Fermi GBM Status, Results, & Plans

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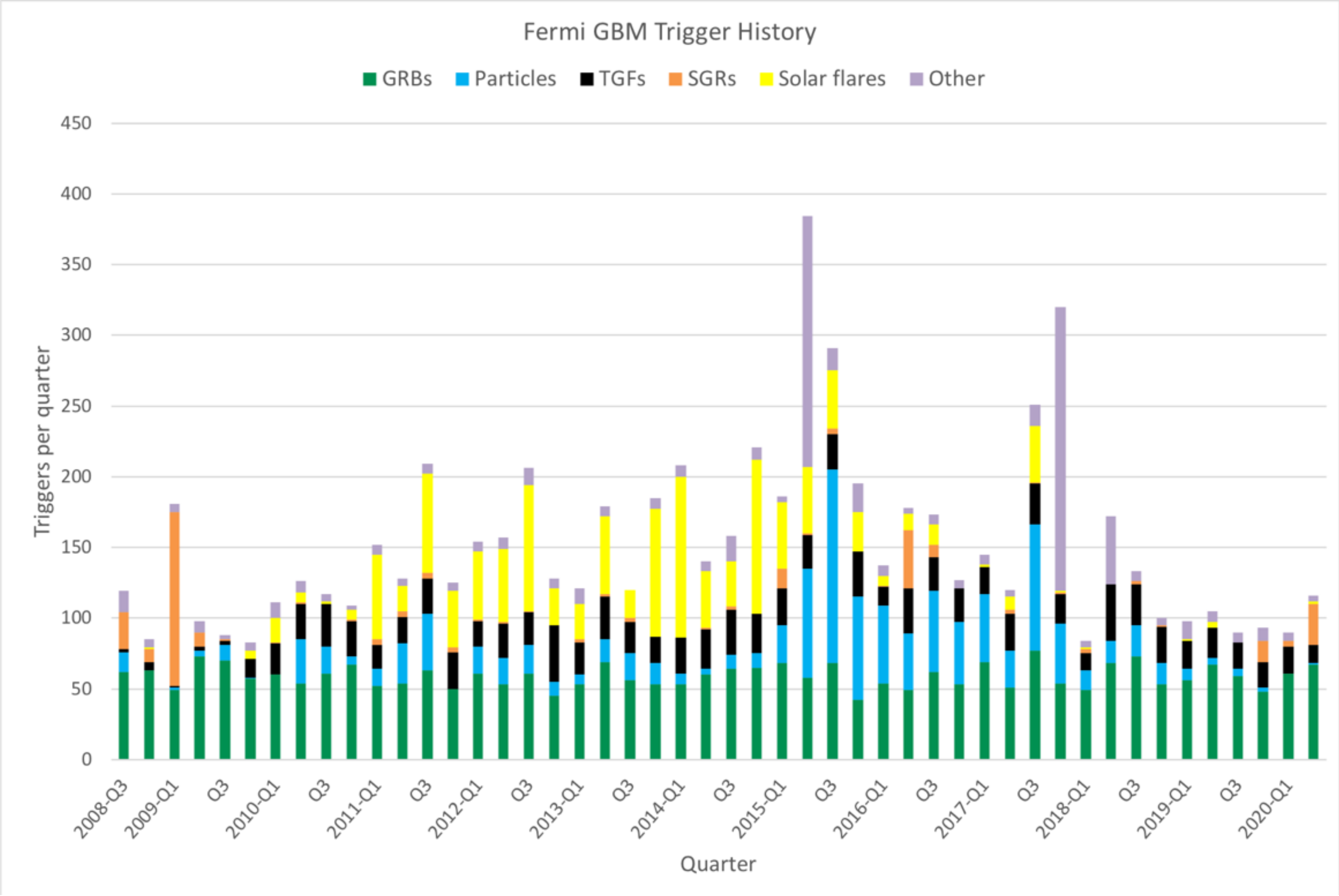
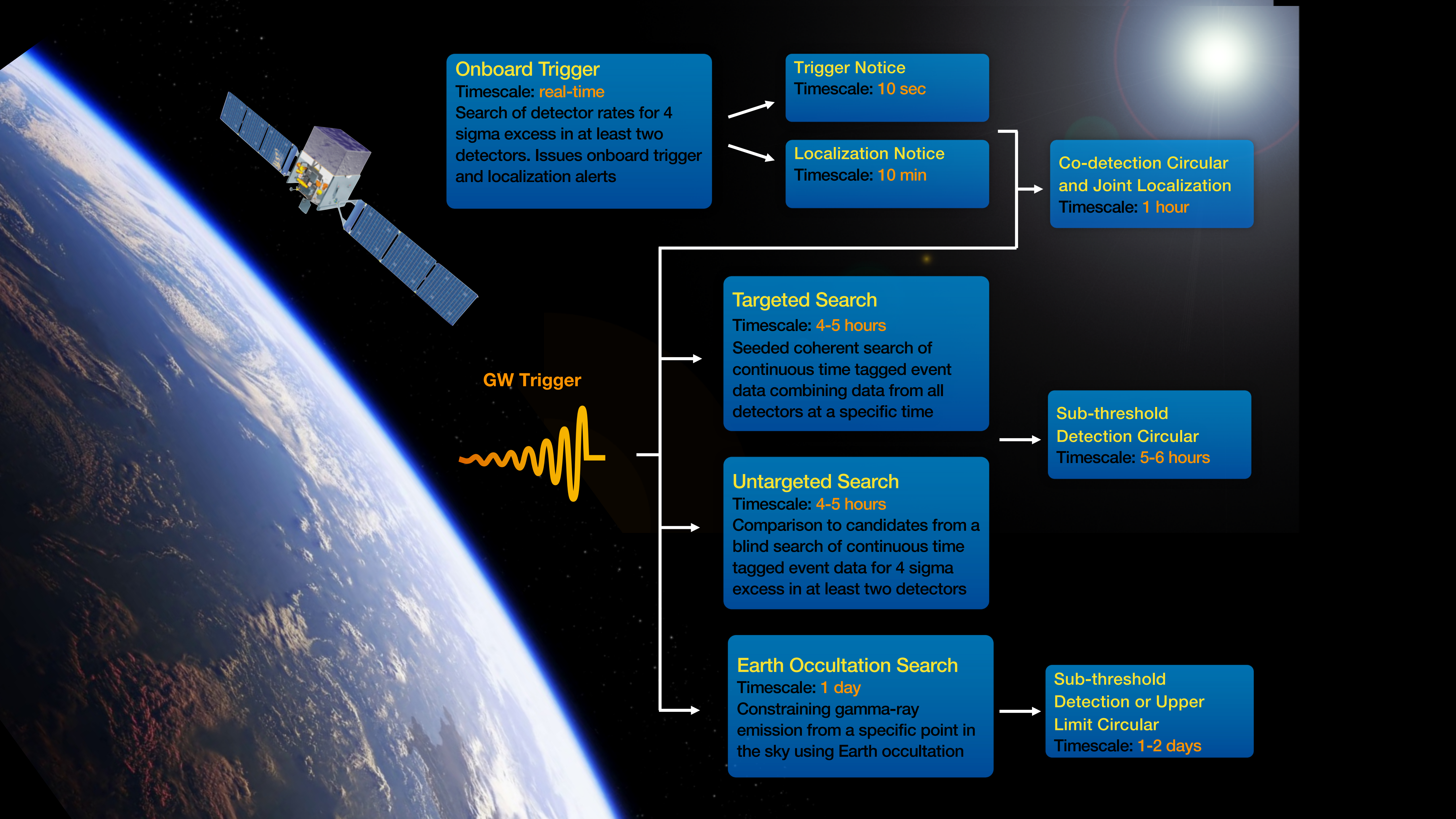
GBM Trigger Rate as of Jun 30, 2020

