Planning for LAT Onboard GRB Trigger and Localization Algorithms

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Synopsis

- **The SRD states:** GRB localization accuracy on-board
  - Requirement (Goal) < 0.17° (0.05°), burst with > 100 γ's, E > 1 GeV

  And: Notification time to Spacecraft (from GRB detection time)
  - Requirement (Goal) < 5 sec (2 sec)

- **For comparison:** With full-up ground reconstruction we generate localizations with error radii <~ 0.05°, burst with > 10 γ's, E > 1 GeV.

  We expect to generate localization benchmarks for on-board algorithms using simulations done in parallel with DC2-level data.

- **Trigger and Localization Sequence:**
  - Send LAT event stream to GRB processor.
  - Apply additional filters, reduce background rate to ~ 30-60 Hz.
  - Run spatial/temporal sliding-window trigger/localization algorithms.
  - Option to utilize GBM trigger time and position to reduce windows.
  - Telemeter localization and other GRB information to ground.
  - Option to send short telemetry alert message containing 10 highest energy GRB events to ground for rapid full-up analysis.

Purpose, Outline of Issues

- **The purpose** is to implement an efficient and robust onboard LAT trigger for GRBs and an accurate localization procedure. Positional and other descriptive information generated by the algorithms are then telemetered as LAT GRB alert for use in afterglow searches.

- **Issues:**
  - Onboard computing capacity is finite and a fully detailed reconstruction is not feasible.
  - The immediate onboard particle/albedo background is too high at 300-500 Hz. Additional filters must be applied to the LAT event stream to reduce the rate to 30-60 Hz then sent to a GRB event buffer for real-time analysis.
  - Most of the ΩA_{eff} for GRB detection is off-axis, but onboard reconstruction degrades off-axis due to rudimentary algorithms. Hough Transform may help at high energy (see "Backups").
  - Just the few, highest energy gammas yield most of the localization accuracy — whereas low energy gammas provide the trigger for the event.

Details: Trigger, Localization Algorithms

- We have a prototype LAT trigger algorithm, demonstrated with background rates of 15-60 Hz over several years of simulations.
- An N-event sliding window is used as the first bootstrap step in searching for significant temporal-spatial clustering. We compute the Log {Joint (spatial*temporal) likelihood} for the tightest spatial cluster of events in the temporal sliding window:

$$\mathrm{Log(P)} = \Sigma\,\mathrm{Log}\{\,[1 - \cos(d_i)]\,/\,2\,\} + \Sigma\,\mathrm{Log}\{\,1 - \exp(-X_i)\,\}$$

- The Log(P) is measured against the near real-time background, and the trigger threshold is also set as a function of the background, such that few (none) false triggers occur and high GRB trigger efficiency is realized (events w/ 5-10 γ's detected). *Formal expectation* that any detection is false << 10^{-6}/day.
- The localization algorithm collects all events between the 1st and last window which trigger (within a time limit, ~ 30 s); computes an energy-weighted centroid. Probable particle events are ID'ed —by virtue of difference between actual and predicted distances from centroid—and then deweighted. Convergence: one iteration.

Background Reduction for GRB Event Buffer

- Complicating problem: Upwards moving albedo and low-energy cosmic γ's look very similar (Note: Low-energy γ's will be retained by the standard filters and sent for ground analysis within the ~ 300 Hz telemetry rate.)
- The upwards moving albedo is ~ 140 Hz, orientation-dependent — alone it is considerably higher than the rate (30-60 Hz) required for the trigger algorithm to function.
- David Wren has proposed two fairly successful methods for reducing the upwards moving albedo rate, to ~ 60 Hz, applying the methods only for events in outer towers AND with CalEnergySum = 0:
  - Method 1: require start of "3-in-a-row" to be an {X,Y} pair in the same layer, and be the uppermost hits of a track; OR
  - Method 2: if event comes from direction consistent with cone defined by Earth, then kill it.

