Search for gravitational wave counterparts with *Fermi* GBM

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The progenitor of short gamma-ray bursts (GRBs) is believed to be the merger of two compact objects. This type of events will also produce gravitational waves. Since the gravitational waves discovery by LIGO, the search for a joint detection with an electromagnetic counterpart has been ongoing. *Fermi* GBM detects ~40 short GRBs per year, and we have been expanding our search looking for faint events in the GBM data that did not trigger onboard.

- The targeted search is a dedicated search for following up gravitational wave events, and is also capable for other multi-messenger and multi-wavelength follow up such as neutrinos.
- The untargeted search is a blind search aiming to double the detection rate of short GRBs by GBM.

Targeted Search

- Automated pipeline development for joint signals in GBM and LIGO. For observing run 1 [1], and updated for observing run 2 [2].
- Looks for coherent signals in all 14 detectors when given an input time and an optional sky map by calculating likelihood ratio of source and background.
- Search time window +/-30s of input event time, timescales from 0.256s to 8s (capable down to 0.064s).
- 3 source spectra using Band function: soft, normal, and hard.
- Upper bounds on impulsive gamma-ray emission can be calculated based on count rates in regions of the provided location probability map. See Figure 1 for example.

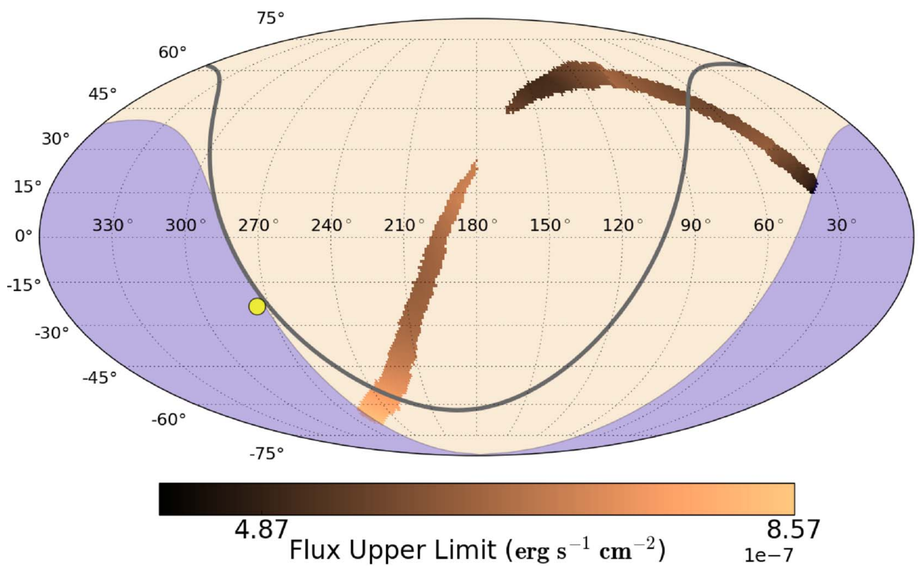


Figure 1. GBM 3σ flux upper limit to GW151226 at energies 10—1000keV, calculated from count rate integrated from +/-30s of the GW trigger time [4]. The spectrum is assumed to be a cutoff power-law fit with Epeak at 566 keV and a photon index of 0.42.

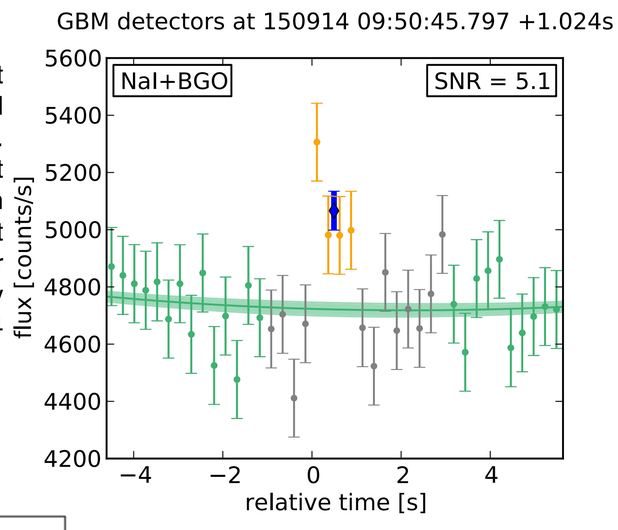


Figure 2. *Right*: Candidate gamma-ray event 0.4s after GW150914, with a duration of 1s and the hard spectral template is preferred. Localization with large contours but consistent with LIGO sky map. Signals were present in many GBM detectors and weak, consistent with a source underneath the spacecraft. After accounting for trials, the false alarm probability of this event being associated with GW150914 is 0.0022 (~3σ) [3].