- Total triggers: 7351
- Gamma-ray Bursts: 2868
- Magnetar Bursts: 333
- Terrestrial Gamma Flashes (TGFs): 1051
- Solar Flares: 1184
- Particles: 1129
- Other: 782




Onboard Trigger
Timescale: real-time
Search of detector rates for 4 sigma excess in at least two detectors. Issues onboard trigger and localization alerts
Trigger Notice
Timescale: 10 sec
Localization Notice
Timescale: 10 min
Co-detection Circular and Joint Localization
Timescale: 1 hour
GW Trigger
Targeted Search
Timescale: 4-5 hours
Seeded coherent search of continuous time tagged event data combining data from all detectors at a specific time
Sub-threshold Detection Circular
Timescale: 5-6 hours
Untargeted Search
Timescale: 4-5 hours
Comparison to candidates from a blind search of continuous time tagged event data for 4 sigma excess in at least two detectors
Earth Occultation Search
Timescale: 1 day
Constraining gamma-ray emission from a specific point in the sky using Earth occultation
Sub-threshold Detection or Upper Limit Circular
Timescale: 1-2 days

Senior Review 2019 PMOs and Goals relevant to GBM

- PMO: Multi-messenger Astrophysics
  1. Automate joint GBM/LIGO/Virgo localization – COMPLETED
  2. Disentangle emission structure, dynamics, and viewing geometry neutron star-neutron star mergers with detection of additional sGRB-GW counterparts – Awaiting detections; O3 detailed studies & software improvements in progress
  3. Use sGRB-GW time delays as probes of cosmology, fundamental physics, and neutron star physics – Awaiting detections; O3 detailed studies & software improvements in progress
  4. Reduce latency of GBM sub-threshold triggers– work begins soon
- PMO: Time-Domain Astrophysics
  - Constrain accreting pulsar geometries via simultaneous timing and spectroscopy in cooperation with NICER and NuSTAR – in progress
- High Risk/High Return Objectives
  - Neutron star physics with Giant Magnetar Flares – in progress

Automated Joint GBM-LIGO Localizations

COMPLETE!

- Worked with collaborators in the LVC to ingest GBM localization maps from on-board triggers and the untargeted search
- The joint localization code is part of RAVEN, the code that is used by the LVC to monitor GRB alerts from GCN notices – GBM ground and FSW
- RAVEN also calculates a joint False Alarm Rate (FAR) from the GW FAR and the rate of GRB detections by GBM
- This was completed late in O3, and will be running in O4. A detection similar to GW170817 will produce a joint alert GCN notice containing a link to the joint localization.

https://git.ligo.org/lscsoft/raven

Follow-up of GBM GRBs with Swift-BAT/GUANO

- The GUANO is a sub-threshold search of BAT data for follow-up of gravitational-wave triggers
- Collaboration with GBM and BAT team members resulted in modifying GUANO to follow-up GBM triggers to recover sub-threshold BAT signals and provide improved arcminute localizations
- Fermi GI Cycle 13 Award
- Since February 2020, GUANO has provided arcminute localizations for 7 GBM GRBs and was able to decrease another GBM localization by ~2/3 by removing the Earth-occulted part of the localization as observed by Swift
- Potentially increases joint Swift-Fermi detections by 30%; improves GBM measurements of spectra and localization systematics estimation

https://arxiv.org/abs/2005.01751

sGRB/GW Follow-up Searches

- Disentangle emission structure, dynamics, and viewing geometry neutron star-neutron star mergers with detection of additional sGRB-GW counterparts – Awaiting detections; O3 detailed studies & software improvements in progress
- Use sGRB-GW time delays as probes of cosmology, fundamental physics, and neutron star physics – Awaiting detections; O3 detailed studies & software improvements in progress
- Reduce latency of GBM sub-threshold triggers– work begins soon

Improvements to the targeted search

- Add the ability to handle skymaps which are smaller than the spatial grid spacing used to compute the GBM detector response across the full sky
  - enables automated analysis of IceCube neutrino events and Swift GRBs
- Improved handling of background estimation near SAA
- Added the ability to inject simulated GRBs directly into the targeted search to better understand our detection efficiency and identify areas that need improvement, including:
  - Corrections to the calculation of the joint spatial association probability
  - Refinements to systematic errors for spatial localizations

