GRB Simulations, Triggers and Alerts: Purposes and Requirements

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June 23, 2002

A. Overview

B. Simulations
Purposes
Simulation Attributes, and Priorities
Requirements for GRB Simulations from Observations
Extant GRB Simulation Packages
Planned Modifications for GRB Simulations

C. Triggers
Requirements/Constraints for LAT GRB Trigger Algorithm
Strawman LAT Trigger Algorithm
Plans for Refined LAT Trigger Approaches

D. Alerts
GBM Actions and Alert
LAT-useful GBM Information, and LAT Alert Message
Plans for LAT Alerts

A. Overview

The general goal is to generate theoretical GRB models which self-consistently reproduce all observed GRB temporal-spectral behavior across the combined GBM-LAT energy regime. Inputs from longer-wavelength observations and analysis provide us with other constraints. Likewise, gamma-ray observations influence the holistic pursuit and understanding of the phenomenon.

In fact, as for much of GLAST science, the gamma-ray band is special for GRBs since the goal of comprehending the mechanism of the central engine can be profitably pursued only with gamma-ray observations. Optical and X-ray observations contribute in this regard, but only in as much as they help determine average burst properties such as total energy release, or help constrain the progenitor class. With the GBM and the LAT we are in good shape to pursue the goal of studying the central engine.

Also, the low-energy gamma-ray band (10's to 100's of keV) is the best portion of the spectrum for signaling a GRB alert. Whereas – depending on the specific fluence and spectral hardness of a given burst – the GBM or the LAT may produce the more precise localization. Regardless, generation of the best localizations is another part that GLAST must play to enable the synergetic science with ground observations.

GRB simulations spanning the GBM+LAT energy bands are the entree to all aspects of the tasks at hand, the first of which are devising an on-board implementable strategy for the LAT trigger and for alert contents. Calculations would suffice for gauging some aspects of the trigger. But detailed aspects – calibrating burst trigger timescale, digging out photons belonging to low-fluence bursts and deciding on a set of on-board filters for the LAT – are really best developed using synthetic burst profiles with energy dependence.

The same burst simulations used for trigger and alert considerations will allow us to develop and test thoroughly the GRB analysis modules.

B. Simulations

Purposes. From the Overview we see that the purposes of GRB simulations include at least the following:

(a) to produce LAT-detected GRB gamma sets for input to trigger and alert algorithms
(b) to make predictions for the LAT distribution of on-board localization error regions – necessary for ground follow-up campaign;
(c) to tailor standard sets of filter cuts for GRBs, on-board and on the ground;
(d) to encourage development of realistic physical models, that will be tested by combined GBM+LAT data;
(e) to test the GRB science analysis tools.

Simulation Attributes, and Priorities. For a work plan, it helps to think through which attributes of bursts need to be well simulated for each purpose, and when each purpose needs to be achieved.

(a) For LAT trigger and alert algorithms: considerations of flight SW development make these tasks the highest priority. Duration and fluence distributions need to be incorporated into simulations for this stage. The (extrapolated) details of burst temporal and spectral development at LAT energies are necessary for simulating the distribution of trigger intervals measured from burst onset – something that will interest GLAST flight SW people and ground follow-up observers.
(b) For on-board localizations: fluence and spectral distributions are required.
(c) For development of special sets of filters for GRBs: fluence and spectral distributions at least are required. Since the LAT filters may employ temporal information (at least, in ground SW) – self-generated and from the GBM – full-up simulations are required.
(d) For physical models: full-up simulations are required, but models will be developed and refined over a few years.
(e) For GRB science analysis tools: full-up simulations are required, based both on physical models to be tested and on observations extrapolated from lower energies. The timescale to have working, formal analysis tools in place is ~ 3 years.

Since some aspects of the highest priority, presumably near-term tasks (a, b & c) will benefit from full-up simulations of burst temporal-spectral development, it only makes sense to engage in a high-fidelity simulation plan from the start.

For the purposes of assisting development of flight SW algorithms, we are already close enough on GRB simulations to make definite plans for finalizing a first working simulation package.

First, let us examine what we know about distributions of observed attributes for GRBs at gamma-ray energies, and decide which attributes are critical to reproduce within simulations in the near term, which can be refined easily, and which should be produced in the long term within physical models.