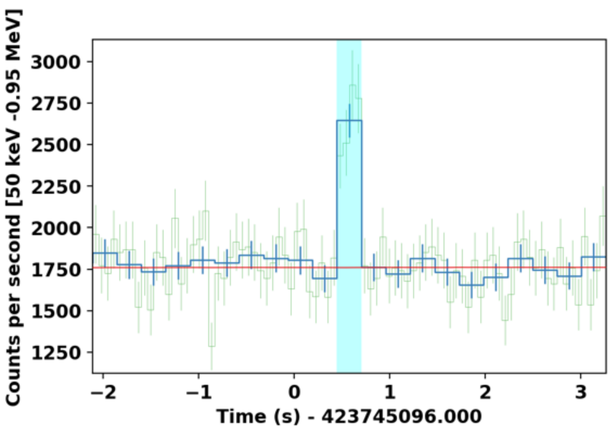
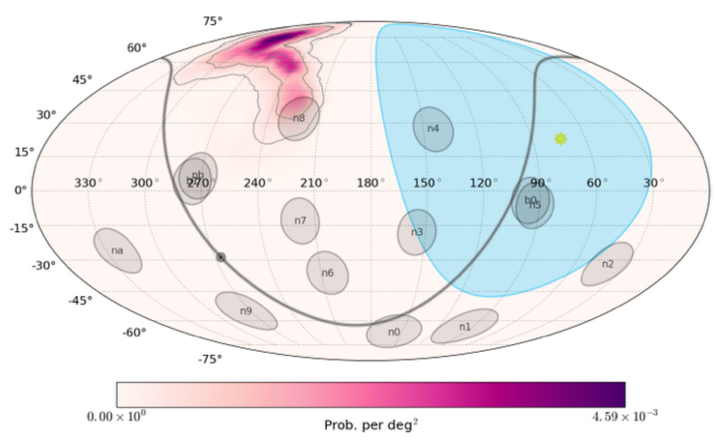


Figure 3. A targeted search candidate likely associated with Swift GRB 140606A, found at timescale 0.256s. *Above*: light curve with T0 as Swift trigger time. *Right:* localization of the candidate in equatorial coordinates. The black line and dot show the Galactic plane and center, blue shaded region is occulted by the Earth, yellow denotes the Sun. The FOV of each GBM detectors are also plotted in grey.



[1] Blackburn et al. ApJS 217, 8 (2015)
[2] Goldstein et al. arXiv:1612.02395
[3] Connaughton et al. ApJ 826, L6 (2016)
[4] Racusin et al. ApJ 835, 82 (2017)

Untargeted Search

- Looks for signals in 2 NaI detectors with 2.5σ and 1.25σ excess above background in the continuous time-tagged events (2μs resolution, 128 energy channels).
- The 2 signal detectors must have valid geometry for a point source.
- 18 timescales: 64ms to 32s.
- 4 energy ranges optimized for short GRBs.
  - 27—539 keV
  - 50—539 keV
  - 102—539 keV
  - 102—985 keV
- 1-day Poisson probability calculated for each event, threshold for notice is 1e-6.

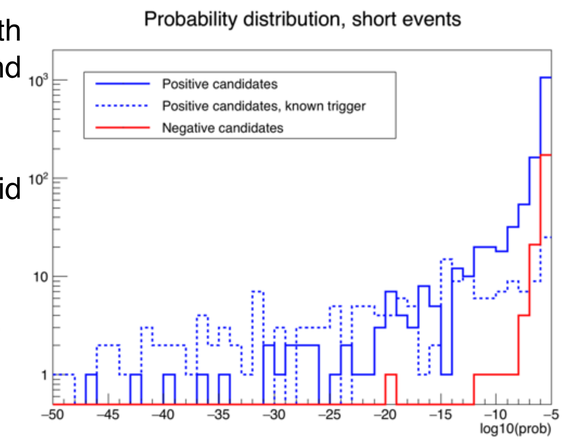


Figure 4. Probability distribution of ≦2.8s candidates found by the search in 30 months of data. Negative candidates are likely fluctuations and used for determining notice threshold.