O3 Follow-up Paper

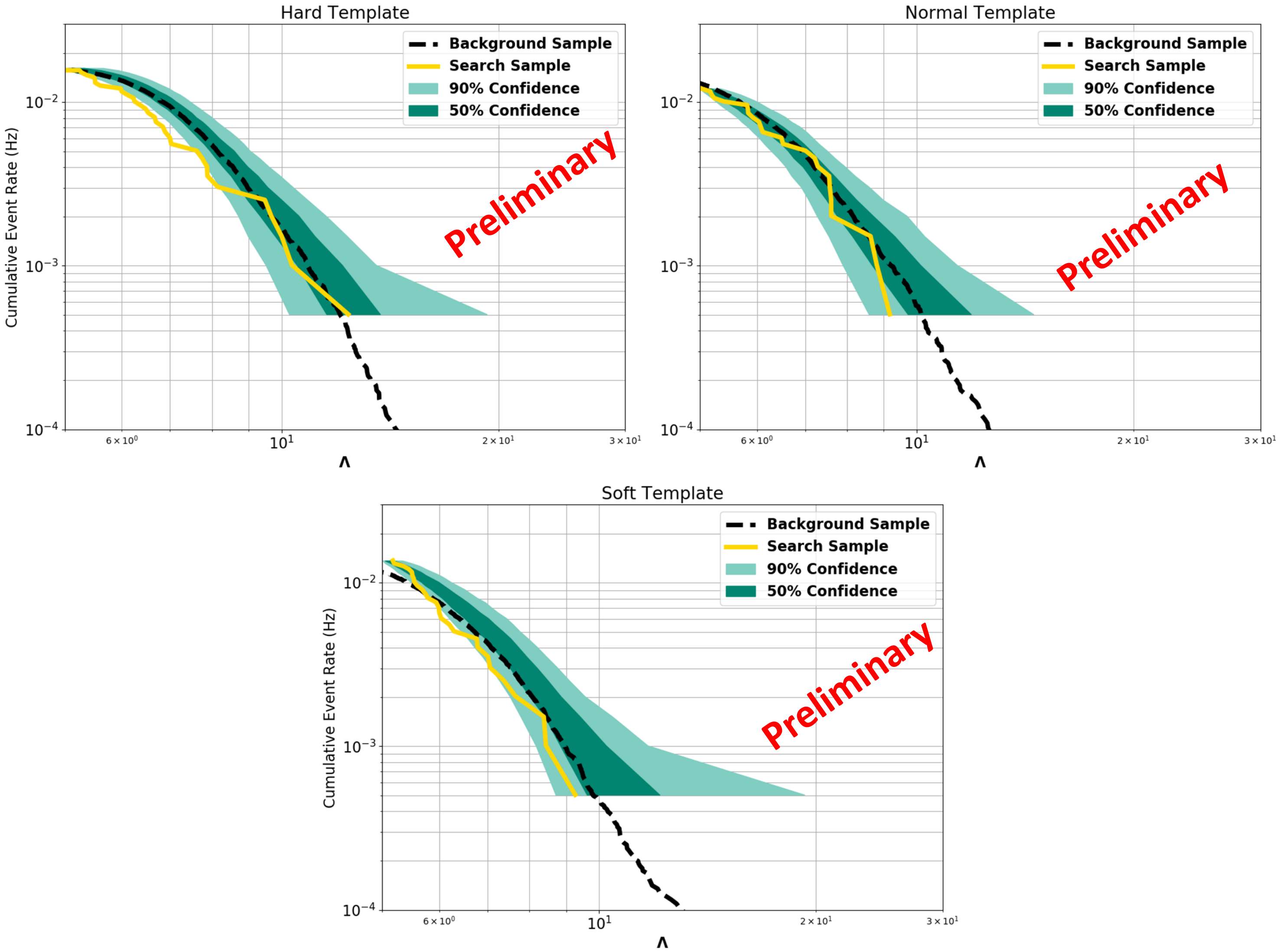
Goals:

- Follow-up events from the LVC O3a catalog paper (eta ~ month)
- Add events from the LVC O3b catalog paper, timeline is unknown at the moment
- Apply an improved ranking statistic that takes into account the probability of spatial coincidence
- Look at whether we can rule out EM emission from BBHs
- Joint collaboration with Swift and the LVC

O3a Follow-up Results

- There are no significant events found in our targeted search for O3a.

- Still waiting on O3b catalog event times to be determined.



C. Fletcher et al. in prep.

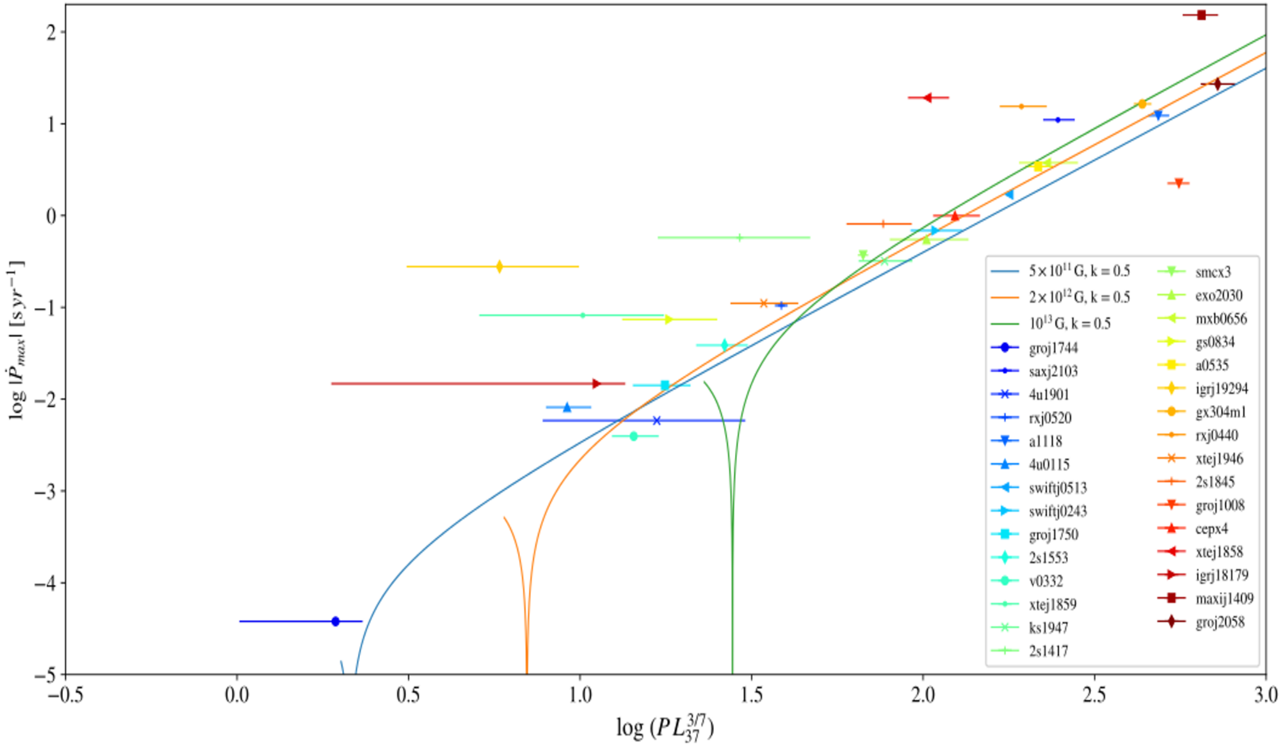
Reduce Latency of GRB follow-up searches – Work will begin soon