Utilize GBM position in LAT Algorithms

- The background against which the LAT trigger will need to work is uncertain — we are still testing additional filters for onboard science.
- We could utilize the GBM position to reduce the background for the LAT trigger and localization algorithms.
  - Upon the initial ("one-bit") trigger signal from the GBM, preserve events going into the LAT GRB event buffer, and those events from a short preceding interval (since within the prompt GRB emission, higher energies tend to come earlier).
  - Utilize the forthcoming GBM position, narrowing the spatial and temporal windows considered by the LAT trigger and localization algorithms. Assuming a GBM positional error radius of 10° (2-3 σ), the Earth-unocculted sky background rate of 300-500 Hz would be reduced by a factor of 300/25000, to ~ 4-6 Hz (inside the GBM error region) — prior to additional filtering of GRB event stream.

Better Accuracy Obtained On Ground

- Alternatively, we could use the prompt GBM information to narrow the temporal and spatial windows searched by the LAT — sending the ~ 10 highest energy LAT events to the ground for "quicklook" analysis:
  - For those fluent bursts where we will obtain an ultimately small LAT error circle, the onboard GBM error circle will also be small — and background contamination in the onboard LAT error region will be low. Thus high energy LAT gammas from the burst will be more readily identified by benefit of the GBM information.
  - The LAT positional accuracy obtained with ground reconstruction will be significantly better at all photon energies than that obtainable onboard, even with the Hough transform approach.
- Lest we forget: The smallest possible LAT localization, delivered quickly to the community, means that larger ground-based telescopes can participate in afterglow searches at earlier epochs. Even past the Swift era, it is likely that spectroscopic redshifts will still be superior to "pseudo" redshifts (presently very immature) obtained from burst prompt emission properties. Know redshift → Know energetics.

Summary of Plans for LAT GRB Onboard Trigger/Localization Algorithms

- Onboard LAT trigger and localization algorithms, demonstrated over several years, work well assuming ground reconstruction accuracy and older estimates of background rates. We recommend consideration of three measures to counter (1) decreased recon accuracy onboard at high off-axis angles, and (2) higher than anticipated background:
  - Application of 2-3 additional filters to **reduce background**, beyond those to be employed on the general LAT event stream. Relevant additional filters have been partly proved out by Wren.
  - Use of the multiple-tower / Hough transform **improved reconstruction** for filtered events (good for high energy γ's).
  - If needed, upon the initial ("one-bit") trigger signal from the GBM, preserve events going into the LAT GRB event buffer. Then utilize the forthcoming GBM position to **reduce background** considered by the LAT trigger and localization algorithms.
- Alternative to Onboard LAT localization is sending the ~ 10 highest energy LAT photons to the ground for "quicklook" analysis. GBM information is required to narrow LAT event search windows.

