



Fermi

Gamma-ray Space Telescope

# Fermi GBM Status, Results, & Plans

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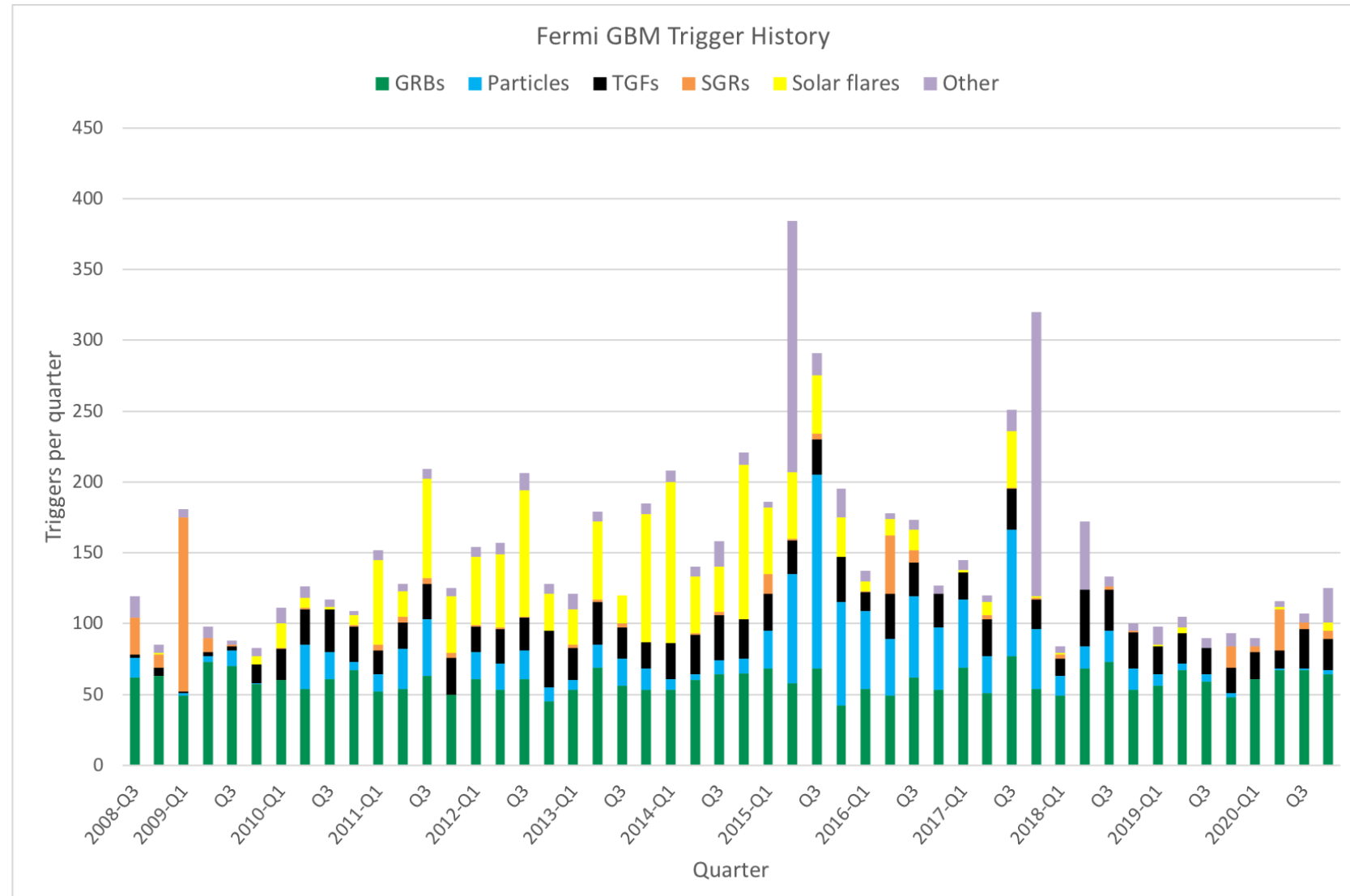
Fermi GBM PI, NASA/MSFC

Fermi Users Group Meeting

Sep 28, 2021

# GBM Trigger Rate as of Sep 28, 2021

- Total triggers: 7890
- Gamma-ray Bursts: 3151
- Magnetar Bursts: 418
- Terrestrial Gamma Flashes (TGFs): 1160
- Solar Flares: 1202
- Particles: 1104
- Other: 855