- Plan – reduce threshold for on-board triggers to allow rapid alerts for weaker GRBs

- Implementation –a new postdoc hire will implement the GBM FSW trigger on the ground so that we can test this idea on existing data

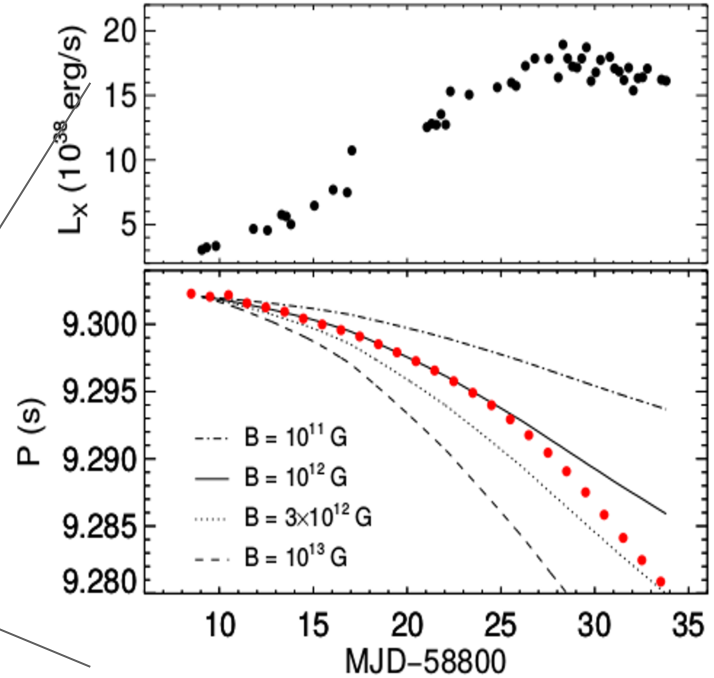
- Next steps - Ground version of FSW trigger will be used to determine the trigger threshold to be used on-board to minimize spurious triggers and to test additional BAP software if needed.

GBM + NICER + NuSTAR united to unveil accreting X-ray pulsars



From Malacaria et al. 2020: all GBM transient pulsars compared to disk accretion models. This is supported by, and influenced new, independent sources analyses, e.g.:

- 2S 1417-624 (Ji et al. 2019): GBM + NICER
- GX 301-2 (Liu 2020): GBM
- GRO J2058+42: GBM + Nustar spectral and timing analysis (Kabiraj & Paul 2020)

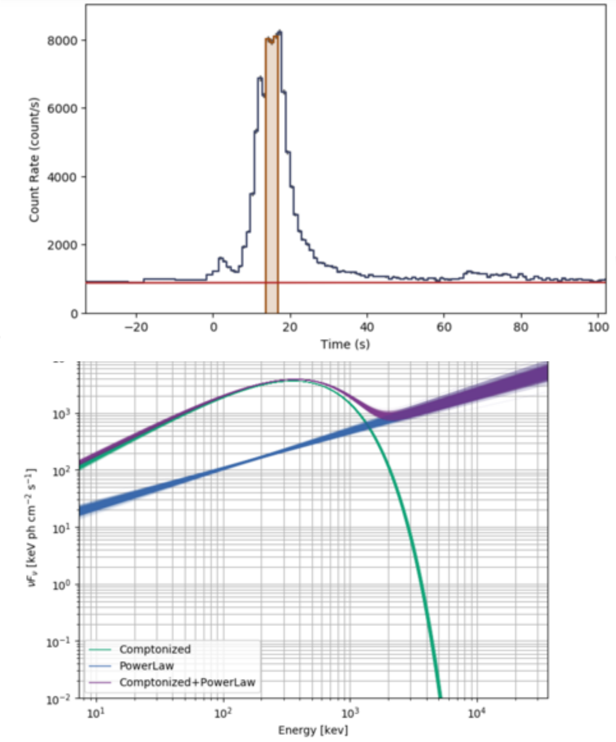


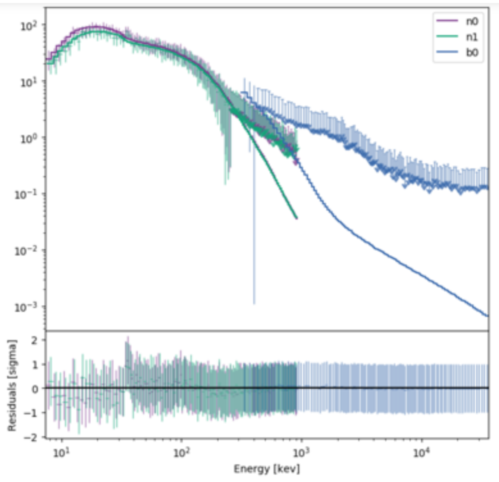
Other recent works:

- GX 301-2: GBM + Nustar find a retrogradely spinning NS (Mokonnen et al. 2020)
- RX J0209.6-7427: GBM + NICER + Nustar analysis (Vasilopolous et al. 2020)