Backups …

Postscript: DC1 Results

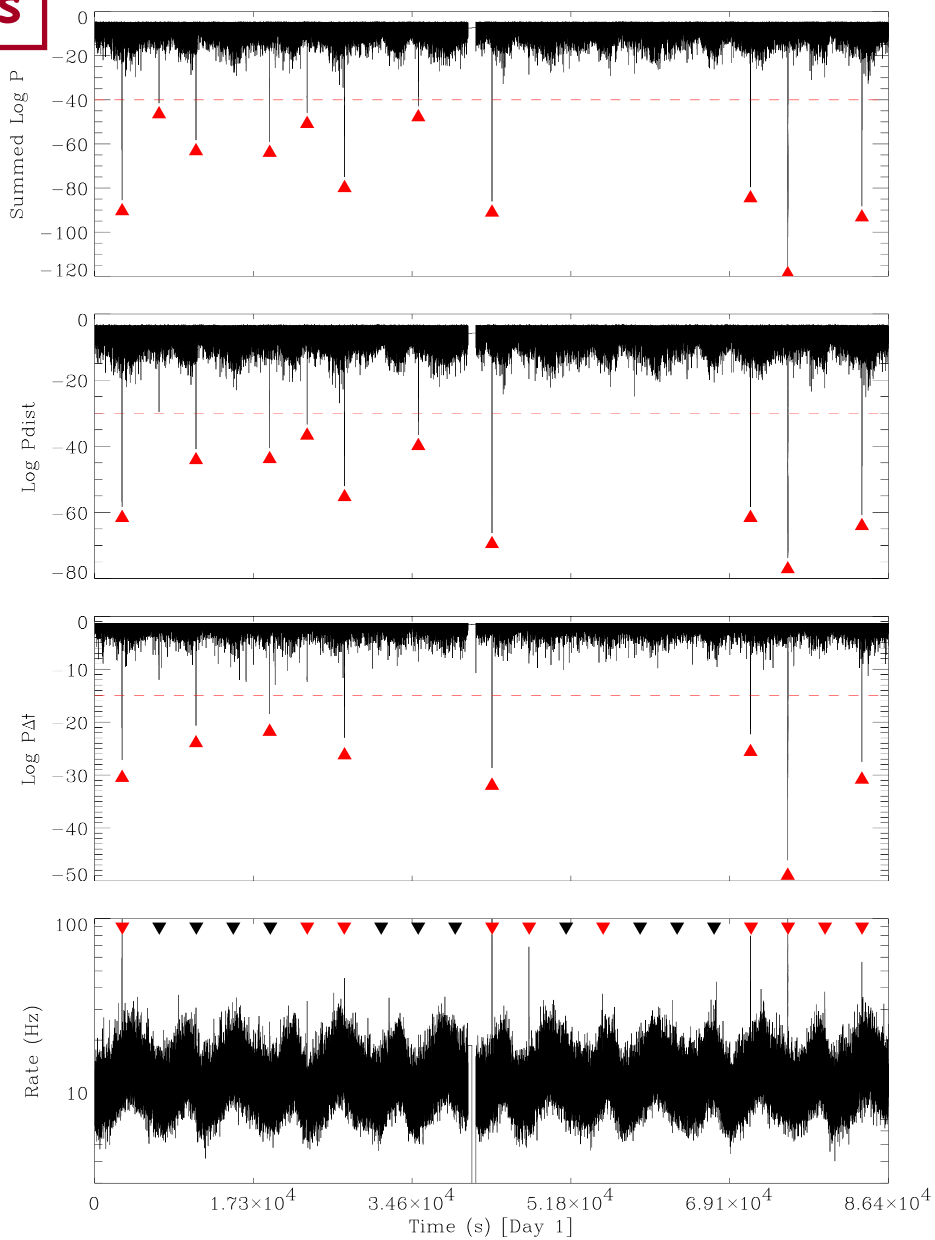
<u>Day 1 Triggers, Panels Top→Bottom</u>:

Log Prob [Δρ's] + Log Prob [Δt's]

Log Prob [Δρ's]

Log Prob [Δt's]

Raw Rate (includes non-recon'ed γ's
— but we don't use them!)



<u>Similar approach to previous studies</u>:

(1) Operate sliding 20-event window;

(2) Find tightest spatial cluster;

(3) Compute log probs for Δt's, Δρ's in the selected cluster;

(4) Exceed threshold value, set to allow < 1 false trigger/6 days?

Real Question is: How many "life-like" GRBs would be detected ?

