Fermi-LAT Stacking Analysis of Swift Localized GRBs

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On behalf of the Fermi collaboration
Motivation

- GRBs in the LAT field of view detected >100 MeV: ~8%
  - 9.3 GRBs expected / yr > 10 photons > 100 MeV
  - 6.3 GRBs observed / yr > 10 photons > 100 MeV

- LAT upper limits of bright/hard GBM bursts indicate spectral steepening and/or cutoffs above > 50 MeV may be common

- Stacking high-energy spectra with power-law slopes may produce a detectable prompt signal >75 MeV, but high-energy spectra with an exponential cutoff may not

- Ubiquitous sub-threshold MeV-GeV extended emission may also produce a detectable stacked signal

- Evidence exists for a sub-threshold population at high off-axis angles
Sub-threshold Population

- Evidence exists for a sub-threshold population at high off-axis angles
- These bursts should be revealed in a stacking analysis
Method

- GBM localization errors are significant compared to the size of the LAT PSF, adding ambiguity to traditional likelihood and count stacking analysis.

- Swift localized GRBs have positional uncertainties that are insignificant compared to the LAT PSF.

- Counting Analysis
  - Compare photons near GRB trigger to an expected background signal.

- Composite Likelihood Analysis
  - Perform likelihood analysis on each source independently and add the likelihood profiles to produce a “composite” likelihood surface.

- Both methods have their strengths/limitations:
  - Counting analysis requires very good estimate of the background.
  - Likelihood analysis depends on templates to model the background.
Background Estimation

- Counting Analysis
  - Need a good estimate of the background for comparison
  - We want to compare our stacking results to those found by stacking the same Ra, Dec and Lat, Lon, but offset in time
  - Fermi returns to the same geomagnetic coordinates roughly every 30 sidereal orbits
  - Background sample is defined as the burst Ra and Dec, but offset by T0 - 30 sidereal orbits (~171915 sec)
  - Cannot use this background estimation for bursts with automated repoint requests!
    - ARR bursts tend to be the highest fluence GBM bursts
Background Orbit

T0 - 30 orbits

T0
Background Estimation

- Composite Likelihood
  - Background can be directly modeled
- Galactic Diffuse
  - A spatial and spectral template developed using tracers of interstellar gas
- Isotropic Diffuse
  - An empirical isotropic spectral template
- Known point sources
  - 2FGL catalog
Sample Selection & Analysis

- Sample Selection
  - Swift GRBs since launch: 369
  - Swift GRBs since launch in FOV: 121
  - Swift GRBs since launch in FOV with GTIs: 105
  - Swift GRBs since launch in FOV with GTIs, not detected: 80
  - Swift GRBs since launch in FOV with GTIs, not detected, no ARRs: 63

- Analysis Implementation
  - P7SOURCE_V6 class data
  - 75 MeV < E < 30 GeV, T0 to T0+1000s, 10 degree ROI
Counting Analysis Results

| Interval | Signal | Background | Significance |
|----------|--------|------------|--------------|
| T0+500   | 549    | 458        | 4.25σ        |

- Excess is maximized with T0+500, from 100 MeV < E < 30 GeV
- Does not include bursts with automated repoint requests (ARRs)!

Daniel Kocevski - Huntsville in Nashville GRB Symposium 2013
**Stacked Light Curve**

- Significant excess starting at T0+100s and lasting ~ 500s when comparing bursts to expected background (excluding ARR bursts)
Composite Likelihood

- Compute the likelihood that the observed photons are from known point sources and an assumed diffuse emission template

- Spatial clustering and/or arrival of multiple high energy of photons is improbable and stands out

- Compute the likelihood that these excess photons are due to point source at the co-aligned GRB positions with a given photon flux and spectral shape

- Coadd these likelihood surfaces and find the flux and index parameters that maximizes this composite likelihood profile

- The difference between the likelihoods with and without a point source at the co-aligned position gives you the test statistic (TS)

- We can include ARR bursts since we can model the background
Composite Likelihood Results

- Significant detection from T0 to T0+500s
  - GRBs: $TS = 36.1 \sim 6\sigma$
  - Background Orbits: $TS = 2 \sim < 1\sigma$
- Not significantly detected below 50s
- TS continues to increase well beyond T90
- Still detected out to T0+1000s
- Consistent with Lange & Pohl 2013
- 95% $\Delta$ Log-likelihood contours contains known GBM measured $\beta$ distribution

| Interval   | Best Fit Flux | Best Fit Index | TS  |
|------------|---------------|----------------|-----|
| T0+500s    | 1.29E-07      | -2.09          | 36.1|
Stacked Light Curve

- Likelihood TS continues to increase out to T0+1000s. ARR bursts must be contributing photons well beyond the bump at ~500s
Interpretation

- A stacking analysis of Fermi-LAT data of Swift localized GRBs reveals a population of bursts just below the LAT sensitivity.

- Significance of this detection increases with integration time, but no significant detection on prompt timescales (<50s)
  - Points to a possible extended emission origin to much of this emission

- Much of this emission may not be due to the extension of the prompt spectrum, but instead due to the interaction of the relativistic blast wave interacting with the ISM (e.g. GRB 110731)

- Steep spectra or high energy spectral turnovers could explain this lack of prompt emission above 75 MeV

- Future spectral fitting using LAT Low Energy (LLE) upper limits may shed further light on the nature of the prompt high energy spectra