients, the search for dark matter, the detection of active galactic nuclei, pulsars,

\(^a\)see [http://www-glast.slac.stanford.edu/software/IS/glast\_lat\_performance.htm](http://www-glast.slac.stanford.edu/software/IS/glast\_lat\_performance.htm) for the LAT performances
supernova remnants and the study of the extragalactic diffuse gamma-ray emission. The second detector onboard the GLAST satellite is the GLAST Burst Monitor (GBM),\textsuperscript{2} which consists of 12 NaI detectors for the 10 keV to 1 MeV range and two BGO detectors for the 150 keV to 30 MeV range. It covers the entire visible sky not occulted by the Earth, extending the spectral coverage of GRBs down to the tens keV range, where most of GRB phenomenology is known since the BATSE instrument. For GRBs, GBM and LAT data will be jointly analyzed, providing information over more than seven energy decades.

2. Gamma-Ray Bursts and GLAST

Gamma-Ray Bursts are flashes of high-energy radiation, probably related to the explosions of massive stars or the merging of compact objects. Their energy is peaked, in the $\nu F_\nu$ spectra, at hundreds of keV, and is typically described with a smoothly broken power law.\textsuperscript{13} GRBs are still a puzzling topic and few observations are currently available above 50 MeV. EGRET detected only a few high-energy bursts,\textsuperscript{3} and did not detect the high energy cutoff or rolloff that must exist for some hard spectra to keep the energy flux finite. Surprisingly, GeV emission was found to last up to 90 minutes after the 150 keV emission;\textsuperscript{4} in addition, an extra spectral component was observed at 100 MeV in GRB941017.\textsuperscript{5}

During the first year it will operate in scanning mode, providing uniform sky coverage every three hours; nevertheless GLAST can re-point, keeping the burst in the LAT field of view studying the development of the burst emission, hours after the trigger, looking, eventually, for delayed high energy emission. GBM and the LAT can independently trigger on GRBs; a rapid alert message will be sent to the ground near real-time using the TDRESS satellites\textsuperscript{b} providing basic information for follow-up observations. According to the predicted sensitivity (0.8 ph/cm$^2$/s), the GBM will detect $\sim$200 bursts per year, of which more than 60 will fall in the 2.4 sr field of view of the LAT.\textsuperscript{6} The initial on-board GBM localization accuracy is $\sim$15 degrees (within 1.8 s), updates with better location will come later. The LAT detector can provide better accuracy, of the order of ten arc minutes or less, depending on the burst intensity. For a few bursts per year the LAT will localize them to sufficiently small error boxes (0.1 degrees) that medium field-of-view instruments can point for follow up observations, providing a

\textsuperscript{b}A cluster of commercial telescopes, available for downlink the alert messages from GLAST.
more precise measurement of the GRB position. GLAST will be able to investigate the emission processes that are present in GRB phenomena and scan the most energetic region where particles are accelerated, probably reaching their highest energy.

3. GRB simulators

In order to simulate GLAST observation of Gamma-Ray Bursts, we adopt the idea of developing a general interface to accommodate different models based on different approaches. In general we consider a GRB flux as a two-dimensional histogram, where the flux (as $N_{ph}/cm^2/s$) is described as a function of energy and time. The physical model describes the GRB phenomena starting from the so-called fireball scenario. In this model we simulate the emission of shells of matter ($e^+$ and $e^-$, mainly), emitted by a central engine with relativistic velocities. The shells can collide producing shocks; part of the energy density dissipated during these shocks is converted into accelerated particles, and part goes into magnetic field energy density. In this standard scenario, particles cool by Synchrotron radiation whereas the pulse shape depends, basically, on geometrical shapes of the emitting shells. Fig. 1 shows the typical spectral shape of a GRB, as described by the fireball model: the first peak of the $\nu F_\nu$ spectrum is due to Synchrotron radiation. Due to the slow cooling time, the synchrotron spectrum shows a cut-off at GeV energies, well in the LAT field of view. Natural extension at high energy is the Inverse Compton radiation, where the synchrotron photons are up-scattered by the accelerated electrons. This mechanism characterizes the second bump in the schematic spectrum of Fig. 1. At high energy the IC spectrum is attenuated mainly by intrinsic absorption between IC photons and Synchrotron photons. This attenuation depends on the Lorentz factor of the emitted material and, for moderate Lorentz factor, can be in the LAT energy range.

A different approach is followed in the phenomenological model, where the GRB behavior is based on observed quantities, mostly coming from the BATSE catalog (Preece et al. 2000). In our model we obtain the temporal-spectral evolution of a GRB by multiplying the “Band” function for a pulse shape, described by a universal family of functions. In agreement with the results from Fenimore et al. (1995) and Norris et al. (1996) the pulse width $W$ depends on the energy ($W(e) = W_0(e/20keV)^{-0.33}$); the spectrum is extrapolated up to LAT energies as well as pulse width scale law. Thus, this model foresee narrower pulses at high energy, as narrow as millisecond time scale. This model, firstly developed by Norris et al. (1996)
Fig. 1. Schematic representation of the spectrum of a GRB as described by the fireball model. In this model we have included the synchrotron spectrum, and the Inverse Compton Component. The synchrotron spectrum is limited at high energy by the maximum energy reached by the accelerated particles, while the Inverse Compton is limited by intrinsic absorption (we have approximated the two components by broken power laws. A detailed calculation would have result in a smoother spectrum. In the picture the energy band for the BATSE, GBM and LAT detectors are depicted. has been recoded and it is now accessible as part of the Science Tools.

