SLAC-PUB-10286
astro-ph/0312337
December 2003

Analysis of Burst Observations by GLAST's LAT Detector

David L. Band*, Seth W. Digel†, the GLAST LAT Collaboration** and the GLAST Science Support Center (GSSC)*

*Code 661, NASA/Goddard Space Flight Center, Greenbelt, MD 20771
†Stanford University, Stanford, CA
**NASA-DOE-International Collaboration

Abstract. Analyzing data from GLAST's Large Area Telescope (LAT) will require sophisticated techniques. The PSF and effective area are functions of both photon energy and the position in the field-of-view. During most of the mission the observatory will survey the sky continuously and thus the LAT will detect each count from a source at a different detector orientation; each count requires its own response function! The likelihood as a function of celestial position and photon energy will be the foundation of the standard analysis techniques. However the 20 MeV–300 GeV emission at the time of the $\sim$100 keV burst emission (timescale of $\sim$10 s) can be isolated and analyzed because essentially no non-burst counts are expected within a PSF radius of the burst location during the burst. Both binned and unbinned (in energy) spectral fitting will be possible. Longer timescale afterglow emission will require the likelihood analysis that will be used for persistent sources.

INTRODUCTION

The detection of the high energy emission from gamma-ray bursts is anticipated to be one of the spectacular observations by the Gamma-ray Large Area Space Telescope (GLAST), NASA's next general gamma-ray astrophysics mission. Scheduled to be launched into low Earth orbit in February, 2007, for 5–10 years of operation, GLAST will consist of two instruments: the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM).

A product of a NASA/DOE/international collaboration, the LAT builds on the success of *CGRO*'s EGRET. The LAT will be a pair conversion telescope: gamma rays will pair-produce in tungsten foils; silicon strip detectors will track the resulting pairs; the resulting particles will deposit energy in a CsI calorimeter; and an anticoincidence detector will veto charged particles. The anticoincidence detector will be segmented to limit the self-vetoing that plagued EGRET. The LAT will be 1.8 m$\times$1.8 m$\times$1m, and weigh $\sim$3000 kg.

The astrophysical photons will be only a small fraction of the total number of events detected by the LAT, most of which will result from charged particles. On board filtering of the events will reduce the $\sim$4 kHz trigger rate to the $\sim$30 Hz event rate that can be downlinked to the ground; ground processing will result in a $\sim$2 Hz photon rate.

The salient detector characteristics are: energy range of $<$20 MeV to $>$300 GeV; 1–10 GeV effective area of $>$8000 cm^2 with half maximum at 55°; angular resolution of $< 3.5^\circ$ at 100 MeV, $< 0.15^\circ$ at 10 GeV; field-of-view of $>$2 sr; deadtime $\sim 20\mu$s per

Work supported in part by the Department of Energy contract DE-AC03-76SF00515.

event (current, $< 100\mu$s required); and time resolution of $\sim 2\mu$s.

A descendant of CGRO's BATSE, the GBM will detect gamma-ray bursts and extend GLAST's burst spectral sensitivity to the $<$10 keV to $>$25 MeV band. Consisting of 12 NaI(Tl) (10–1000 keV) and 2 BGO (0.15–25 MeV) detectors, the GBM will monitor $>$8 sr of the sky, including the LAT's field-of-view (FOV). Bursts will be localized to $< 15^\circ$ (1σ) by comparing the rates in different detectors.

Typically GLAST will survey the sky continuously. After a $\sim$ 60 day checkout phase, GLAST will undertake a one year sky survey while the LAT team calibrates the instrument. In survey mode GLAST will rock $\sim 35^\circ$ above and below the orbital plane about the zenith direction once per orbit. While pointed observations proposed by guest investigators will be feasible during subsequent years, continued survey mode operation will usually be most efficient, and is expected to predominate. Therefore most persistent sources will be observed at a variety of detector orientations; each count will be characterized by a different response function.

Both the GBM and the LAT will have burst triggers. The GBM will notify the LAT when it triggers. When either instrument triggers, a notice with a preliminary localization will be sent immediately to the ground through TDRSS and will then be disseminated by GCN. Additional data will be downlinked through TDRSS for an improved localization at the Mission Operations Center. Both Instrument Operations Centers will calculate "final" positions from the full downlinked data. GCN will disseminate all positions.

The LAT will determine whether the burst was intense enough for a followup 5 hour pointed observation at the burst location (interrupted by earth occultations). The threshold will be higher for bursts the GBM detected outside the LAT's FOV.

STANDARD SOURCE ANALYSIS

The LAT PSF is large ($\sim 3.5^\circ$) at low energy ($\sim$100 MeV), small ($< 0.15^\circ$) at high energy ($\sim$10 GeV). With the LAT's large effective area, many sources will be detected; their PSFs will merge at low energy. Therefore the analysis must be 3 dimensional—2 spatial and 1 spectral—and time is an additional dimension for variable sources. Diffuse emission underlies the point sources. For a typical analysis the source model must include: all point sources within a few PSF lengths of the region of interest; extended sources (e.g., supernova remnants); spatially variable diffuse Galactic emission (which must be modeled); and isotropic extragalactic emission. Sources are defined by positions, spectra, and perhaps time histories. Initial values may be extracted from the point source catalog the LAT team will compile. Consequently the source model will have many parameters. In an analysis some will be fitted, some will be fixed.

The instrument response (PSF, effective area, energy resolution) will at least be a function of energy and angle to the LAT normal; other parameters may be relevant such as the azimuthal angle around the LAT normal or the conversion layer (the front or back of the LAT). Since the LAT will usually survey the sky, a source will be observed at different instrument orientations. Each count will be characterized by many observables, and therefore a very large data space results. Even with 10^5 counts, this data space will be sparsely populated. Note that what high energy astrophysicists call a "count" is a "photon" to some particle physicists.