Requirements for GRB Simulations from Observations. Synthetic bursts that mimic BATSE-detected bursts are easily produced by drawing from distributions of observed parameters measured at energies ~ 25 keV – 1 MeV. Extrapolation of burst time profiles to GLAST energies benefits from spectral trends determined at BATSE energies, and from spectral indices measured by EGRET. But we keep in mind that still, these are large extrapolations – a factor of up to 10^3 in energy, goint from 1 MeV to 1 GeV – and therefore not much can be said definitively about short timescale behavior of GRBs at the highest observed energies, due to EGRET's deadtime of ~ 100 ms.

Distributions of several GRB attributes or average properties have been measured with varying degrees of accuracy for the necessary parameters. All but item (6) below are incorporated into the "GRBmaker" modules that make synthetic GRBs.

(1) duration distribution – measurement procedure follows brightness-independent analysis of Bonnell & Norris (1997 ApJ, 490, 79), using nearly complete catalog of BATSE bursts

(2) peak-flux distribution – patterned after Pendleton et al. (measurements: Bonnell & Norris, unpublished)

(3) flux normalization at EGRET energy – extrapolated from Preece et al. (ApJS 2000, 126, 19) spectral catalog distribution to GLAST energies, and compared with EGRET burst data

(4) β (upper index of Band model) spectral power-law index – from Preece et al.

(5) distribution of number of pulses per burst – N_{pulses} from Norris et al. (ApJ 1996, 459, 393)

(6) distribution of intervals between pulses – not implemented (but see Norris et al.)

(7) width of pulse as a function of energy – taken as $W_{pulse} \propto E^{-1/3}$ (from Norris et al.)

(8) rise/decay pulse ratio – implemented as $W_{rise}/W_{decay} = 0.4 \pm 0.1$ (from Norris et al.)

(9) pulse peak shift as a function of energy – implemented as $\tau_{peak} = ½W_{rise}$ (from Norris et al.)

(10) N bursts per year – $N_{GRBs} \approx 667$ bursts yr^{-1} full sky (Paciesas et al. 1999 ApJS, 122, 465)

In GRBmaker the parameters β, W_{pulse}, W_{rise}/W_{decay}, and τ_{peak} are approximated as uniform per burst for expediency. For W_{pulse} and the latter two related quantities, there have been qualitative remarks in the literature suggesting self-similarity of pulse shape within a given burst.

Attributes (1–4 and 10) are required to match burst fluence and spectral properties, which are relevant for the GLAST detection rate. Attributes (5–7) are necessary for achieving some fidelity of temporal appearance, and thus for the trigger business. Attributes (8 and 9) are niceties, and their effects are negligible for all flight SW issues.

It is worth noting that as we proceed through temporal attributes (5–9), the characterizations from BATSE observations become progressively less dependable (very approximately speaking) at GLAST energies.

Extant GRB Simulation Packages. Two LAT GRB simulation codes exist: one based on observations and extrapolations, “GRBmaker” (Jay Norris and Jerry Bonnell); and one based on the physical model of colliding pairs of (shocked) shells, “GRBsim” (Nicola Omodei et al.).

A third expedient for simulations is to utilize BATSE time profiles, with signal and background (and possibly energy response) appropriately scaled for the GBM. While this approach is exactly relevant for the GBM energy regime, to make the analytic continuation of temporal-spectral development for a given burst up to LAT energies would be tantamount to what GRBmaker does. (The pulse attributes used in GRBmaker were gotten from burst analysis of apparently separable pulses in bright BATSE bursts.)

Nevertheless, for the purpose of exploring trigger threshold questions, a simple IDL code was implemented that performs the necessary signal and background rescaling from BATSE bursts (JPN). This code could be used to address various questions relevant to the GBM. Of course the rescaling procedure is simplicity itself and is easily implemented by anyone.

Planned Modifications for GRB Simulations. The general plan is to integrate the C++ modules for GRBsim and GRBmaker into as common an environment as profitable, so the two approaches can share code easily. Where necessary the coding style, etc. of the attributes' distribution modules of GRBmaker may need to be adapted so that GRBsim can make use of them as appropriate (e.g., distributions in duration, peak-flux, spectral index, and number of pulses per burst).