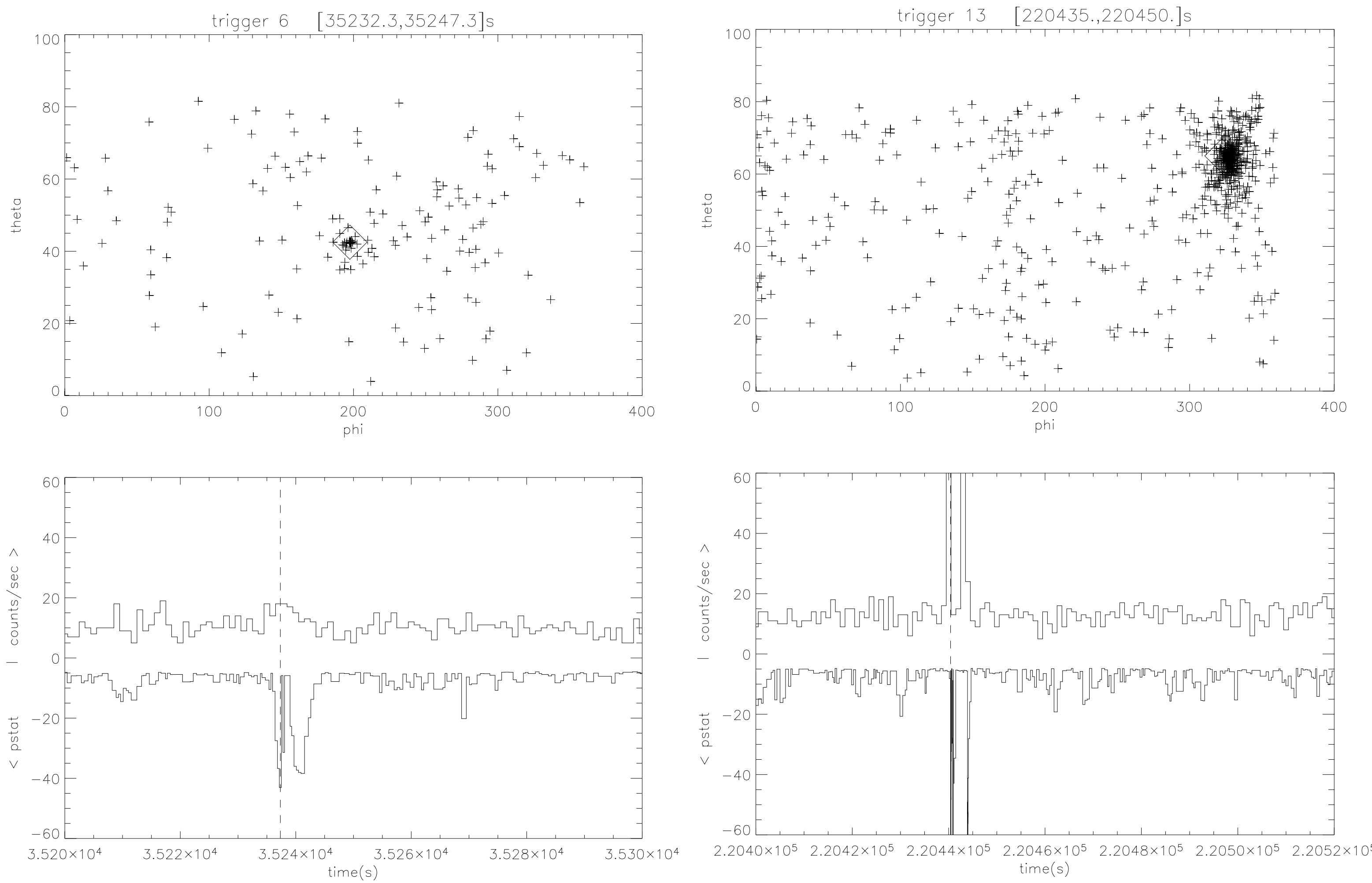
Days 2→6 Triggers

Estimates: Times, Positions, Integral Counts

T_{min}	T_{max}	{RA, Dec}	ε_{est}	ε_{act}	"$N\sigma$"	$N_{>10MeV}$	$N_{>100MeV}$	$N_{>1GeV}$
176748.2	176860.1	128.78, 64.31	0.029	0.026	0.90	1633	1521	135
215700.4	215740.7	251.61, 27.82	0.090	0.070	0.77	514	224	24
220440.4	220444.0	134.39, -2.81	0.052	0.131	2.52	329	309	32
327096.0	327096.0	319.80, 73.29	4.418	0.621	0.14	10	5	0
386280.7	386309.7	199.14, 33.45	0.346	0.165	0.48	58	26	1
410280.2	410313.4	236.71, 41.72	0.122	0.033	0.27	372	153	10

- Very sensitive trigger — incorporates most of the useful information.
- 17 detections: 11 on Day 1; 6 on Days 2-6. Some bright, some dim.
- No false trigger. *Formal expectation* any detection is false << 10^{-6}/day.
- Additional aspects we will evaluate for on-board implementation:
  - Floating threshold; 2-D PSF; spatial clustering (Galactic Plane)

