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Gamma Ray Bursts and Data Challenge One: Searching GRB in one week of simulated GLAST LAT data(*)

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Summary. — GLAST (Gamma-ray Large Area Space Telescope) is a gamma-ray astronomy mission that will be launched in mid 2007. The main instrument is the LAT (Large Area Telescope), a pair conversion telescope with sensitivity in the range 20 MeV–300 GeV. Data Challenge One (DC1) was the simulation of one week of observation of the entire gamma-ray sky by the LAT detector. The simulated data was similar to the real data, which allowed for the development of scientific software. In this paper we present the GRB simulations and the detection algorithms developed by the GLAST GRB and Solar Flare Science Team.

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1. – Introduction

The Large Area Telescope (LAT), the main detector onboard the GLAST satellite, will observe the sky between 20 MeV and 300 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

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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 Monte Carlo based on Geant4 tool [3]. 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), organized by the LAT Collaboration from December 2003 to February 2004, represented the first opportunity to test the complete simulation chain, and the first attempt to perform scientific analyses on simulated data.

2. – The description of the sky and the Gamma-Ray Burst models

For DC1, only the gamma-ray sky was simulated, while the cosmic-ray flux (about 10^4 times greater) was modeled separately for development of the background rejection algorithms. These algorithms were then applied to the simulated gamma-ray data. The gamma-ray sky simulated for DC1 was quite rich: a variety of sources was included. The simulation software takes into account the relative fluxes and computes from which source the next photon arrives. Two different simulators for GRBs were developed for Data Challenge purposes. One is based on the physical fireball model [4] and was used for simulating bursts during the first day of the DC1, the other is based on extrapolating BATSE results to LAT energy band. The physical model [8] starts from the ejection of shells with different velocities by the GRB engine. 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 of the synchrotron photons is the natural extension to 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 $10^{-5}\,\mathrm{erg/cm^2}$ between 25 keV and 1 MeV. The phenomenological model is based instead on the observations of GRB made mainly by the BATSE detector. An empirical description for the spectral shape and for the pulse shape is provided. Norris *et al.* [5] introduced a phenomenological description for the pulse shape of GRBs in the BATSE domain. They performed a series of temporal fits on BATSE bursts, fitting the observed pulse profiles with an empirical pulse shape. The distribution of the fitted pulse profiles is adopted. The spectral function introduced by Band *et al.* [6] has proved to be a robust description of the GRB observed emission between a few keV and a few MeV. The spectral evolution is based on the analysis by Preece *et al.* [7] that presented a catalogue of 156 bright bursts from the BATSE catalogue using high energy resolution data (covering an energy range between 28 keV to 1800 keV). They fitted a series of time resolved spectra using different spectral shapes and derived the evolution of spectral parameters adopted in the phenomenolgical model. The spectral shape and the pulse shape are indeed parameterized functions, which can be used as fitting functions for BATSE data. In particular, each pulse of each lightcurve is fitted, and several spectra for each burst were fitted. Distributions of the parameters were calculated from the best fit values. The distributions can now be used for sampling random parameters, and a simulated burst signal can be obtained. The phenomenological model, which well describes the BATSE observation, is extrapolated to LAT energies to obtain the expected GRB properties at high energy.

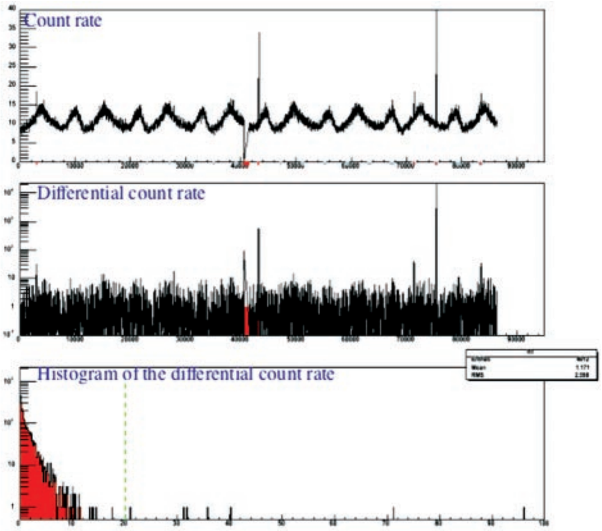

Fig. 1. – Top: count rate for the first simulated day of the DC1 for the entire f.o.v. Middle: differential count rate. Bottom: histogram of the differential count rate. GRB are the outliers of the distribution.

3. – 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 were studied. The idea of the *rate trigger* is simple: the GRB flux must be greater than the expected fluctuations of the background rate. We compute the count rate by fixing a window of M events:

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

where $t_{i\in[0,N]}$ is the temporal series of N events ($j \in [0, N/M]$).

The first panel of fig. 1 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 in the first simulated day 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 fig. 1 with $M = 200$. The long period oscillations are not visible while short transient phenomena are enhanced by the differential operator. The rate trigger detects a transient if the differential count rate exceeds a fixed threshold. The third panel of fig. 1 represents the histogram of the differential count rate. Gamma Ray Bursts 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 results in a false trigger when a GRB falls in two regions defined

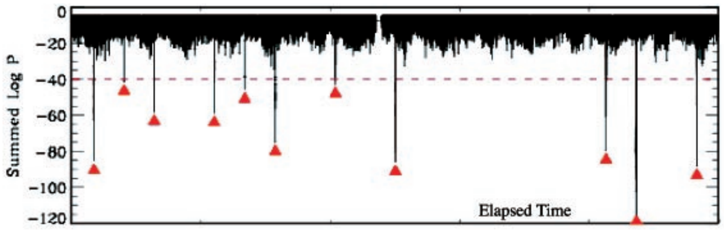

Fig. 2. – Temporal evolution of the joint log probability. Triangles are triggered bursts.

by the instrument coordinate system. A more interesting and complete scheme will be studied when background charged particles also will be introduced as Data Challenge source. Another algorithm was developed by the GRB science team. The *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

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

Figure 2 shows the evolution of the Joint Log Probability with time.

4. – Results and conclusions

Different algorithms were successfully applied for searching for transient signals in DC1 data. Bright bursts (with fluence greater than $10^{-5}\,\mathrm{erg/cm^2}$ 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 gives good results; the code implementing the algorithm is easy to maintain and runs fast. The best results in terms of triggered GRBs were obtained using the GRB tracker trigger algorithm which detected all the GRB generated within the LAT field of view. The Rate Trigger missed only 1 burst when the segmentation of the sky into sub-regions was applied. 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.

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