Fermi-GBM follow-up of gravitational waves during O4

Lorenzo Scotton (UAH)
on behalf of the
Fermi-GBM Team

September 9, 2024

lorenzo.scotton@uah.edu

11th International Fermi Symposium
College Park, MD, USA
September 9-13, 2024

Motivations

- **The joint detection of GRB 170817A / GW170817**
  - Binary neutron star (BNS) mergers are progenitors to short GRBs.
  - Constraints on gamma-ray emitting region in the GRB.
  - Constraints on speed of gravity, Lorentz invariance, Shapiro delay.
  - Origins of heavy elements via subsequent kilonova.

- **Open questions**
  - Rate of short GRB / kilonova production via BNS mergers.
  - Structure of off-axis emission in GRBs.
  - Expected time delay between GW and GRB, which in turn informs measurements of fundamental physics parameters like speed of gravity.
  - Long GRBs with kilonovae (GRB 230307A, GRB 211211A).

Targeted Search

- Likelihood implementation described in L. Blackburn et al 2015 ApJS 217 8
- Computed separately for each point on the sky using detector responses for 3 characteristic spectra describe most GRBs seen by GBM.

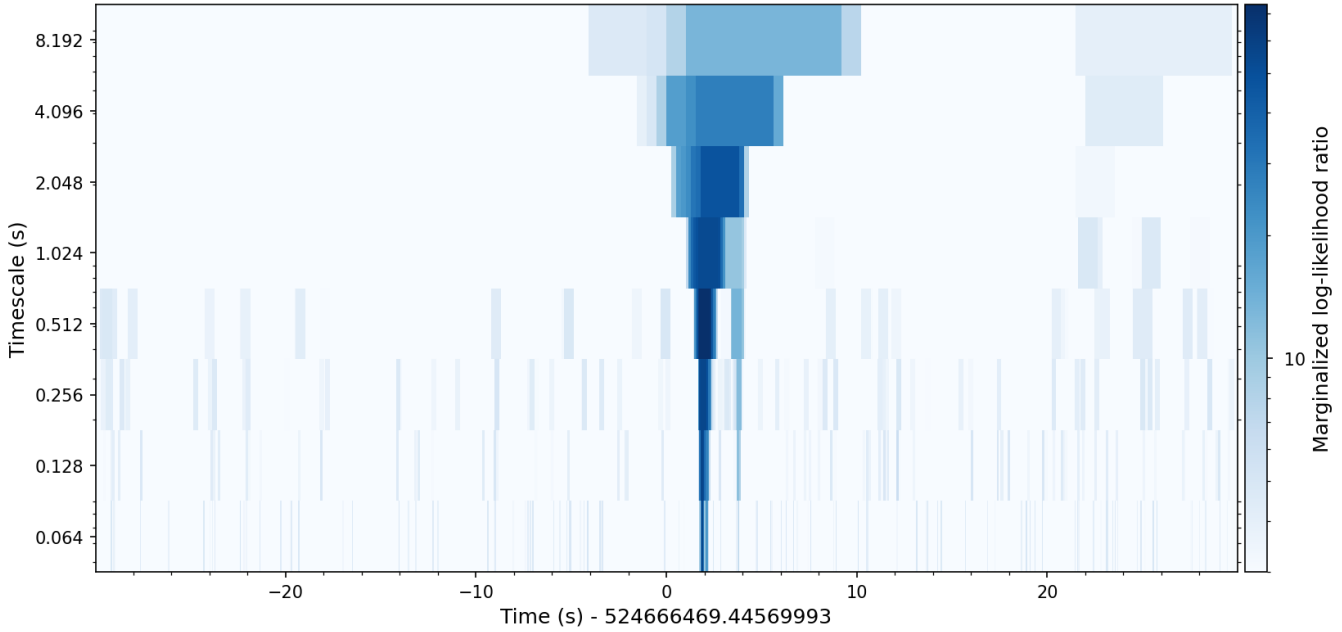
Table 3. Spectral templates used by the *Fermi*-GBM Targeted Search.