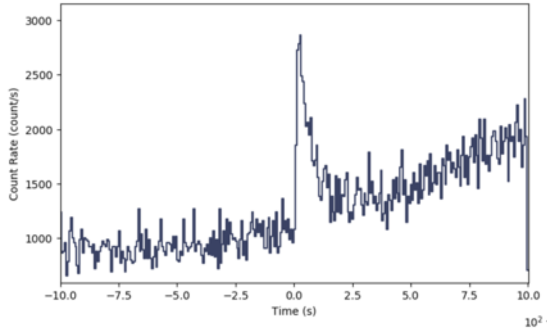
Fermi GBM Data Tools

- Python API for GBM Data Analysis, including interfaces to GBM Data and catalogs, as well as high-level data reduction operations such as binning and background fitting
- Fully documented, with Jupyter notebook tutorials

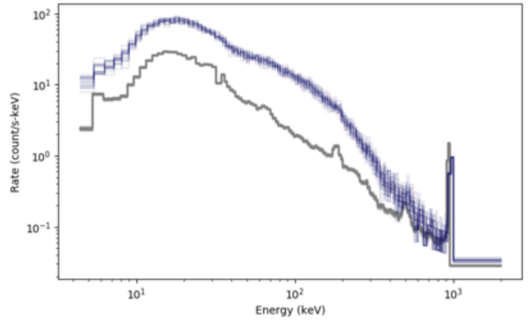




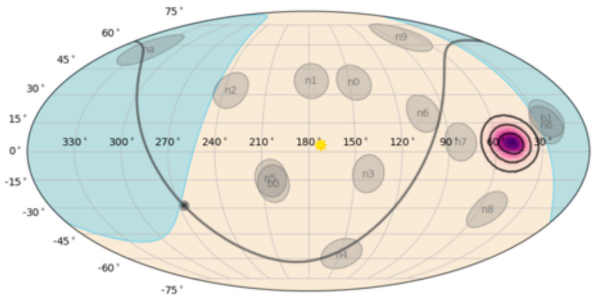
Lightcurves and spectral fitting

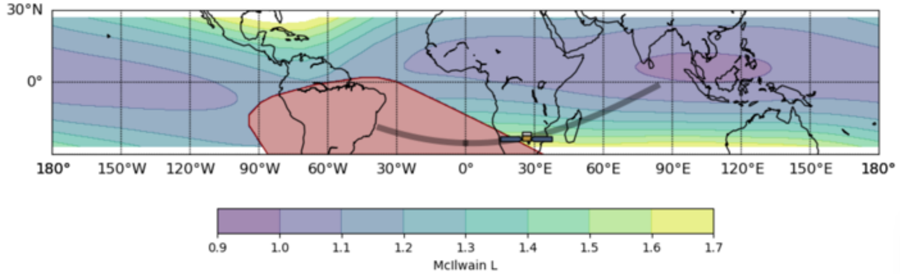


Temporal and spectral simulations

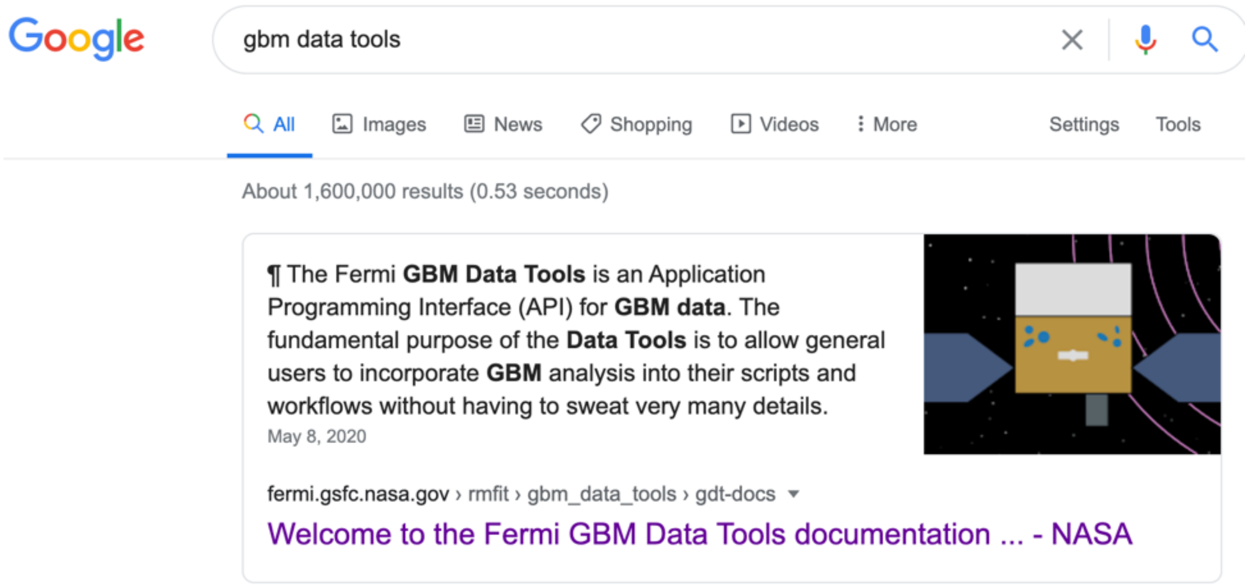


Localization maps and observing conditions





Fermi GBM Data Tools



Google featured result

- First version (1.0.2) released at the FSSC on April 7, 2020. Minor release with some bug fixes released on May 8. Another minor update very soon.
- Lots of community interest, several questions via the FSSC Help Desk
- Interest from other instruments about using the Data Tools as a basis for their science analysis. BurstCube is actively incorporating the Data Tools into their ground analysis software
- Still working to get them hosted on the NASA GitHub; will make community contributions a lot easier
- Fermi GI Cycle 13 award to add the GBM response generator with expanded capabilities and localization algorithm

Summary

- GBM is operating nominally with no issues
- For the 6 goals for GBM in the 2019 Senior review proposal, one has been completed, three are in progress, and two are awaiting new detections of NS-NS mergers.
  - Automated joint GBM-LIGO/Virgo localization is COMPLETED
  - A detailed search for GBM counterparts to events in the LIGO/Virgo O3 catalog is in progress
  - The GBM team is actively improving software for GW follow-up in preparation for LIGO/Virgo O4 to increase our chances of detecting the next NS-NS merger event.
  - Work to improve latency for sub-threshold triggers will begin soon
  - The GBM Compendium paper was published + 5 outside author led papers using GBM data to improve our understanding of accreting pulsar geometries
  - Neutron Star Physics with Giant Magnetar Flares – in progress
- The GBM team is actively developing public user tools to improve access to and usability of GBM data.

