The Standard Analysis Environment for GLAST's LAT Detector

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The Mission

The **G**amma-ray **L**arge **A**rea **S**pace **T**elescope (GLAST) is the next NASA gamma-ray astrophysics mission, which is scheduled to be launched into low Earth orbit in September, 2007, for 5-10 years of operation. To learn more about GLAST see:

Mission overview: 24.05—Ritz et al.
Large Area Telescope (LAT):
- **Tracker:** 24.04—Johnson et al.
- **Calorimeter:** 24.08—Strickman et al.
- **Anti-Coincidence Detector:** 24.02—Hartman et al.
- **Instrument Integration:** 24.03—Grove et al.

GLAST Burst Monitor (GBM): 24.06—Kouveliotou et al.
Multiwavelength planning: 24.07—Thompson et al.
User support:
- **The GLAST Science Support Center (GSSC):** 24.10—Stephens et al.
- **Serving Data to the Community:** 34.07—Horner et al.
- **The Analysis Software:** THIS POSTER!

What You Need to Know

Large Field-of-View (FOV)—The LAT will detect photons that can be used in data analysis (=counts) up to ~66º off-axis! The effective area decreases off-axis, but the solid angle increases, and therefore a large fraction of the data will be taken off-axis. The GBM will detect bursts down to the Earth's limb.

Scanning Will Predominate—While GLAST can point at individual sources, there will rarely be any advantage because of the LAT's large FOV. Usually GLAST will rock ~35° above and below the orbital plane once per orbit for uniform sky coverage. Figure 1 shows the time-varying angle between a source and the LAT normal.

Energy-Dependent Point Spread Function (PSF)—The LAT's PSF will be ~3.5º at 100 MeV, <0.15º at 10 GeV (68% containment radius) with significant tails that will decrease as a power law with radius.

Bright Astrophysical Background—LAT sources will be observed against a bright spatially varying Galactic and isotropic Extragalactic diffuse background. GBM bursts will be detected against a substantial background count rate.

Low Count Rate—The average LAT count rate from astrophysical sources (including the background) will be 2-3 counts/s.

Consequence for Data Analysis: Most persistent sources will be observed by the LAT at a variety of detector orientations; each count must be analyzed using the response function appropriate for the detector orientation when the count was detected. Counts from different sources, including the diffuse background, will often overlap.

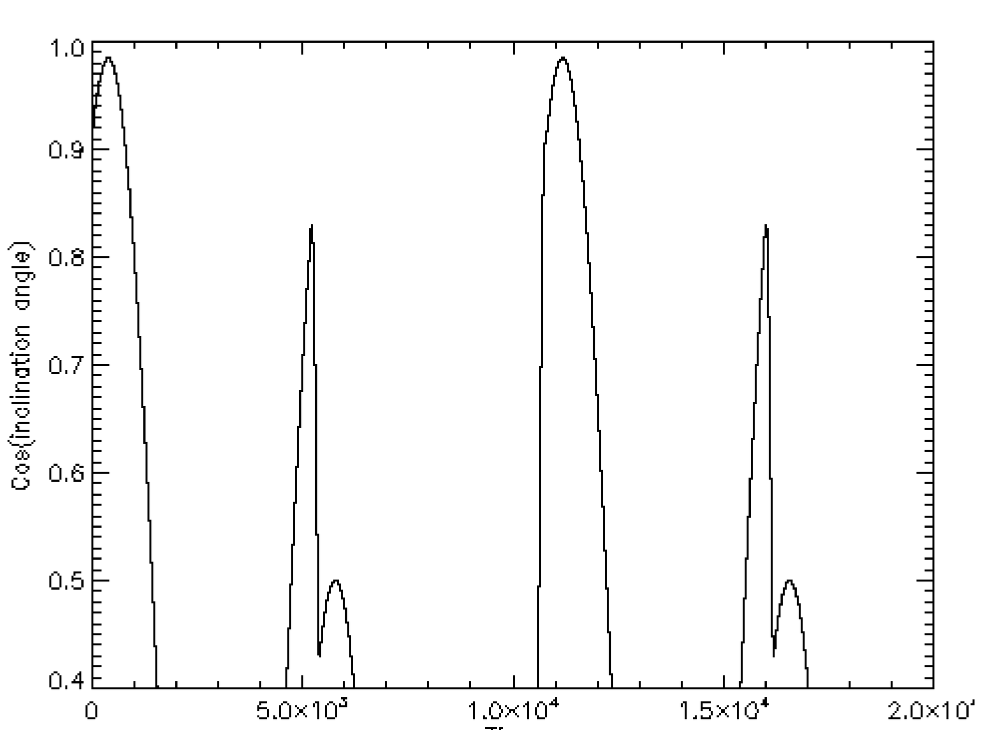

Figure 1—Variation of the cosine of the angle between the LAT normal and a source 25º from the orbital plane. The abrupt changes result from slews between the two rocking angles. Data from cos(LAT normal angle)>0.4 will be used. Approximately 4 orbits are shown.