For each simulated burst a sequence of photons is sampled, in agreement with the spectral-temporal development of the flux. Each photon is then processed by a Monte Carlo simulator, based on GEANT4 toolkit, which follows the propagation of particles in the detector. Another (faster) approach is to use the parameterized response of the instrument, using the Instrument Response Function (IRF). Even in this case the followed approach is photon-by-photon, and the output format is the same as in the case of the full Monte Carlo approach. GRBs can be combined with other classes of sources, (stationary and flaring AGN, solar flares, SNR, Pulsars,...), building a very complex and, possibly realistic, picture of the gamma-ray sky. The GRB simulators are also able to interface the GBM software providing correct input files for the detector simulators. In this case the approach is slightly different. The GRB simulators produce a temporal series of Band parameters, fitting continuously the GBM counterpart of a LAT bursts. These parameters are then used to compute the GBM response and the final output is a series of FITS files, that can be analyzed jointly with LAT data, producing sky-maps, lightcurve, and spectral joint spectral fits. Fig. 2 is an example of combined light curve of a simulated bursts. Combining GBM and LAT data a GRB can be simultaneously studied in an energy

\[A set of tools for analyzing (and simulating) LAT data, that the LAT team will deliver to the community.\]
Fig. 2. Combination of the simulated counts rate of the BGO (B1), two NaI detectors (N5 and N6) of the GBM experiment, over-imposed with the LAT light curve. LAT will have enough temporal resolution to correlate low energy spikes with high energy temporal profiles, understanding details of the emission process. In the figure is well visible the ‘time-lag’ between low energy and high energy temporal structures as well as the characteristic ‘pulse paradigm’, for which high energy pulses are narrower than low energy pulses.

band larger than seven orders of magnitude, making GLAST a very powerful tool for understanding the correlation between the low-energy and high-energy spectra in GRBs.

4. Study the LAT’s GRB sensitivity

We used the BATSE catalog for building up our statistics. Considering the flux threshold (0.3 ph/cm$^2$/s) and the field of view of the BATSE instrument, the expected number of burst per year over the full sky is 650. For each simulated burst the duration is drawn from the observed $T_{90}$ distribution and its flux is sampled from the BATSE peak flux distribution in the 50-300 keV energy range.$^{12}$ The number of pulses is fixed by the total burst duration. The peak energy $E_p$ and the low and high energy spectral indices $\alpha$ and $\beta$ are sampled from the observed distributions.$^{13,14}$ In this model, long and short bursts are treated separately. At high-energy photons produced by GRB at cosmological distances can be absorbed by the Extragalactic Background Light (optical-UV photon), producing pairs. In our simulation we have included this effect, adopting the EBL model proposed in$^{15}$ and adopting the redshift distribution for short bursts proposed by Guetta et al.(2005).$^{16}$ Long bursts are likely related to the explosive end of massive stars, whose distributions are well traced by the Star Formation
History.\textsuperscript{17}

We simulate one year of observations in scanning mode. The orbit of the GLAST satellite, the South Atlantic Anomaly (SAA) passages and the Earth occultation are correctly considered. In Fig.3 we plot the number of expected bursts per year as a function of the number of photons per burst detected by the LAT, where different lines refer to different energy thresholds. The EBL attenuation affects only the high-energy curve, as expected from the theory, leaving the sensitivities almost unchanged with thresholds less than 10 GeV. In this calculation, LAT will independently detect 50-70 burst per year, depending on the sensitivity of the detection algorithm. Few bursts per year will have a sufficient amount of counts in the LAT detector to allow detailed spectra studies, combining the LAT and the GBM spectra.

![Graph showing GRB rate vs. number of photons detected.](image)

Fig. 3. Model-dependent LAT GRB sensitivity. The GRB spectrum is extrapolated from BATSE to LAT energies. The burst rate in the 4π sphere is assumed to be 650 GRB/yr (above 0.3 ph s\(^{-1}\) cm\(^{-2}\) in the 50-300 keV band), in agreement with BATSE statistics. The bursts here simulated do not have the Inverse Compton Component. The effect of the EBL absorption is included. Different curves refer to different energy thresholds.
5. Conclusions

LAT is a new window to GRBs, covering energy where we basically don’t have information about how the GRB spectrum looks like. Different emission mechanism can take place at high energy; the most probable one is the Inverse Compton scattering. This component can enhance the spectrum at the LAT energies increasing the GRB yield. On the other hand, absorption phenomena can suppress the spectrum in the LAT domain. In case of IC component, the intrinsic absorption by pair production is the most effective one, and it is the limit for high energy emission. In case of moderate bulk Lorentz factor of the emitting shell, this component is in the LAT energy range, and in case of bright burst can be measured with statistically significance. Further works will study these effect in detail.

References

8. T. Piran, Physics Reports, **314**, 57 (1999)