- GCN notice type Fermi-GBM SubThreshold now available. http://gcn.gsfc.nasa.gov/gcn/fermi.html
- Localization FITS file, contour sky map, and lightcurve of each event are linked via the GCN notice.
- Expected rate of notice ~70/month, higher during active periods of galactic transients.
- Time delay for notice range from 0.5 to 6 hours, due to ground processing.
- List of candidates from older data (2013 and on) are available. http://gammaray.nsstc.nasa.gov/gbm/science/sgrb_search.html

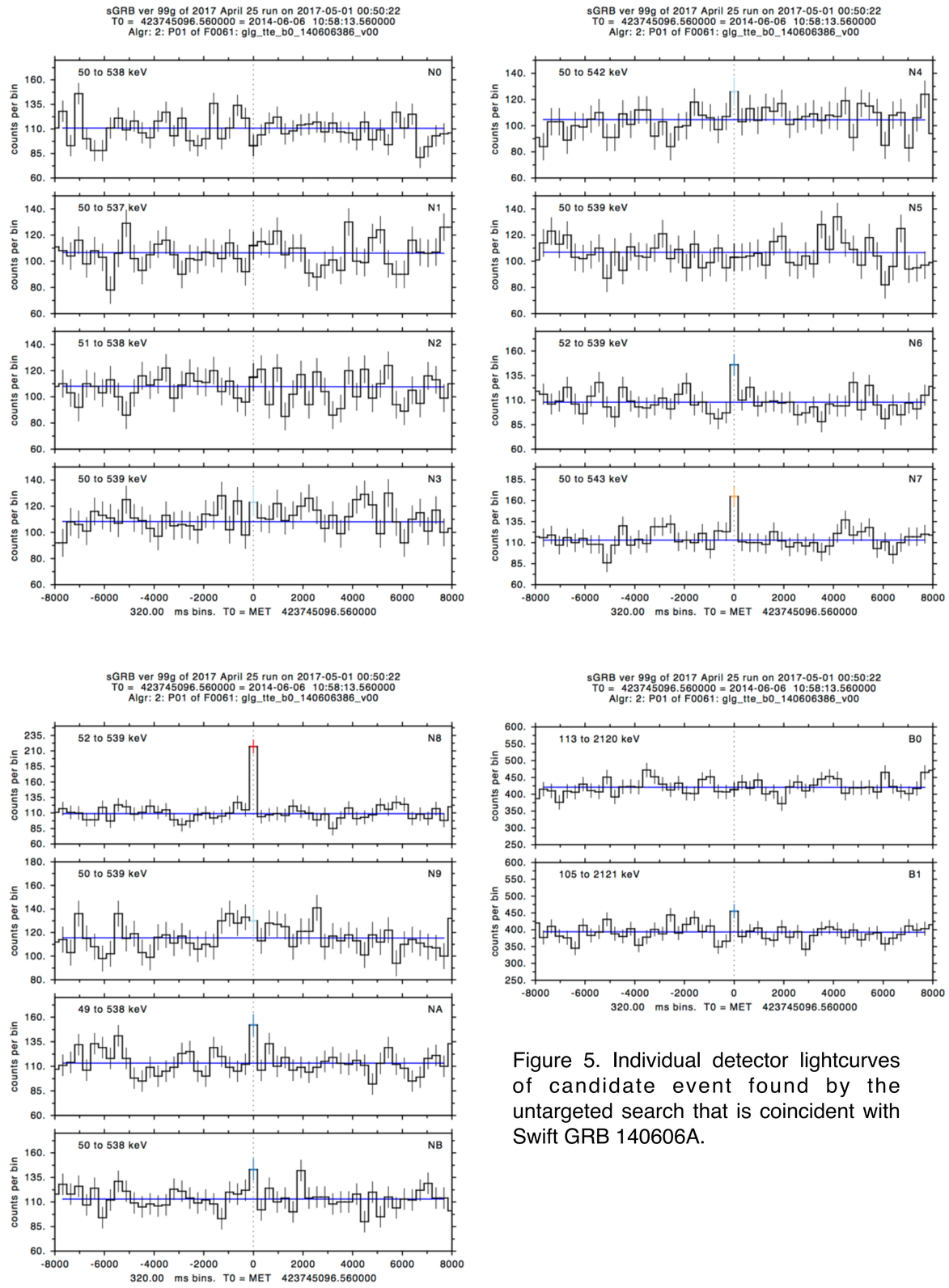


Figure 5. Individual detector lightcurves of candidate event found by the untargeted search that is coincident with Swift GRB 140606A.