Software Nitty-Gritty

The new tools that the mission will provide to analyze GLAST data are called the "Standard Analysis Environment" (SAE). The software, data, documentation and technical assistance will all be available through the GSSC website (http://glast.gsfc.nasa.gov/SSC/). Information provided here is relevant to the user community unaffiliated with the instrument teams.

Scope—The SAE is for the analysis of counts that have already been reconstructed from the raw data and classified as resulting from photons. The LAT instrument team will perform the reconstruction and classification. Similarly, the GBM team will assign energies to the counts from their detectors. While the SAE is being developed primarily for the LAT data, it will be capable of analyzing GBM burst data.

FTOOLS—The SAE will be standard FTOOLS. A GUI interface will also be provided. Generic FTOOLS utilities can be used on the GLAST data files.

Software Source—During the early part of the mission the SAE will be downloaded from the GSSC website; later in the mission the SAE will be downloaded with other FTOOLS from the HEASARC website. As with all FTOOLs, a script will install the software; source code will also be available.

Data Source—GLAST data will be downloaded from the HEASARC's BROWSE interface; links will be provided from the GSSC website.

Simulation Capabilities—Users will be able to simulate an observation; the simulated data can then be analyzed using the SAE tools.

Documentation—The GSSC website will provide online and printable manuals:
- Installation manual
- Reference manual—description of all the inputs to each tool
- Analysis threads—step-by-step examples of standard analyses
- Detailed manual—includes the methodology implemented in each tool

Technical Support—Provided by the GSSC through an online helpdesk (http://glast.gsfc.nasa.gov/ssc/help/)

Summary

Analyzing data from GLAST's Large Area Telescope (LAT) will require sophisticated techniques. Because GLAST will scan the sky continuously during most of the mission, each LAT count from a given source will be detected at a different detector orientation in the LAT's large field-of-view. Sources cannot be analyzed in isolation because the point source function (PSF) is large (68% of the counts within 3.5º) at low energy (~100 MeV) and near-by sources will overlap; at high energy (e.g., 10 GeV) the PSF is much smaller. The analysis of pulsars and gamma-ray bursts will be simplified by their temporal signatures.

The Data

"Photon list"—A list of the LAT counts (=detected photons) from a specified time and spatial range. Each count is characterized by the quantities necessary to specify the instrument response for that count, such as time, energy, and apparent direction. Note that the GBM's fundamental data type is also a list of counts.

Pointing/Livetime History—The orientation of the LAT, the livetime rate, and spacecraft position sampled every 30 s.

Additional Data—Data such as a model of the diffuse background, ephemerides of pulsars that might be detectable by the LAT, in addition to instrument response data, will also be provided.