Template	Type	Parameters
hard	Cut-off Power-law (Goldstein et al. 2016)	$E_{peak} = 1500$ keV, $\alpha = -1.5$
normal	Band (Band et al. 1993)	$E_{peak} = 230$ keV, $\alpha = -1.0$, $\beta = -2.3$
soft	Band (Band et al. 1993)	$E_{peak} = 70$ keV, $\alpha = -1.9$, $\beta = -3.7$

- Logarithm of the the likelihood is marginalized over the sky, spectral templates, and source flux.

Targeted Search

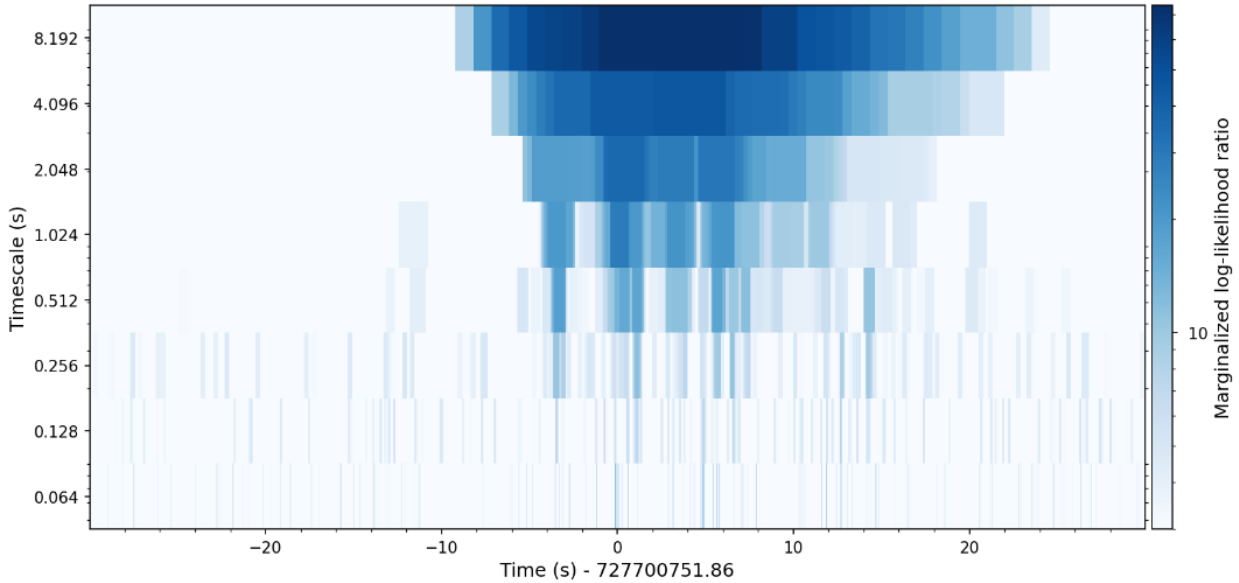
- Scans CTTE data from -1s to +10s around an external trigger time to look for a short GRB.
- Eight characteristic emission timescales: from 64 ms to 8.192 s using data from all 14 detectors.
- Returns likelihood ratio of signal vs background.
- Automatic follow-up over Integral SPI-ACS, Swift-BAT, HAWC, IceCube in addition to GW alerts.
- Manual follow-up over Konus-Wind, AstroSAT, GECAM, SVOM and EP.