Backup

Added the ability to handle small skymaps

- The targeted search analyzes the sky using a set of grid points for the GBM detector response from locations that are spaced by 5 degrees.

- This is appropriate for identifying candidate events in GBM but became problematic when computing quantities, such as flux upper limits, that are marginalized over externally provided skymaps in cases where the skymaps are smaller than the grid spacing:

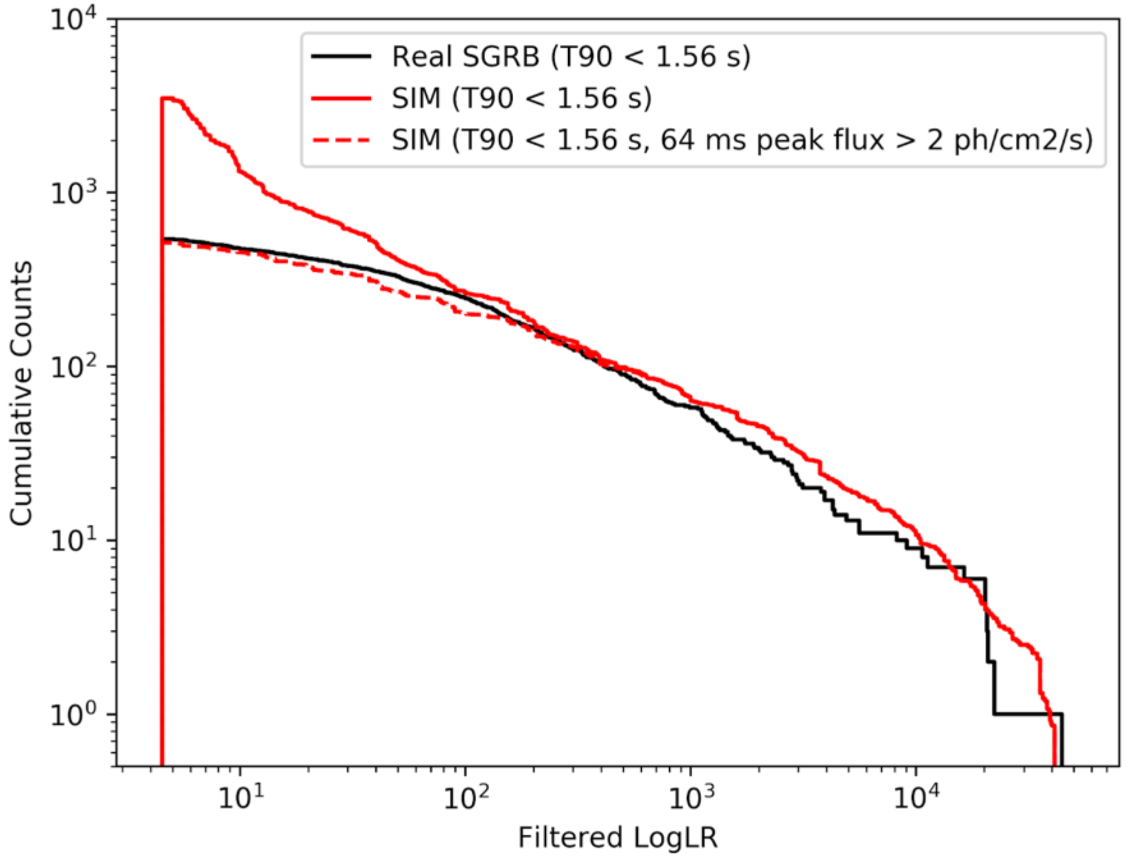
Unphysical upper limits computed for the IceCube-200117A high energy neutrino alert

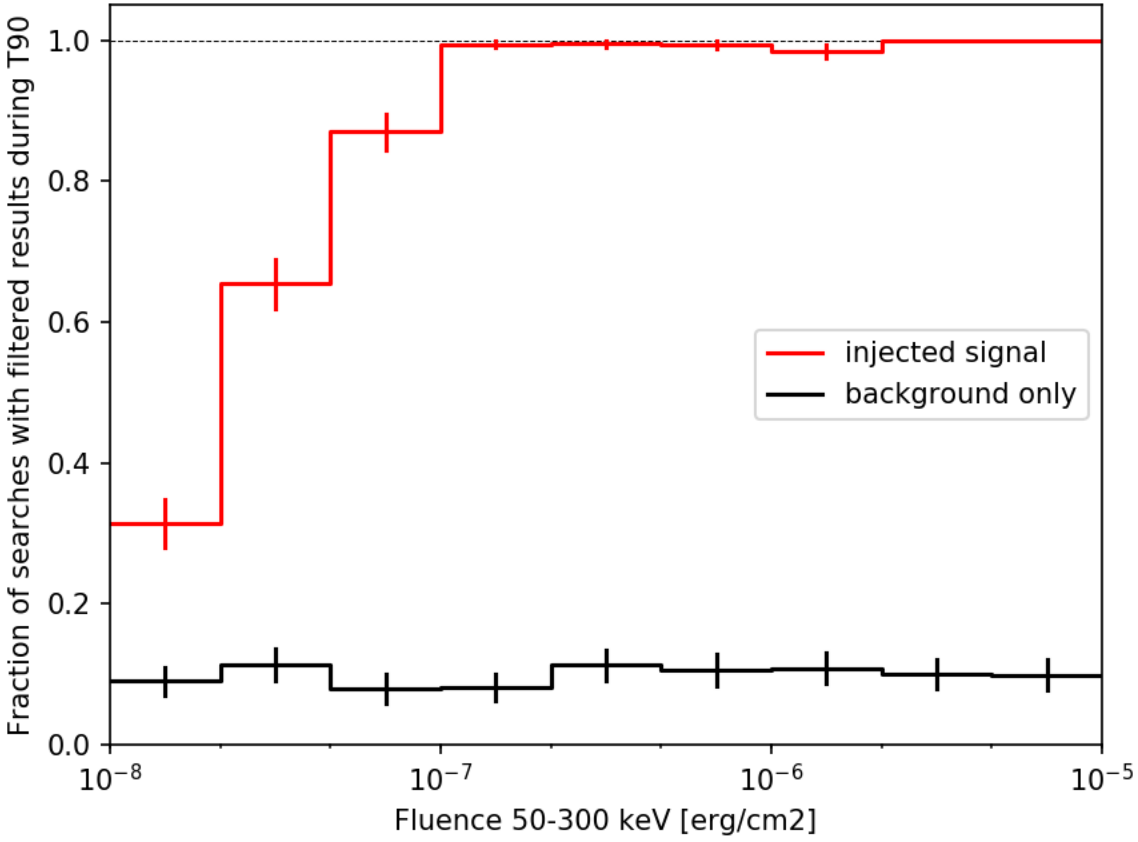
Duration	soft	norm	hard
0.128 s:	6.3e-104	9.9e-104	2.1e-103
Units: ergs cm^{-2} s^{-1}			