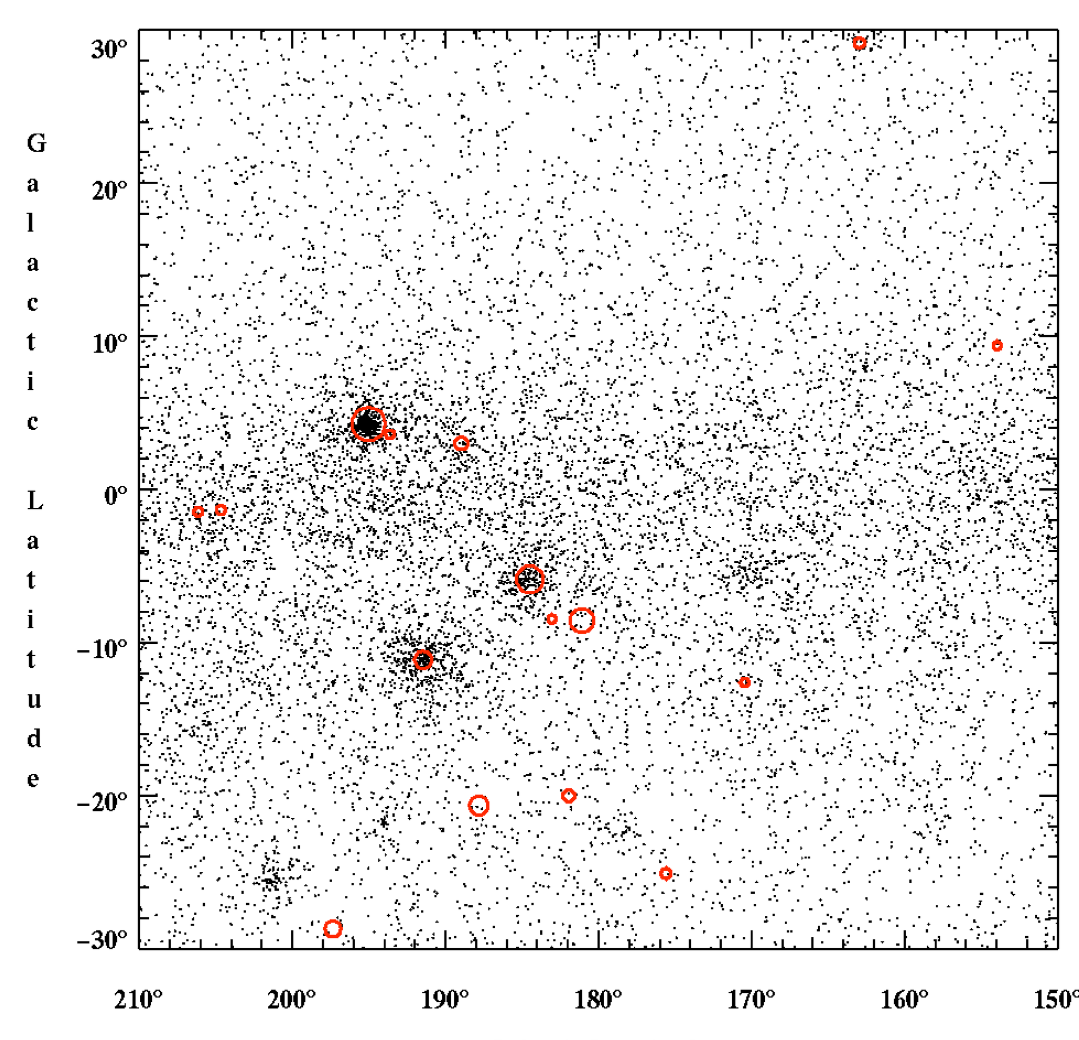

Figure2—One day's worth of simulated LAT survey data for a large region about the Galactic anticenter. The model of the celestial sky included Galactic and extragalactic diffuse, pulsars, blazars, and other sources. All 11,600 gamma rays >100 MeV are plotted. The red circles mark the positions of sources with fluxes $>2\_10^{-7}$ cm^{-2} s^{-1} in the 3rd EGRET catalog, with size related to flux.

Standard Source Analysis

With the LAT's large effective area, many sources will be detected; their PSFs will merge at low energy (see Figure 2). Since the counts might originate from one of several sources (including the diffuse background), the analysis must be 3 dimensional: 2 spatial and 1 spectral (and time must be an additional dimension if the source is not persistent). For a typical analysis the source model must include: all point sources within a few PSF radii of the region of interest; diffuse sources (e.g., supernova remnants); diffuse spatially variable Galactic emission (which must be modeled); and diffuse isotropic extragalactic emission. Sources are defined by position, spectra, and perhaps time history. Initial values may be extracted from the point source catalog that will be compiled by the LAT team. 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 the very 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, the e^+e^- conversion layer (the front or back of the LAT), or the vertex angle between the electron-positron pair. Since the LAT will usually survey the sky, a source will be observed at different instrument orientations. The observables for a count are: apparent energy; apparent origin (2 observables); time; front vs. back of the LAT; and perhaps other detailed information from the Tracker (e.g., the vertex angle between the electron-positron pair). Therefore, a very large data space results. Even with 10^5 counts, this data space will be sparsely populated.

Likelihoods are 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 parameter space where counts were not observed. Evaluating the likelihood proceeds by breaking the space into bins, and calculating the probability of the detected counts in each bin; either finite or infinitesimal size bins can be used.

The likelihood will be calculated many times as parameter values are varied, 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×time).

A comparison of the likelihood for different models (e.g., with and without an additional point source) will indicate which model is preferred. The best-fit model parameters and their confidence regions will be calculated from the likelihood as a function of the model parameters.