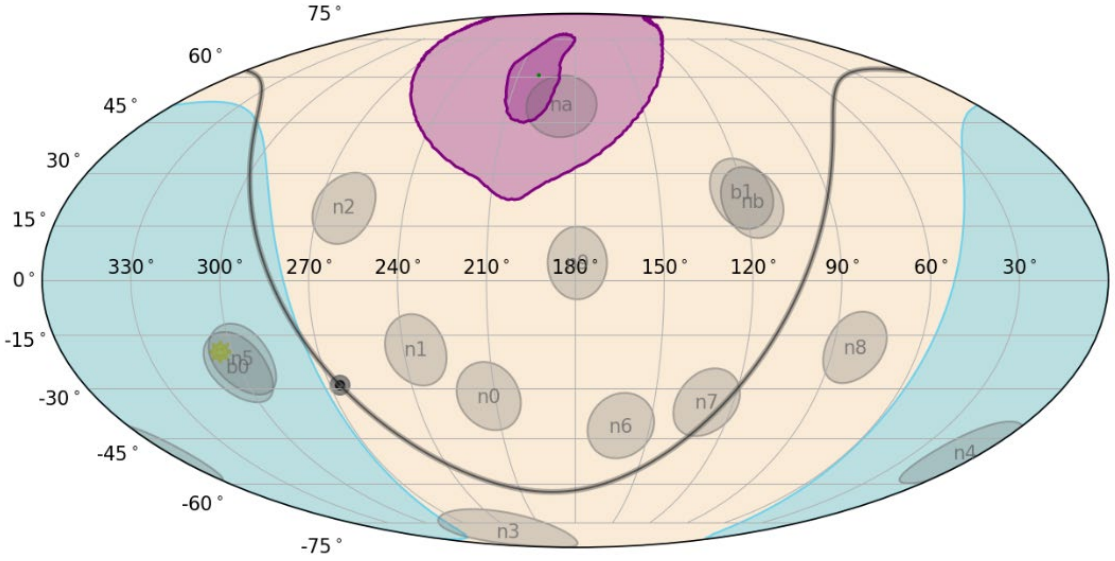
Waterfall plot for GRB 170817A (centered at GW170817 trigger time).

Sub-Threshold Detection of GRB 240123A

- Detected by Swift-BAT.
- No GBM onboard trigger.
- Recovered by the Targeted Search (Scotton et al. 2024, GCN 35610):
  - timescale = 8.192 s, FAR = 3.9e-05 Hz and normal spectrum.
  - location consistent with Swift-BAT.



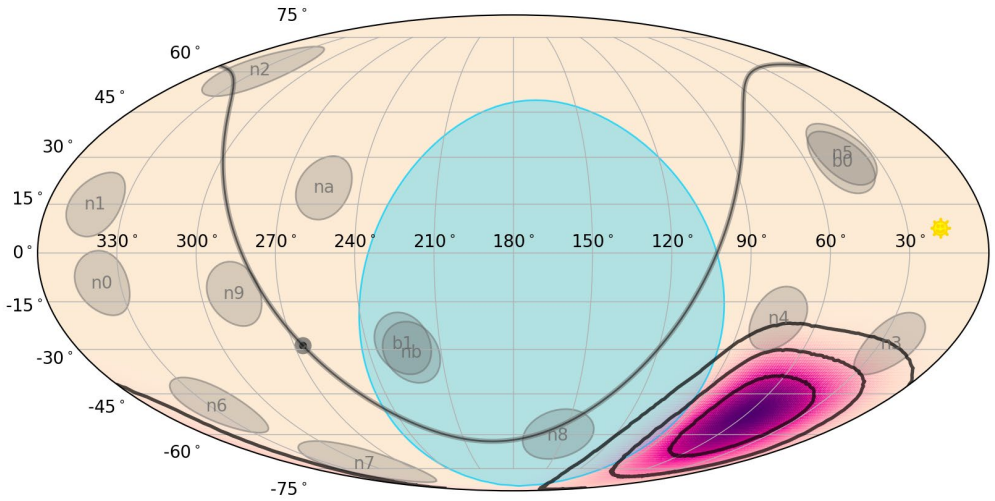
Waterfall plot.