# Senior Review 2019 Prioritized Mission Objectives (PMO) 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; progress with O3 detailed studies & software improvements
  3. Use sGRB-GW time delays as probes of cosmology, fundamental physics, and neutron star physics – Awaiting detections; progress with O3 detailed studies & software improvements
  4. Explore reducing the latency of GBM sub-threshold triggers– work in progress
- PMO: Time-Domain Astrophysics
  - Constrain accreting pulsar geometries via simultaneous timing and spectroscopy in cooperation with NICER and NuSTAR – MAJOR PROGRESS
- High Risk/High Return Objectives
  - Neutron star physics with Giant Magnetar Flares – MAJOR 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.
- Joint Localizations are automatically distributed through the LVC stream to the follow-up community

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

# 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; progress in O3 detailed studies & software improvements
- Use sGRB-GW time delays as probes of cosmology, fundamental physics, and neutron star physics – Awaiting detections; progress in O3 detailed studies & software improvements
- Explore reducing the latency of GBM sub-threshold triggers– work in progress

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

- The GUANO is a sub-threshold search of BAT data designed for follow-up of gravitational-wave triggers.
- Collaboration with GBM and BAT team members resulted in modifying GUANO to follow-up GBM triggers using GBM spectral parameters to recover sub-threshold BAT signals and provide improved arcminute localizations
- Fermi GI Cycle 13 and Cycle 14 Awards
- Since February 2020, GUANO has reported arcminute localizations for 18 GBM GRBs and was able to decrease another GBM localization by  $\sim 2/3$  by removing the Earth-occulted part of the localization as observed by Swift. Work is on-going to automatically decrease the localization region for many more GRBs
- GBM is responsible for the majority of successfully recovered GRB localizations
  - GBM accounts for 18/21 successfully recovered arcminute GRB localizations.
  - GBM triggers account for about  $\frac{1}{4}$  of the total number of trigger requests.
- Potentially increases joint Swift-Fermi detections by 30%; improves GBM measurements of spectra and localization systematics estimation

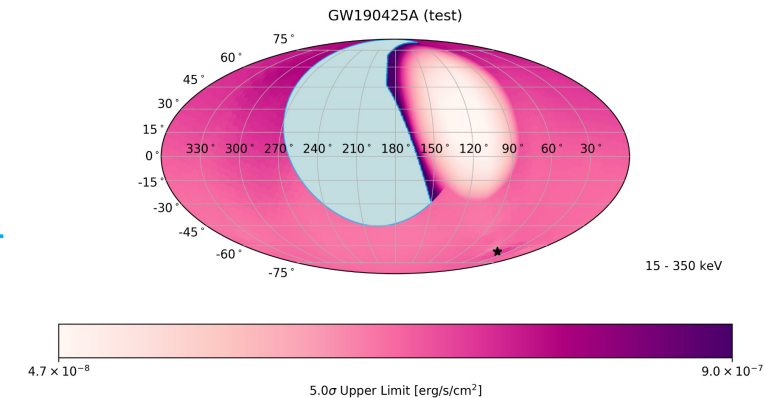
<https://arxiv.org/abs/2005.01751>

# Improvements to the targeted search

- Added 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
- Added Flux upper limits as a function of sky position
- The targeted search now automatically follows-up GCNs for GRBs detected with other missions, neutrino detections, and GW events.
  - GRBs detected (~monthly) and some SGR flares. One GRB was high redshift

# Joint GRB/GW papers

- O3a & O3b Follow-up paper (C. Fletcher et al. in prep) – joint with LVC and Swift
  - Search Fermi GBM and Swift BAT for events coincident w/ GW.
  - Improved ranking statistic that takes spatial coincidence into account
  - Provides marginalized and upper limit sky maps from both GBM and BAT
  - Examining how lack of EM emission from BBH mergers compares to theoretical predictions
  - No significant events found in GBM targeted search for O3a or O3b
- Single interferometer coincidence with GBM – joint with LVC
  - C. Stachie et al., 2020, *Classical and Quantum Gravity*, 37, id. 175001
  - New method to search for gamma-ray counterparts to single GW detector triggers
  - No significant candidates found in the search