To exercise GBM-LAT combined analysis tools, the GRB simulations should be extended to include the GBM energy range. In principle, GRBmaker works across the whole energy range with the change of a single parameter value (E_{min}), and can make fluences consistent with the requirement for illuminating GBM modules by simple modification of the flux normalization scheme. Then a single burst's temporal-spectral behavior could be simulated across the combined GBM-LAT energy band with minimal augmentations to GRBmaker.

At GBM energies, large numbers of photons will be generated for some bursts. At classical GRB energies, detection is usually performed for binned rates, rather than photon by photon as with the LAT. The binned (in energy and time) incident photon rates are multiplied by a detector response matrix (DRM: photons to counts) to produce binned detector count rates. The science analysis SW which performs these energy matrix manipulations is part of the GBM SW suite. (Bringing together the LAT and GBM detected photons is a still incompletely conceived part of the GLAST GRB analysis suite.) A supplementary approach is to simulate the GBM detectors and process their detected photons within GLEAM.

The detailed tasks necessary to achieve fully utilizable GRB simulation packages for purposes (a–c) are described in a separate GRB Science Team document, **GRB_WorkPlan_020621** (first version: June 21, 2002).

C. Triggers

Requirements/Constraints for LAT GRB Trigger Algorithm. First, the GRB trigger must be implementable in LAT flight SW. The trigger mechanism is by definition real-time, considering each LAT event as it arises. Essentially, the trigger should do something like the following: perform spatial cuts on the LAT event stream and look for significant temporal/spatial "clusters" (the spectral information is embodied in the spatial dimensions via the LAT PSF). Thus, the trigger must somehow bootstrap itself, assembling mutually reinforcing probabilities from the temporal and spatial domains and comparing against the changing LAT background. The trigger will utilize event directions provided by the on-board (~ minimal) track reconstruction algorithm.

Also, the LAT trigger mechanism is independent of the GBM trigger – no GBM information is conveyed to the LAT unless there is already a GBM trigger, in which case the LAT *assumes* that it is time to consider generating an alert to the ground. GBM information may then influence the portion of alert content coming from the LAT (see next section, **D. Alerts**).

Note that the current plan envisions the GBM producing a trigger when 2 or more detectors' count rates exceed ~ 4.5 σ above background (in some canonical energy band, ~ 40 – 300 keV).

Strawman LAT Trigger Algorithm. A simple algorithm was coded in IDL (December 1999) as an existence proof that the LAT could easily trigger on bursts (on the GRB/SF website, under "Other Contributions," see description under "Strawman GRB Tracker Trigger"). Most synthetic bursts made by the IDL forerunner of GRBmaker were easily detected, assuming a ~ 4 Hz residual background. This on-board rate might have been realistically achievable in the old days with plenty of flight SW capacity, but nowadays we should assume that ~ 30 Hz background obtains for simulation purposes. The IDL trigger algorithm searched a sliding event window for spatial clusters in the distances between pairs of LAT events. The tightest event cluster and their associated times provided the input to a crude likelihood algorithm. Exceeding an adjustable threshold signals a trigger. The trick is to minimize triggers from statistical fluctuations and maximize GRB detections. For the LAT trigger, a false alarm rate significantly lower than the GBM's trigger rate seems reasonable, since the GBM sees legitimate (non-GRB) flaring sources, and larger fractional background fluctuations that are not experienced by the LAT. The total GBM trigger rate is predicted to be ~ 1 event / day (~ 25% non-GRB).

Plans for Refined LAT Trigger Approaches. Discussions so far have centered on dividing the implementation of a refined trigger algorithm into the two apparent parts: spatial and temporal. Also, it would be good to have the old strawman algorithm working, and evaluate its efficacy as a benchmark, using newly generated synthetic bursts. The work to define an optimal GRB LAT trigger algorithm is also described in **GRB_WorkPlan_020621** .

