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GAMMA RAY BURSTS AND DATA CHALLENGE ONE: SEARCHING GRB IN ONE DAY OF SIMULATED GLAST DATA

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Abstract

GLAST (Gamma-ray Large Area Space Telescope) is a gamma-ray astronomy mission that will be launched in early 2007. The main instrument is the LAT (Large Area Telescope), a pair conversion telescope with sensitivity in the range 20 MeV-500 GeV. Data Challenge One (DC1) is the simulation of one day of observation of the entire gamma-ray sky by the LAT detector. The simulated data is similar to the real data, which allows for the development of scientific software. In this paper we present the GRB simulations and the detection algorithms developed by part of the GLAST GRB and Solar Flare Science Team[1]

[1]David Band, Jerry Bonnell, Monica Brigida, Johann Cohen-Tanugi, Riccardo Giannitrapani, Tune Kamae, Francesco Longo, Jay Norris, Nicola Omodei and Mikel Winai.

1 The Data Challenge One

The Large Area Telescope (LAT), the main detector onboard the GLAST satellite, will observe the sky between 20 MeV and 500 GeV. It is composed of a modular structure made by 16 identical towers. Each tower is composed of an hodoscopic calorimeter of 8.4 radiation length and of a silicon tracker module made of 19 stacked trays which provides 18 X-Y planes for the tracking of the electron-positron pair. The array of 4×4 towers is shielded by segmented scintillator tiles which provide the anti coincidence for rejection of charged particles. The LAT team has developed a full simulation environment[2], which allows the detailed study of the instrument performances and the development of scientific analysis software. The simulation starts from a detailed description of the sky. It takes into account the orbital motion of the satellite and computes the correct illumination of the detector. The incoming particles are then propagated into the detector using a montecarlo based on Geant4 tool. The digitized events are processed with the reconstruction tools. Time, direction and energy of each incoming gamma ray are computed and stored. The Data Challenge One (DC1) represented the first opportunity to test the complete simulation chain, and the first attempt to perform scientific analyses on simulated data.

1.1 The description of the sky and the Gamma-Ray Burst model

For DC1, only the gamma-ray sky has been simulated, while the cosmic-ray flux (about 10^4 times greater) was modeled separately for development of the background rejection algorithms, and that these algorithms were applied to the simulated gamma-ray data. The gamma-ray sky is made by a variety of sources: the software takes into account the relative fluxes and computes from which source arrives the next photon. The diffuse extragalactic source is an isotropic component while the galactic diffuse radiation has been obtained extrapolating the galactic map observed by EGRET at LAT energies. Furthermore, the third EGRET catalogue has been used to determine the contribution of all the point sources observed by EGRET. Similar simulated point sources fainter than could be detected by EGRET were also included. One of the most exciting target opportunities for the GLAST mission is the observation of GRBs, transient sources whose durations range between milliseconds and some hundreds of seconds. GRBs have typically a very complex temporal structure made of several spikes of the time scale of the order of milliseconds. Two different simulators for GRB have been developed for Data Challenge purposes. One is based on the physical fireball model[3] and has been used for simulating the first day of the DC1, the other is based on the phenomenological model and is also available in the GLAST software[5]. In the first day 21 bursts have been generated, one every $\sim$ 4000 seconds starting at $\sim 3000s$. The

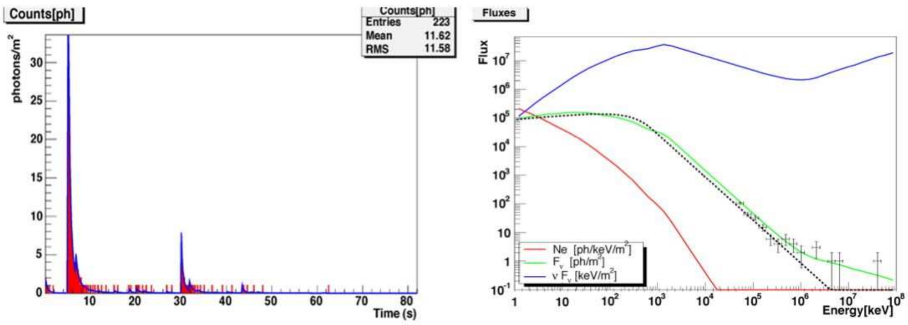

Figure 1: Simulated light curve and spectrum from the GRB physical model. Left: LAT expected light curve. The histogram represents the arrival times of the extracted photons. Right: Filled line, from top to bottom: νF_ν, F_ν, N_ν. The dashed line is a fit with the Band function, with parameters:$\{\alpha = -0.86, \beta = -2.5, E_0 = 446.684 eV\}$. Crosses are the extracted photons.