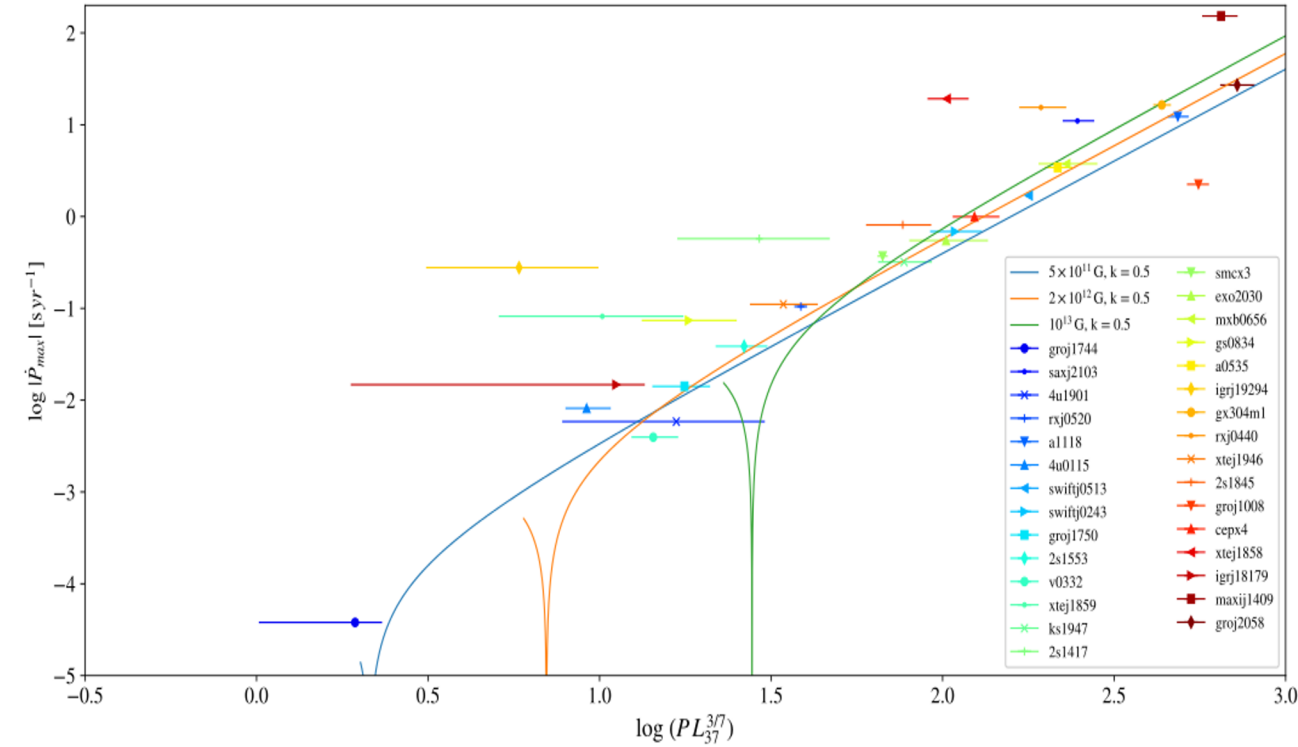
# Explore Reducing Latency of GRB follow-up searches

- Plan – reduce threshold for on-board triggers to allow rapid alerts for weaker GRBs
- Implementation – new postdoc hire has begun implementing the GBM FSW trigger on the ground
  - Ground GBM FSW triggering software was producing an excess number of triggers.
  - Error has been found in code and progress has resumed.
- Under discussion (planned before submission of senior review proposal) Feasibility Study.
  - Lower trigger threshold onboard Fermi during working hours for up to a week
  - Work with GCN to suppress sub-threshold triggers
- Planned (for 2022 Senior review)
  - Develop new GCN notice type for subthreshold triggers
  - Develop a plan for how to process a GRBs that would trigger under the standard trigger and now trigger earlier with the lower threshold trigger

# GBM + NICER + NuSTAR united to unveil accreting X-ray pulsars – Major Progress

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.:

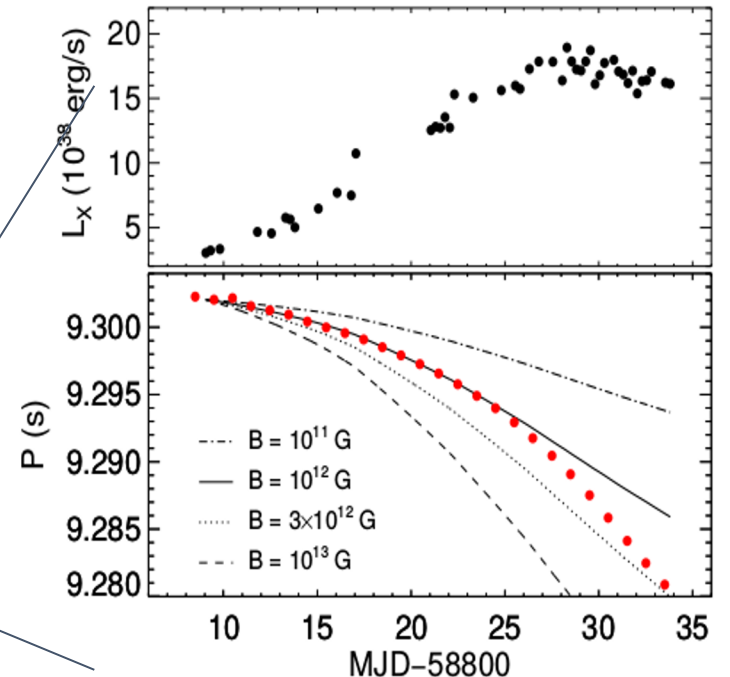
- 2S 1417-624 (Ji et al. 2019): GBM + NICER
- GX 301-2 (Liu 2020): GBM
- GRO J2058+42: GBM + Nustar spectral and timing analysis (Kabiraj & Paul 2020)