The GLAST likelihood tools include the basic likelihood tool, a tool that calculates the exposure (i.e., the quantities that need only be calculated once for a given analysis), a model definition tool and post-processing tools.

Special Cases

A complex likelihood calculation is required to analyze the standard LAT observation because the typical count may result from one of a number of point sources in addition to the diffuse background. The likelihood methodology considers the probability that the count originated from each possible source. However, in a number of cases a temporal signal identifies the count's origin.

Gamma-Ray Bursts

The duration of the ~100 keV burst emission is (relatively) short—at most 10's of seconds. Therefore, effectively the LAT's pointing will not change significantly during the burst. This means that all the photons can be treated as having one response function.

Within a PSF radius of the burst position less than one non-burst photon per minute is expected. Therefore, we can treat all photons within 1-2 PSF radii as burst photons.

Multi-source, spatial analysis is unnecessary for spectral analysis because: a) all the counts in the PSF centered on the burst originate in the burst, and b) all the counts have the same response function. Spatial analysis will be necessary for localizing the burst and to study afterglows that linger for tens of minutes. All the photons within the PSF and within a time range during the burst can be binned into a count spectrum (apparent energy is the single dimension), and the techniques of traditional spectral analysis (e.g., using XSPEC) 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.

GLAST burst tools calculate the LAT and GBM response functions for one dimensional spectral analysis (e.g., the RSP files used by XSPEC), and bin event lists (both LAT and GBM) into binned spectra (e.g., the PHA files used by XSPEC). A temporal analysis tool is also being developed.

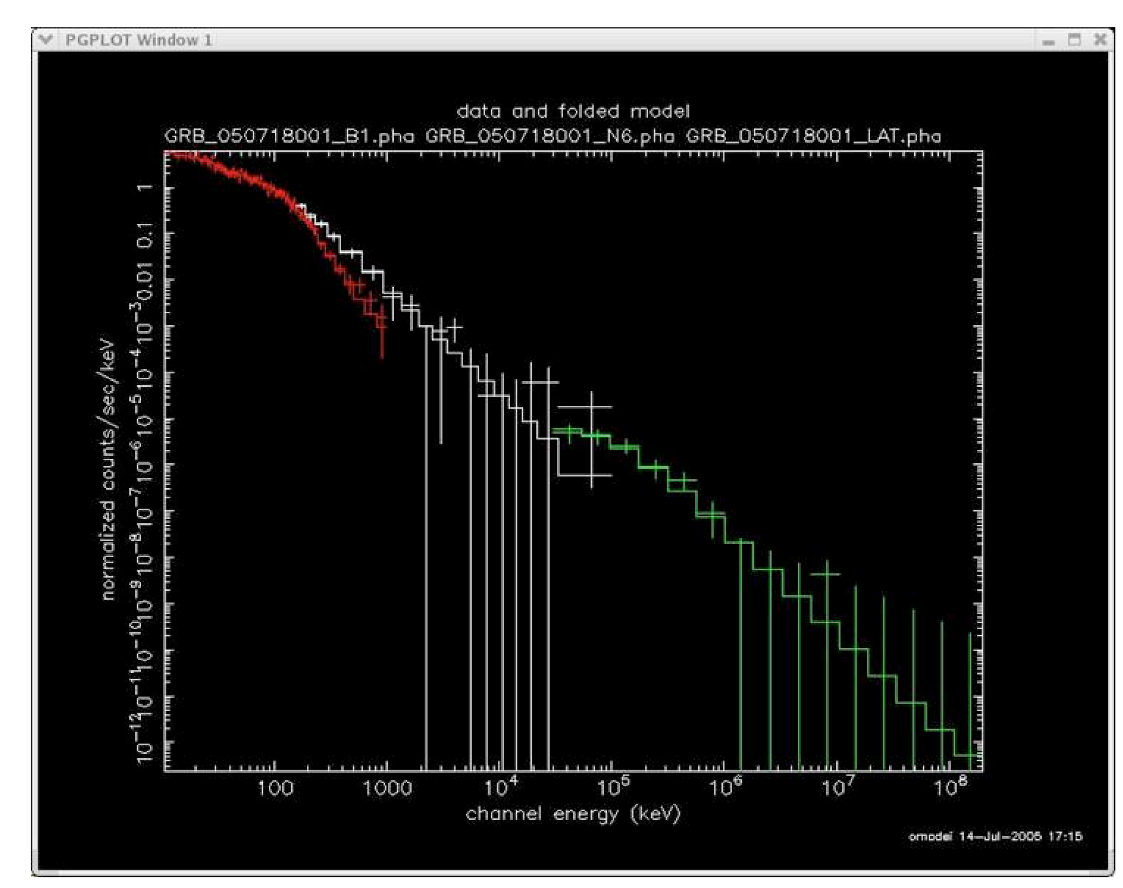

Figure 3—XSPEC joint fit to a simulated GBM and LAT burst spectrum.