As was the case for EGRET[1] and earlier gamma-ray missions[2], likelihoods will be the foundation of our analyses (e.g., detecting sources, determining source intensities, fitting spectral parameters, setting upper limits). The likelihood is the probability of the data (the counts that were detected) given the model (the photon sources). The data consist of both the counts that were detected, and the regions of data space where counts were not observed. The calculation of the likelihood will be difficult because many counts will sparsely populate an enormous data space.

The likelihood will be calculated many times as the source model is changed (for example in fitting source parameters), and factors that are not model-dependent should be calculated once for a given analysis. Many of these quantities will have units of "exposure" (area$\times$time).

BURST SPECTRAL ANALYSIS

The duration of the $\sim$100 keV burst emission is (relatively) short—at most 10's of seconds. Therefore, the LAT's pointing will not change significantly during the burst, and all the counts can be treated as having one response function. Within a PSF radius of the burst position less than one non-burst count per minute is expected: [$\sim$2 Hz cts over the FOV] / [2 sr FOV] $\times$ [$\pi(3.5^\circ\pi/180)^2$ sr within PSF radius] = $\sim$0.01 Hz cts within a PSF radius or 0.7 cts/minute within a PSF radius. Therefore, we can treat all counts within 1–2 PSF radii as burst photons.

Since a) all the counts within a PSF radius of the burst originated in the burst, and b) all the counts have the same response function, multi-source spatial analysis is unnecessary for spectral analysis! Spatial analysis might be necessary for localizing the burst. All the counts within a PSF radius and within a time range can be binned into a count spectrum (apparent energy is the single dimension), and traditional spectral analysis can be applied to the resulting series of LAT count spectra. The GBM data (also a list of counts) can be binned with the same time binning, and then joint fits can be performed.

The afterglow will most likely produce a small number of counts accumulated over timescales of tens of minutes to hours. Thus afterglow data must be analyzed with the general likelihood tool being developed for LAT data analysis.

The LAT team and the GLAST Science Support Center (GSSC) are developing a suite of tools to analyze both LAT and GBM data. These tools will use the HEAdas system supported on both Windows and LINUX platforms; most of the tools will be FTOOLS. Therefore the data will be in FITS files, and the tools will use IRAF-style parameter files. Here we describe the methodology for burst spectral analysis.

Extract LAT Counts: The user will extract the LAT counts from a specified time and region (here a circle around the burst position) from a GSSC database. The web-based extraction tool will return a FITS file with the requested counts and a second FITS file describing the instrument's pointing and livetime during the burst. Users will have a tool to perform further selections.

Extract GBM Counts: The GSSC will provide GBM counts in a FITS file. Users will fit polynomial (in time) background models to data before and after the burst.

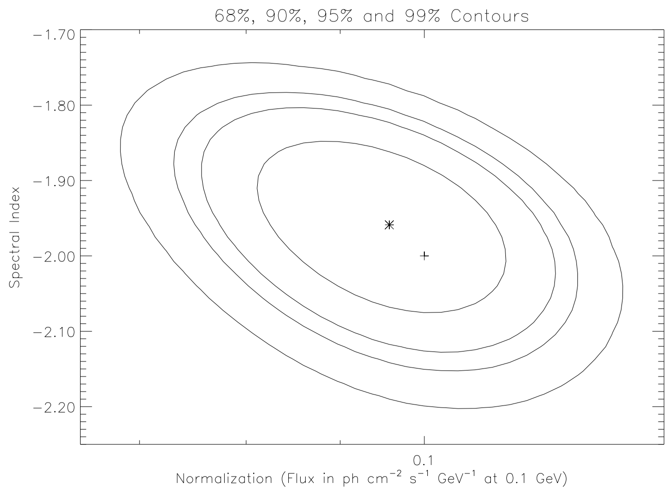

FIGURE 1. Confidence region for a sample power law LAT count spectrum with 115 counts. The asterisk marks the likelihood maximum and the cross the input parameters.

Bin Counts: An event binning tool will bin the LAT or GBM counts in both energy and time, resulting in a series of count spectra spanning the burst. The energy grid will be user specified. The time bins may be a) equally spaced, b) user specified, c) chosen to have equal signal-to-noise ratios in a user-specified energy band, or d) chosen by Bayesian Blocks[3]. The LAT counts are assumed to have no background, while the expected GBM background in each bin will be calculated from the background model.

DRM Generation: The LAT response function will be collapsed into a Detector Response Matrix (DRM), the product of the effective area at the position of the burst and the energy redistribution matrix. The effective area will account for the size of the region from which the counts were extracted. GBM DRMs will be supplied for each burst, and users will have a tool to calculate their own GBM DRMs.

Spectral Fitting—Binned Spectra: The spectra can be fit using XSPEC, with scripts automating the fitting of series of spectra. Spectra from the LAT, GBM and other missions (e.g., Swift) may be fit separately or jointly. Of course, the relative calibration of the different instruments will have to be understood. The XSPEC team is adding the capability of saving the results of the spectral fitting, along with the model spectra.

Spectral Fitting—Spectra Unbinned in Energy: For a burst with few counts a likelihood treatment using a variant of the standard likelihood tool may be more powerful; see Fig. 1. In this case the likelihood function will be calculated for the apparent energy of LAT counts accumulated over a time period of interest. Assuming the LAT spectrum is an extrapolation to higher energy of the GBM-observed spectrum, the GBM spectral fits can be used as priors on the LAT parameters.

REFERENCES

1. Mattox, J., et al. 1996, ApJ, 461, 396
2. Pollock, A., et al. 1981, A&A, 94, 116

3. Scargle, J. 1998, ApJ, 504, 405