NASA EM Followup of LIGO-Virgo Candidate Events

L. Blackburn for the LIGO Scientific Collaboration and Virgo Collaboration
NASA Goddard Space Flight Center

Abstract

We present a strategy for a follow-up of LIGO-Virgo candidate events using offline survey data from several NASA high-energy photon instruments aboard RXTE, Swift, and Fermi. Time and sky-location information provided by the GW trigger allows for a targeted search for prompt and afterglow EM signals. In doing so, we expect to be sensitive to signals which are too weak to be publicly reported as astrophysical EM events.

EM detectors:

Mission	Instrument	Energy	FOV *	Δθ	$T_{transit}$
RXTE	ASM	1–10 keV	3%	<1°	1.5 hr
SWIFT	BAT	20–150 keV	15%	<1°	n/a
FERMI	GBM	20 keV–40 MeV	65%	>5°	3 hr
FERMI	LAT	20 MeV-300 GeV	20%	1–5°	3 hr

* FOV: fraction of sky observed, Δθ: source localization resolution, $T_{transit}$: time required for full-sky coverage

LIGO-Virgo GW network:

Instruments	Frequency	Optimal NS/NS–NS/BH Range
H1L1V1	50–6000 Hz	~30–70 Mpc [1]

Searches

Prompt search

Search for prompt signal in GBM detectors [-10s, 60s] about time of GW event. Timescales and energy ranges are similar to those used on-board to target GRB's. Use GW source localization to aid in combining GBM detector data and in background rejection. Tune for a 0.001 coincidence probability per GW event.

Search for a prompt signal in BAT total lightcurve data (no imaging available for prompt, un-triggered events) [-10s, 60s] about time of GW event. Only search if BAT orientation (~15°) is consistent with GW source localization. Tune for a 0.001 coincidence probability per GW event.

LIGO-Virgo coherent burst and insprial events (~1/wk)

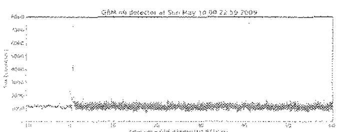
Afterglow search

Search for ASM rate excess in 90 s dwells for locations (0.1° resolution) within the GW sky map for several days following GW event. Known active X-ray sources are fit to the ASM shadow mask data and subtracted from the analysis to increase sensitivity and must be checked separately. Tune for a 0.001 coincidence probability per GW event.

Search LAT data for an excess in high-energy photons consistent with the GW reconstructed location within several hours following the GW event. Individual photons detected by LAT are localized to ~5°. Tune for a 0.001 coincidence probability per GW event.

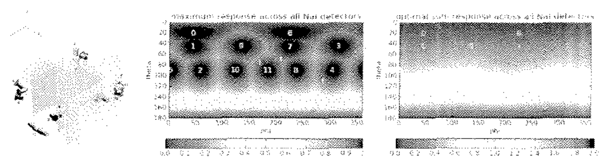
FERMI Gamma-ray Burst Monitor [2] (GBM)

GBM offline data includes count rates (0.256 s bins, 8 energy channels) of the 12 NaI (8 keV-1 MeV) and 2 BGO (200 keV-40 MeV) detectors.



GRB10090510: a strong, short GRB observed in the GBM detectors. The on-board trigger increases the time-resolution of the binned detector counts immediately following the event.

The NaI detectors are semi-directional (~cos θ response) and can be used for source localization and consistency checks. The GW location can be used as a basis for a coherent sum of the 12 data streams, increasing the overall response of the network compared to a single-detector approach.



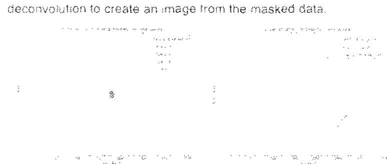
(Meegan et al 2009)

Nominal threshold for triggering an on-board event is 4.5 σ in 2+ NaI detectors.

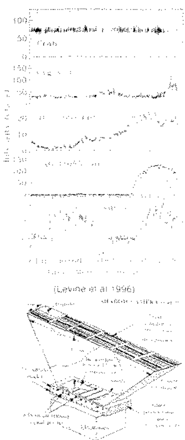
RXTE All Sky Monitor [3] (ASM)

The ASM aboard RXTE provides a 90 s 1–10 keV (3 sub-bands) snapshot of an area in the sky as often as every 90 minutes. Localization of ~0.1° is achieved by use of three cameras each equipped with a shadow mask.

The analysis method of fitting the amplitudes of a small number of point sources in the FOV to the masked data is generally used to produce sensitive light curves for sources of interest (right). Here we make use of the same technique to scan the finite sky-extent of the GW trigger in the few days following the event to search for X-ray afterglow signals. The GW skymap is divided into 0.1° "test" points whose 90 s dwell amplitudes are fit to the data along with a catalog of known active source locations. The sensitivity of the 90 s dwells is about 20 mCrab (4×10^{-10} erg/s/cm^2), and can be improved by averaging measurements for the duration of an expected signal. This method of analyzing a limited region of the sky is more sensitive than the standard un-triggered all-sky search for ASM transients which uses FFT deconvolution to create an image from the masked data.

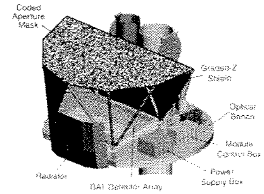


Signal-to-noise of flux measurements (left) for test locations, and the location of known X-ray sources (right). Special consideration is needed when a known active X-ray source falls within the GW skymap region.



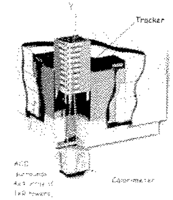
(Levine et al 1996)

SWIFT Burst Alert Telescope [4] (BAT)



- BAT lightcurve data contains total flux counts at 64 ms resolution in various energy bands.
- For un-triggered (low threshold) events, imaging is only available offline for 5 minute timescales.
- Usability depends on level of non-Gaussian transients.

FERMI Large Area Telescope [5] (LAT)



- LAT complete individual photon data available for offline analysis.
- Each photon characterized by time, sky location and energy. Single photon resolved at 10° (10 MeV) to 0.1° (10 GeV). Cluster of photons improves source location estimate.
- Likelihood statistic used by LAT team to identify significant clusters of photons.

1. LSC and Virgo Collaboration, *Predictions for the Rates of Compact Binary Coalescences Observable by Ground-based Gravitational-wave Detectors*, Class. Quantum Grav. 27 (2010) 173001
2. C. Meegan et al., *The Fermi Gamma-ray Burst Monitor*, ApJ 702 (2009) 791
3. A. Levine et al., *First Results from the All-Sky Monitor on the Rossi X-ray Timing Explorer*, ApJ 469 (1996) L33
4. S. Barthelmy et al., *The Burst Alert Telescope (BAT) on the SWIFT Midex Mission*, Space Science Reviews 120 (2005), Issue 3-4, 143
5. Fermi/LAT Collaboration: W. B. Atwood et al., *The Large Area Telescope on the Fermi Gamma-ray Space Telescope Mission*, ApJ 697 (2009) 1071

01/2011
LIGO G1100017