bursts are isotropically distributed in the sky, thus some of those are outside the f.o.v. of the instrument and cannot be detected. The physical model[4] starts from the ejection of shells with different velocities. Their Lorentz factors are randomly generated allowing the possibility of internal inelastic shocks. Particles (electrons and positrons) are accelerated, and a randomly oriented magnetic field is built up in the shocked region due to repartitioning of the energy. Synchrotron emission is the main spectral component and the most efficient cooling mechanism. Inverse Compton scattering (SSC) is its natural extension at higher energies. The instantaneous spectrum is computed and the characteristic spiky temporal structure is reproduced. The GRB fluence is normalized at BATSE energy: all the simulated bursts have fluences between 10^{-7} and $10^{-5} erg/cm^2$ between 25 keV and 1 MeV. In a further step the software samples photon energies above a fixed threshold (typically 20 MeV) from the instantaneous spectrum. These photons are then processed by the Montecarlo. Figure 1 represents the light curve (left) and the integrated spectrum (right) for a typical GRB simulated by the GLAST GRB physical model.

2 Trigger and Alert algorithms

Several groups within the LAT collaboration are prototyping trigger and alert algorithms for detecting transient signals in DC1 data, and different algorithms have been studied. The idea of the **rate trigger** is simple: GRB are short phenomena in time and their flux is higher than the flux coming from the gamma background. The rate trigger detects a transient if the differential flux exceeds a fixed threshold. We compute the count rate by fixing a window of M events:

$$R_j = \frac{M}{t_{M(j+1)} - t_{Mj}}, \quad (1)$$

where $t_{i \in [0,N]}$ is the temporal series of N events ($j \in [0, N/M]$). The first panel of Figure 2 shows the count rate for the simulated day for the entire field of view. The periodic oscillations are due to the scanning motion of the satellite across the galactic plane. The most intense GRBs ($time \sim 3000$, 43000, 71000, 75000, 83000) are visible in the time history. The differential count rate is the quantity $R_{j+1} - R_j$ and it is shown in the second panel of Figure 2 with $M = 200$. The long period oscillations are not yet visible while short transient phenomena are enhanced by the differential operator. The third panel of Figure 2 represents the histogram of the differential count rate. The gamma background photons make up the exponential distribution, while Gamma Ray Bursts, for which the differential count rate is high, are the "outliers" of this distribution. This method is efficient for bright GRBs, for which the flux exceeds the background flux, while faint bursts, for which the flux is comparable to the gamma background, may not be triggered. An efficient improvement of the rate trigger is the **segmentation of the sky** in different regions where the rate trigger is successively applied. There are two ways for dividing the sky, depending on which coordinate system one chooses, the galactic coordinate system or the instrument system. The main difference between the two is that, the non stationarity of the background due to the orbital motion can be reflected as false trigger if the instrument coordinate system is chosen. A more interesting and complete scheme will be studied when background charged particles also will be introduced as Data Challenge source. Another algorithm has been developed by the GRB science team. The **Strawman GRB tracker trigger algorithm** makes maximal use of the unbinned photon data coming into the GRB buffer to form probabilities from the temporal and spatial information. A sliding window approach is used: a window of N_{range} photons is moved by N_{move}. The $N \times (N-1)$ distances on the sphere between the N_{range} photons are computed. Each of the N_{range} photons is considered the potential nucleus of a spatial cluster and the cluster with the smallest average distance for the retained photons is selected. For this cluster the chance spatial and temporal probabilities are computed. In particular, if R is the count rate, the joint log probability (JLP) is:

$$JLP = \sum \log_{10}[(1 - \cos(d_i))/2] + \sum \log_{10}[1 - (1 + R\Delta t_j)\exp(-R\Delta t_j)] \quad (2)$$

Figure 3 shows the evolution of the Joint Log Probability with time.