D. Alerts

GBM Actions and Alert. The GBM issues a "one-bit" indication over a dedicated wire to the LAT that a trigger has occurred, within ~ 5 ms of the GBM trigger time. Within ~ 2 s a first, coarse on-board localization is generated, available to the LAT via the S/C. Information is provided via TDRS to the ground for an on-ground accurate computation (~ once) of the GRB localization, on a timescale of minutes after the GRB trigger. With burst in progress, on-board GBM localizations continue to be recomputed and made available to the LAT, all via the S/C. At > 30 s, the GBM issues a recommendation to the LAT on the advisability of repointing the S/C in order to orient the LAT towards the GRB direction; the LAT must decide whether or not repointing appears to be scientifically advantageous (e.g., for a sufficiently bright burst that was not originally in the LAT FOV). For reference, the required S/C slew rate is 75° / 10 minutes, with a goal of 75° / 5 minutes.

[Note: For ground follow-up observations, the minimum total time from GBM trigger to arrival of a GCN notice at a ground observatory is estimated as follows:

~ 2 s for first, coarse localization (but probably tens of seconds for a refined LAT localization)

~ 7 s to lock onto TDRRS
~ 7 s for GCN calculation and communications
~ 16 s total]

LAT-useful GBM Information, and LAT Alert Message. Any arrangements for the LAT to avail itself of particular pieces of GBM information are up to the LAT team to demonstrate (to itself) as necessary/useful. What kinds of information might be available and useful to the LAT? Currently the GBM alert information is envisioned to include, in addition to location: spectral, flux and fluence parameters, maximum burst rates and background rates, classification as GRB or non-GRB, and an evaluation that the burst is "short" (duration < 2 s) or not.

Any real-time GBM information that demonstrably enhances the LAT localization – which may be more accurate than the GBM localization in some cases – would be beneficial. While the LAT on-board localization will be computed using less-than-optimal tracker reconstruction, in the event of a sufficiently bright, spectrally hard burst, it may be possible to use a portion of the telemetry volume to send a small set of the highest energy photons detected from the burst to the ground, where a highly accurate LAT localization could be computed in near real-time. Whether the on-board computation using all burst photons, or a ground computation using ~ tens of photons would yield a significantly better localization – this is something we need to simulate.

For reference, a medium to large LAT event generates ~ 10 kbits of tracker telemetered data. Thus for instance, ten relatively high-energy LAT events would require ~ 100 seconds of TDRS link time @ 1 kbit s^{-1}. The TDRS time costs, but is in principle unlimited for an alert. The main issue then is LAT or GBM packet priority within the alert message. A second issue is the added complexity of flight SW necessary to include in the alert the event descriptions for a small set of LAT photons.

One issue for LAT alerts is how accurately can the photon energy be determined by the flight SW, i.e., for application to localization and spectral parameter measurement. Conversations with J.J. Russell and Mark Strickman illuminate our current understanding, which will need iterative updating in terms of what can/will flight SW do: Tracker information is very important below ~ 100 MeV. In the regime 50–100 MeV tracker energy deposition is predominant; combined calorimeter and tracker information results in ~ 30-20% energy resolution, but this is realized using the full reconstructive power of GLASTsim. In the regime 1 – few × 100 MeV, the calorimeter information dominates. Leakage is the dominant uncertainty at higher energies. What might be available on-board for energy estimation: total number of tracker hits in the thin and thick layers, and raw signals from the calorimeter crystal ends with some crude calibration possibly applied.

In principle, the LAT could make use of the GBM on-board localization to refine the LAT's on-board identification of GRB photons. This spatial information could improve the LAT's on-board localization. Similarly, the LAT photon identifications and localization might benefit from use of compressed GBM temporal information, such as the times of pulse peaks at relatively high GBM energies. Like other GBM burst parameters, such temporal information could be made available through the S/C interface. The specific algorithm utilizing GBM temporal information might be fine-tuned during the mission, as we gain knowledge about burst behavior (peak migration as a function of energy) at high energies.

Here are some obvious kinds of descriptors determined by the LAT which the alert message might include: trigger time and/or burst onset time; total estimated number of detected photons in the burst; spectral hardness or power-law index; burst duration. Each candidate measureable quantity needs to be mathematically defined, and justified – based on immediate usefulness in the alert to ground observers. Also, it would good to generate distributions of expected parameter errors for duration and spectral index, assuming the input parameter distributions as implemented in the simulations.

Plans for LAT Alerts. The work to consider alert questions and define useful LAT parameters to be included in an alert is described in **GRB_WorkPlan_020621** .