Pulsars

The detection of pulsations will confirm the presence of a pulsar; this is the first goal of any pulsar analysis, and the first analysis step is purely temporal. The counts from the vicinity of a point source suspected of being a pulsar are accumulated into a count list, which is investigated for evidence of pulsations.

The low count rate from LAT-observed sources poses a challenging data analysis problem. Even from the Crab pulsar a count is recorded only once every ~500 pulses. The period-derivative matters over the timescale necessary to accumulate enough counts to determine the ephemeris, and therefore a blind search must include both the period and period-derivative (or frequency and frequency-derivative). In addition, the pulsar may 'glitch' over these long timescales.

In most cases the analyst will consider a candidate pulsar with a known ephemeris—radio astronomers associated with the GLAST mission will monitor dozens of radio pulsars that may have high gamma-ray pulsed emission. The SAE includes a tool for a limited search around the period and period-derivative of the candidate pulsar (see Figure 4).

Once the ephemeris has been determined, the pulse profile can be plotted after assigning pulse phases to each count. The standard likelihood analysis can be applied to counts from different pulse phases to determine the pulse fraction, and to resolve the temporal evolution of the spectrum.

GLAST pulsar tools perform: barycentric correction for each count, pulse phase assignment, and limited ephemeris search.

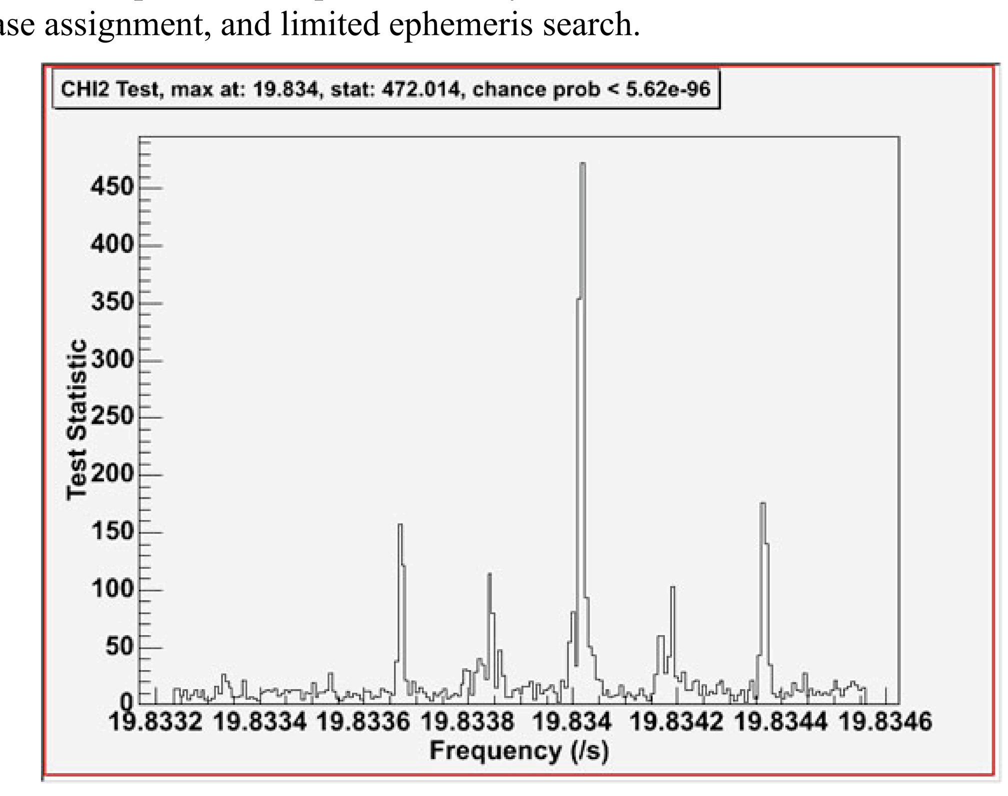

Figure 4—Result of a limited period search for simulated pulsar data.