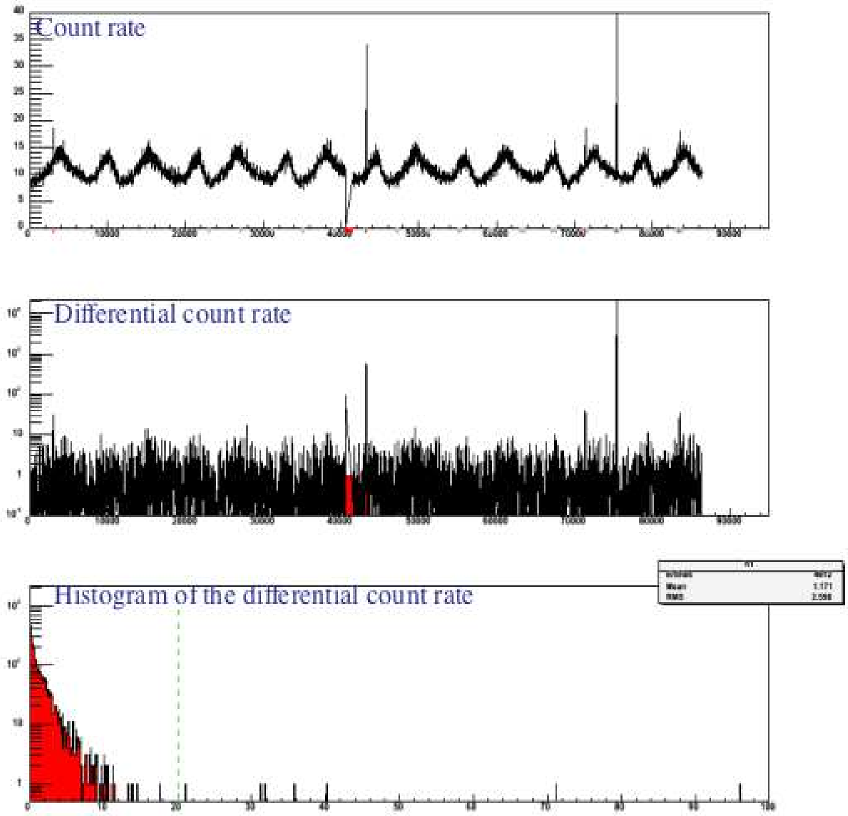

Figure 2: Top: count rate for the simulated day of the DC1 for the entire f.o.v. Middle: differential count rate. Bottom: histogram of the differential count rate. GRB are the outliers of the distribution.

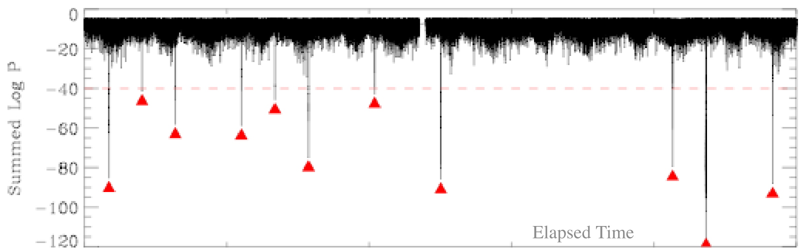

Figure 3: Temporal evolution of the joint log probability. Triangles are triggered bursts.

Algorithm	Trigger/Generated
Rate Trigger	7/21
Rate Trigger in Inst. coord.	10/21
Rate Trigger in Gal. coord.	10/21
Strawman trigger Alg.	11/21

Table 1: Ratio between the triggered and the generated GRBs.

3 Results and conclusions

Different algorithms have been successfully applied for searching for transient signals in DC1 data. The general results are summarized in Tab.1. Bright bursts (with fluence greater than $10^{-5} erg/cm^2$ between 20 kev and 1 MeV) can be detected with simple and trivial algorithms. More sophisticated algorithms have to be developed for detecting faint GRBs. The segmentation of the sky into sub-regions gave good results, maintaining the algorithm easy and the execution fast. The best results in terms of triggered GRBs were obtained using the Strawman GRB tracker trigger algorithm, based on the joint log probability. Further studies will include the particle background, and the possibility to implement an on-board LAT alert algorithm. All of these items will be addressed for the next Data Challenge (DC2), in which one month of simulated data will be produced.

References

[1] R. Bellazzini et al., Nucl. Phys. B (Proc. Suppl.) 113 (2002) 303, 309

[2] P. Boinee et al., (2003), (astro-ph/0308120)

[3] T. Piran, Physics Reports 314 (1999) 575, 667 (astro-ph/9810256)

[4] http://www.pi.infn.it/∼omodei/GRBSimulator/GRBSimulation.html

[5] http://glast.stanford.edu/cgi-bin/cvsweb/SLAC/GRB/