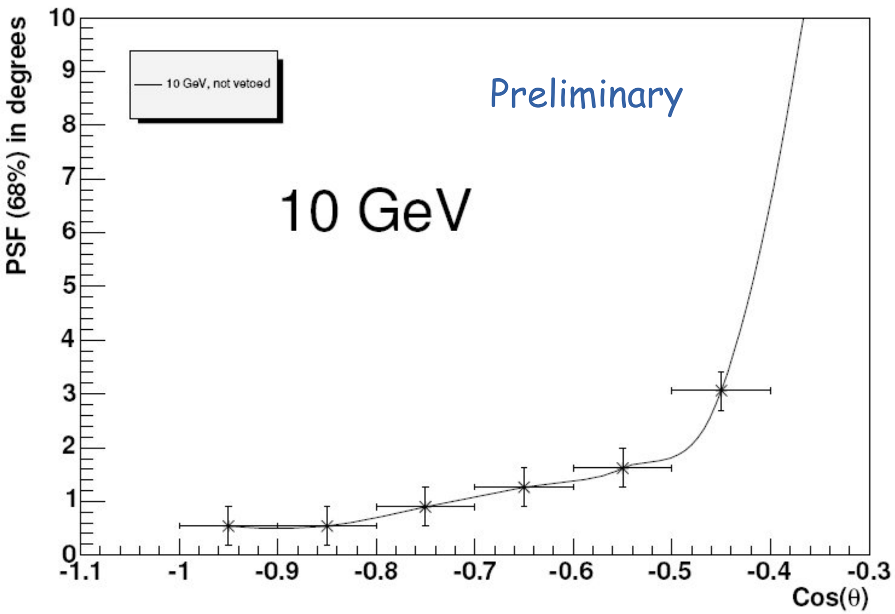
GRB Trigger regions



On-board Reconstruction Accuracy Problem

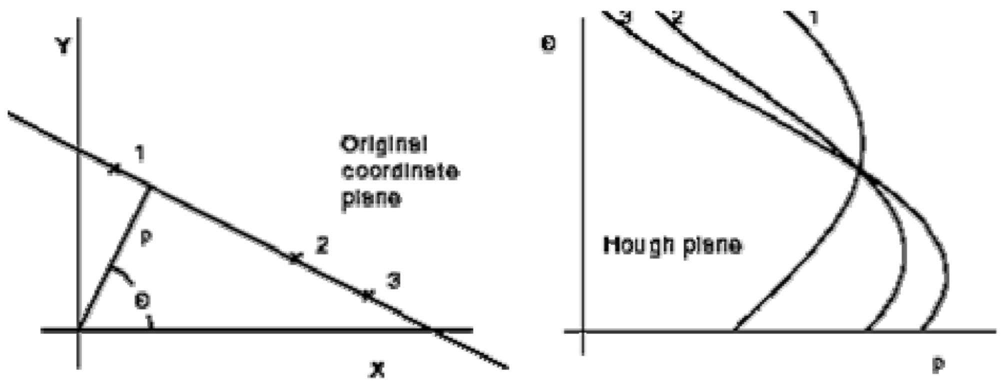
- Off-axis, where most of the LAT's ΩA_{eff} is, the reconstruction error increases. The figure below shows the 68% PSF vs. cos(θ) for 10 GeV γ's as reconstructed on-board, illustrating decreased accuracy off-axis (similar trend obtains at lower energies, where most GRB γ's are detected). — Compare to plots on slide 15, where use of Hough transform flattens PSF.

- The increased recon error off-axis results from the "track tower crossing" problem: Standard onboard recon considers towers in isolation. Hence, the uppermost hits required for a "3-in-a-row" trigger are often not in the same tower — the found "3-in-a-row" set will be lower in the 2nd tower, into which the track has crossed, and the attendant larger multiple scattering results in worse recon.



Hough Transform

- The basic idea:
  - Transform a coordinate in Cartesian space into a line in (rho, theta) parameter space.
  - Collinear points in Cartesian space have intersecting lines in parameter space
  - Pick out the point of intersection in parameter space, and one gets the line (track) in Cartesian space



David Wren 22

Promising approach being explored by Wren is the "Hough Transform," which picks out colinear hits in polar coordinate space —especially good at higher energies where tracks are straighter (tolerance for track curvature might need to be energy-dependent).

Hough Transform Improves Reconstruction

- The figures below show the 68% PSF obtained via multiple-tower, onboard recon with the Hough transform for 1 and 10 GeV gammas. This more complex reconstruction would need to be performed only on events sent to the GRB event buffer. The PSF via Hough transform is significantly flattened across cos(θ) for high energy events. Improved accuracy can be obtained with finer binning in polar coordinate space, at the expense of longer computation time for the transform.