- The solution was to project results from the 5 deg grid onto the resolution of the input skymap when marginalizing over skymaps that are smaller than the grid spacing → allows automated analysis of IceCube neutrino events + Swift GRBs

Added the ability to inject simulated GRBs

- Allows us to model expected signals from short GRBs using much higher statistics than are available with current data ⟶ more detail, more ability to fine tune the search

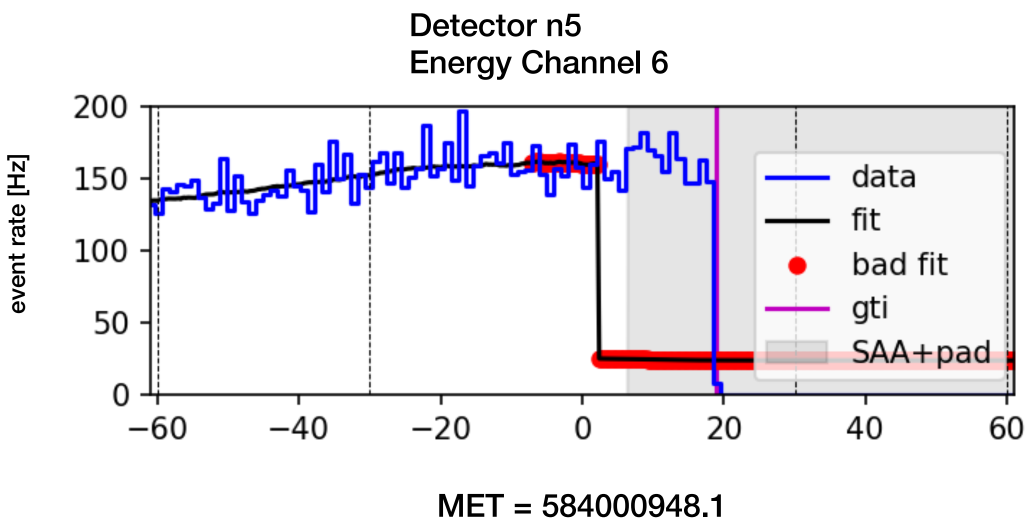




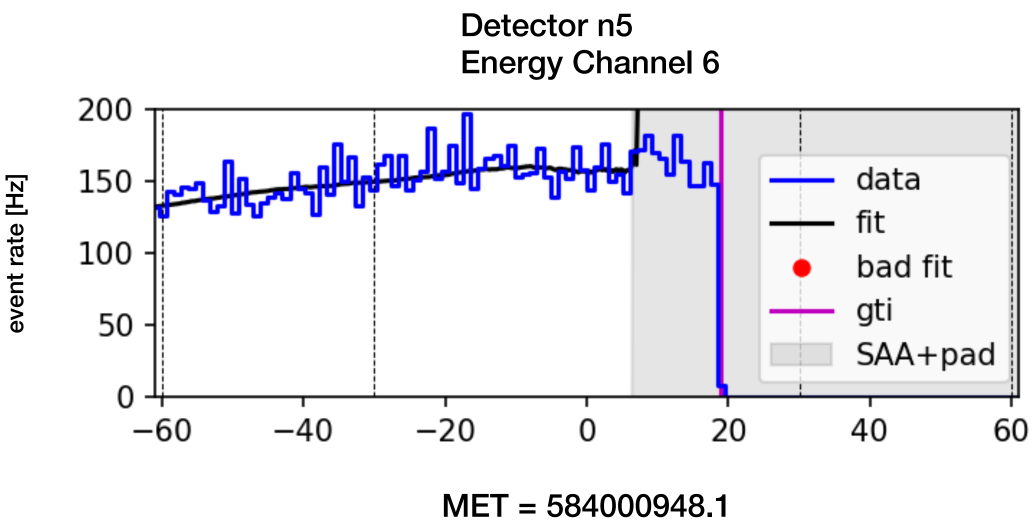
Improved handling of background near SAA

- Re-processing data for the O3 paper revealed a subset of events (0.5%) with poor background fits at times near SAA entry and exit
- The issue was traced to a logic error in GBM data tools which has now been corrected