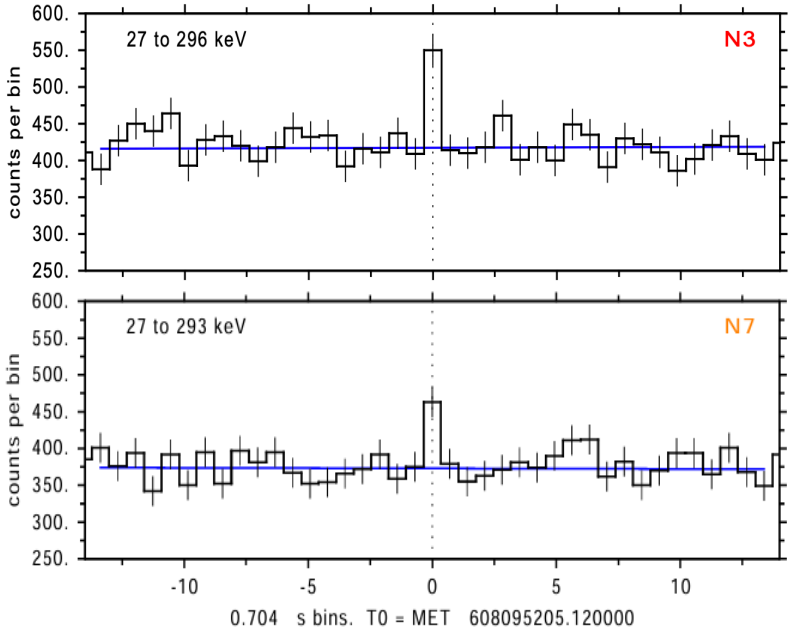


Localization map.

Untargeted Search

- Scans CTTE data continuously for GRB-like transients below the onboard trigger threshold.
- Eighteen timescales ranging from 64 ms to 31 s and five energy bins from 27 keV to 985 keV.
- Short GRB candidates when at least two detectors exceed 2.5σ and 1.25σ above the background rate.





GRB 200409A detected by the Untargeted Search and also seen by Swift.

Data Products

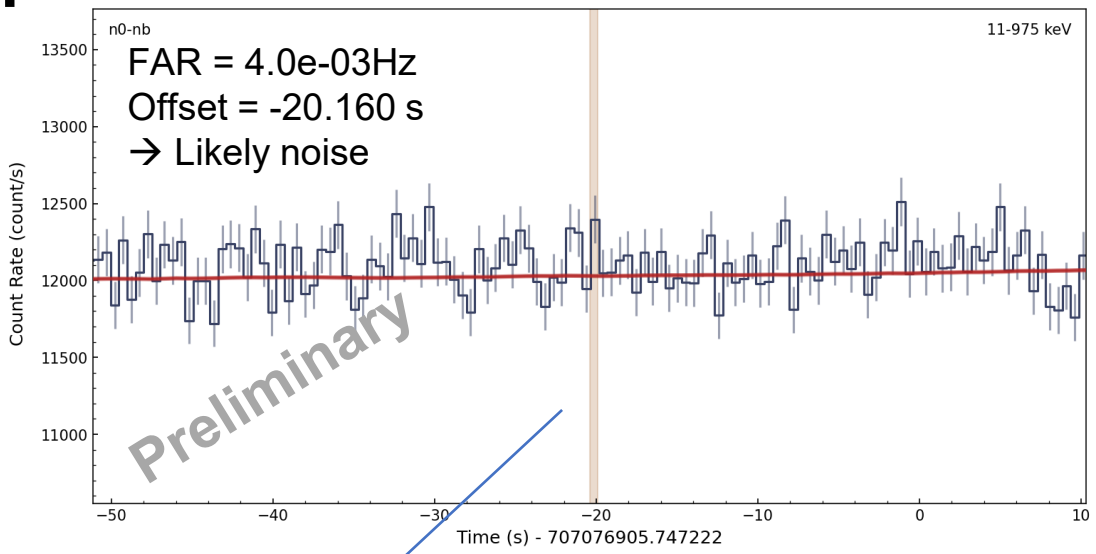
Data Product	Latency	Contents	Rate	Link
Trigger Alert	< 1 min	Detection of a transient	~640 triggers per year (~240 GRBs per year)	Fermi GBM Trigger Catalog
GRB Final Localization	< 20 min	~deg scale HEALPix map	~40 sGRBs per year	Fermi GBM Burst Catalog
Continuous Subthreshold Candidates	4 – 5 hr	reliability score HEALPix map	~60 high-reliability candidates per year	Fermi GBM Subthreshold Trigger Archive
Targeted Follow-up Candidates	4 – 5 hr	False Alarm Rate, HEALPix map		GCN Circular for high SNR candidates

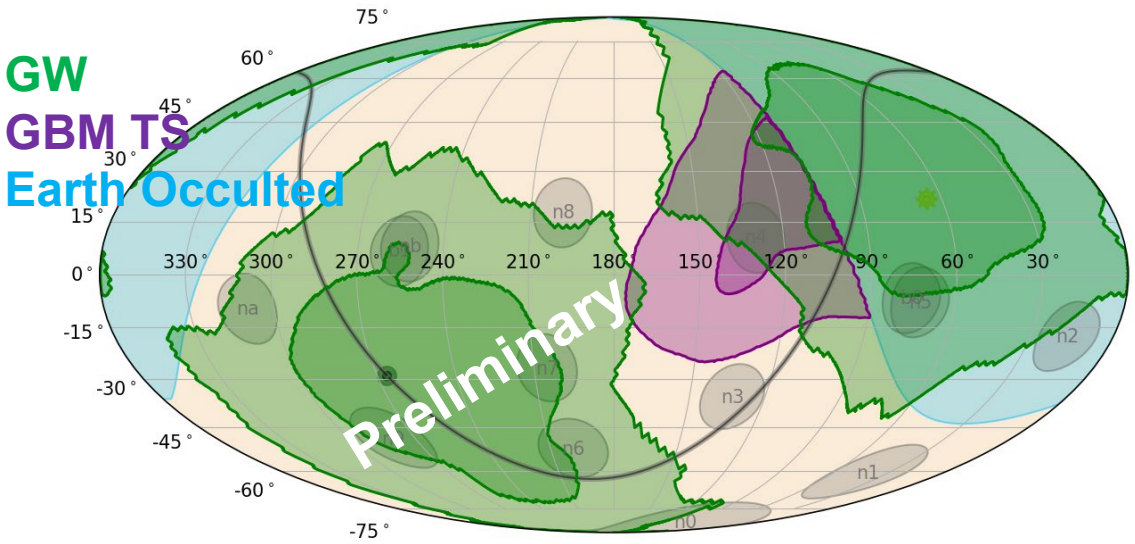
Improvements in O4

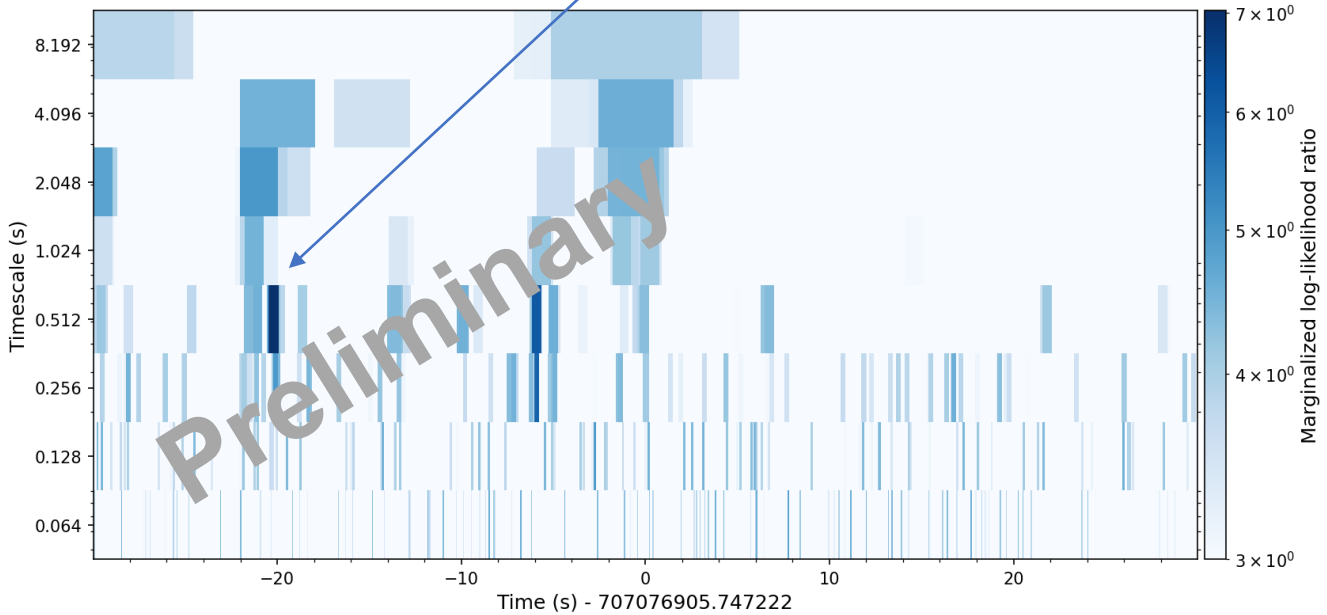
- **Targeted Search**:
  - Removal of 4–12 keV energy channel in NaI data to exclude detector noise and Galactic transients.
  - Better background fitting near the SAA reduces local particle background triggers.
  - Systematic uncertainty associated with the localization is improved: now accounting for atmospheric scattering.
- **Onboard**: trigger threshold lowered from 4.5σ to 4.2σ for an increase of short-GRB detections up to 20%.