Before the correction



After the correction

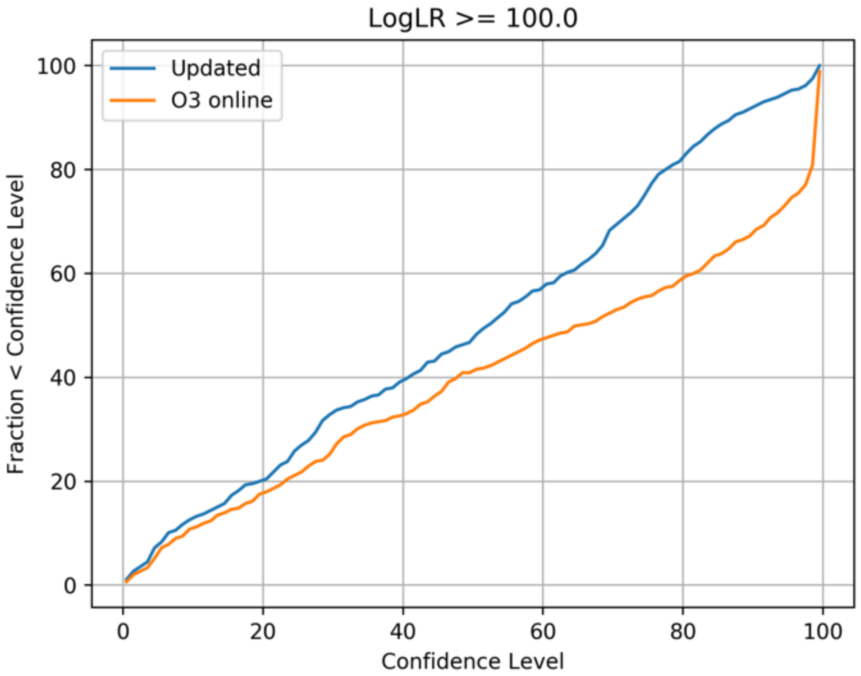


Refined Localization Systematics

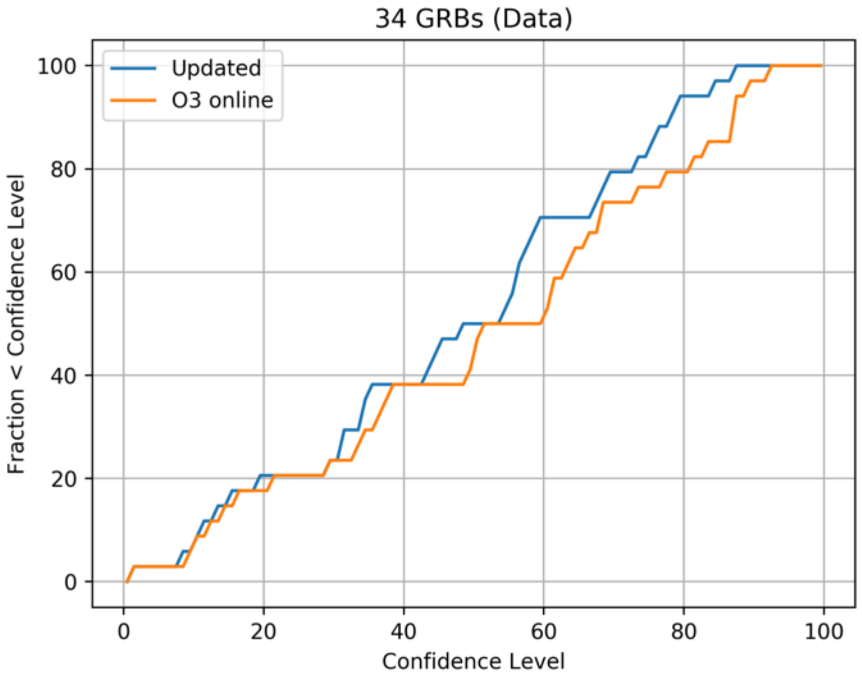
- Original estimation of the systematic error on localizations produced by the targeted search was performed with a small sample of 34 short GRBs that were jointly detected by GBM and Swift. This identified a single Gaussian error component that was added to the statistical error of all localizations.

- Producing a larger sample of localizations from simulated short GRBs allowed us to identify a subset of detections which require a second, larger Gaussian error component. The larger sample also allowed us to refine the systematic error estimation to account for the spacecraft rocking angle.

Observed vs estimated localization confidence level after applying systematic error for simulated events



Observed vs estimated localization confidence level after applying systematic error for 34 real GRBs

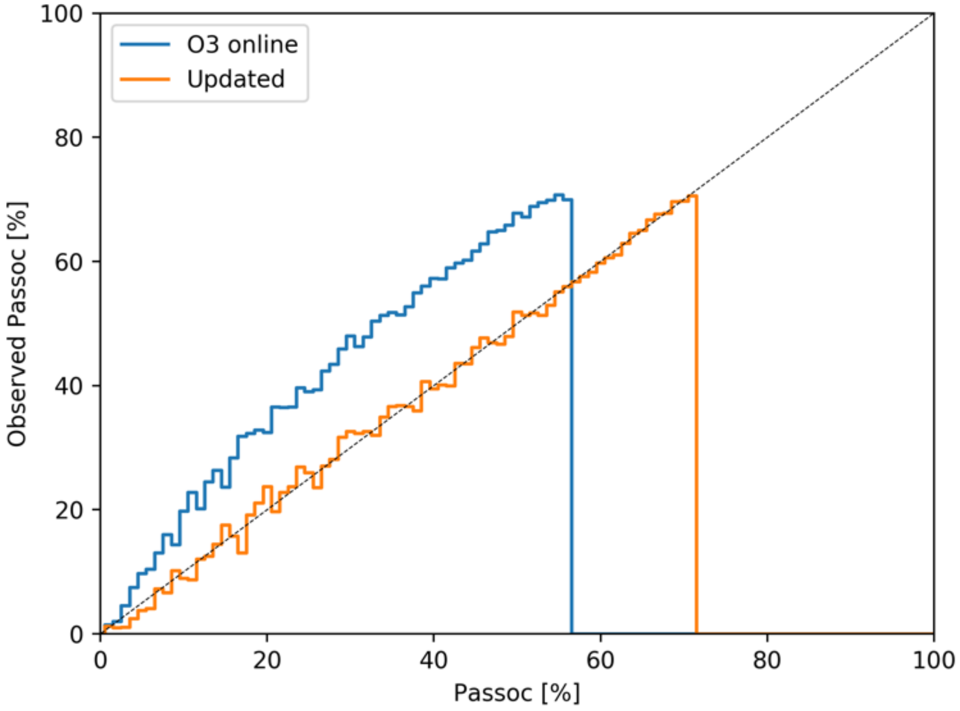


Corrections to Spatial Association Probability

- Modeling a large sample of simulated short GRBs revealed a discrepancy in our computation of the spatial association probability (Passoc) between GBM candidate events and the external localization

- Correcting the discrepancy allowed us to gain additional discrimination power between signal and background when using Passoc as part of a ranking statistic. Roughly a factor of 2 improvement relative to O2 ranking statistic

Observed vs Estimated Spatial Association Probability for one pairing of simulated skymaps



Updated Ranking Statistic

$$R = \frac{p_{\mathrm{astro}} \times p_{\mathrm{visible}} \times p_{\mathrm{assoc}}}{|\Delta t| \times \mathrm{FAR}_{\mathrm{GBM}}}$$