Preliminary Results From O4

- **GW candidates: 127** (143 Total – 16 Retracted)
- 8 cases with probability of NSBH more than 5%.
- Publish GCN for a significant joint detection, or the upper limit when the probability of BNS of NSBH more than 5%.
- No significant detection of EM counterpart of BNS, NSBH or BBH.



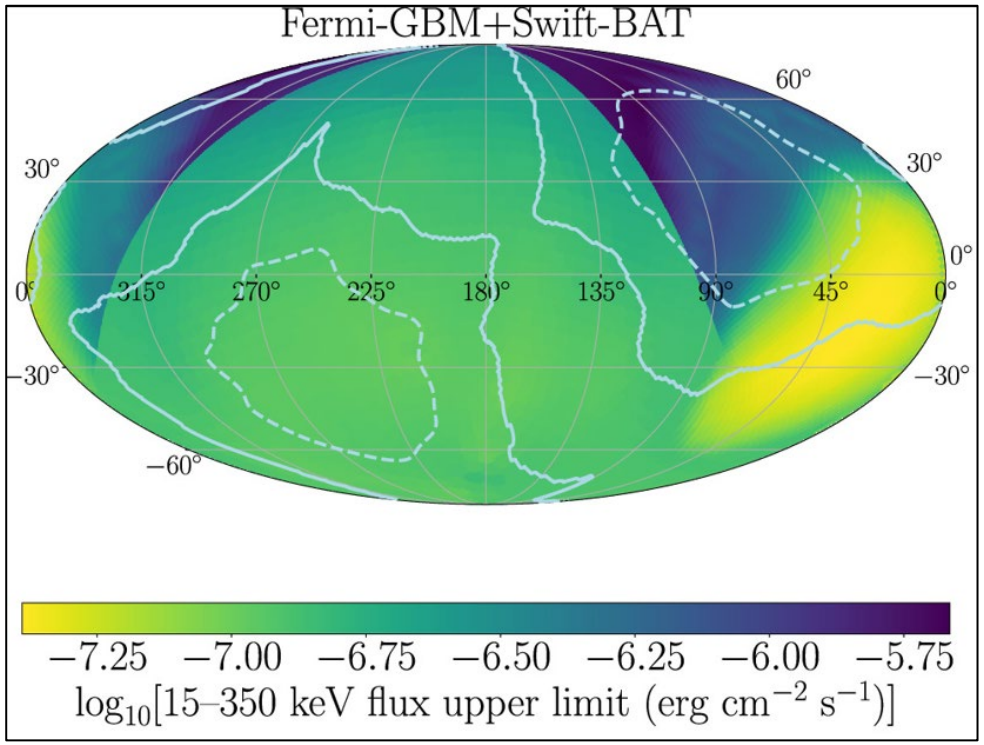




Targeted Search results for GW230529, first confirmed Mass Gap (Ronchini *et al.* 2024 *ApJL,* Abac *et al.* 2024 *ApJL*).

Summary

- LIGO, Fermi-GBM, and Swift-BAT are working together to enhance the number of joint GRB-GW detections.
- Automatic follow-up over Integral SPI-ACS, HAWC, IceCube in addition to Swift-BAT and GW alerts.
- No significant detection of a GRB counterpart to GW events during O4.
- 127 GW candidates so far during O4.
- **BNS/NSBH upper limits are not constraining:** increased event distances compared to GW170817, partial coverage in some cases, potentially unfavorable viewing angles.



Joint Fermi-GBM and Swift-BAT upper limits for GW230529. (Ronchini *et al.* 2024 *ApJL)*

- **Gamma-ray Targeted Search:** mission-agnostic version of the Targeted Search based on the Gamma-ray Data Tools (See A. Goldstein's talk on Thursday and D. Kocevski's poster).