XTE J1858+034 – GBM constraints on distance and NuSTAR cyclotron line (Malacaria et al. 2021)

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)

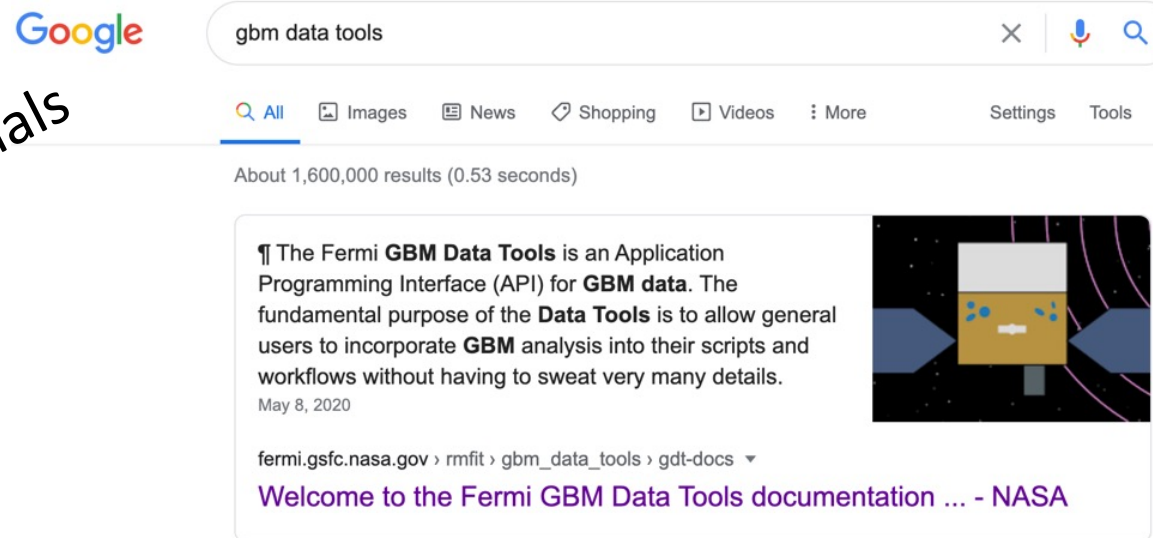


# Neutron Star Physics with Giant Magnetar Flares: Major Progress

- Four papers published related to an extragalactic Giant Magnetar Flare detected with Fermi GBM as GRB 200415A
  - Roberts et al. 2021, “Rapid Spectral Variability of a Giant Flare from an Extragalactic Magnetar”, *Nature*, 589, 207 – detailed study of GBM and Swift/BAT GUANO observations
  - Burns et al. 2021, “Identification of a Local Sample of Gamma-ray Bursts Consistent with a Magnetar Giant Flare Origin” – quantifies extragalactic giant magnetar flare events in several GRB catalogs, including GBM GRB catalog data
  - Svinkin et al. 2021, “A Bright Gamma-ray Flare Interpreted as a Giant Magnetar Flare in NCG 253” – IPN localization (includes GBM) and host identification
  - The Fermi-LAT collaboration et al. 2021, “High-Energy emission from a Magnetar Giant Flare in the Sculptor Galaxy,” *Nature Astronomy*, 5, 385

# Fermi GBM Data Tools

New video tutorials available!



Google featured result

- First version (1.0.2) released at the FSSC on April 7, 2020. Current version is v.1.1.0
- 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
  - Awarded ADAP proposal to adapt GBM data tools for similar mission data: BATSE, HETE-2, etc.
- 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

# GBM technical initiatives for Senior Review 2022

- New alert formats/distribution methods (e.g., TACH, SCIMMA)
- Improve response generator, atmospheric scattering, and localization tools and incorporate into GBM data tools
- Expand and Improve Targeted search
  - Improve infrastructure and response to handle an order of magnitude higher GW events
  - Adapt the targeted search for Extragalactic Giant Magnetar Flares and for magnetar flares associated with Fast Radio Bursts (New MOU with CHIME for FRBs; Fermi GI Cycle 14 funding for archival searches)
  - Explore development of a position based targeted search – stacking lcs over the duration of the mission
- Untargeted search improvements
  - More stringent notice criteria, longer candidate events (up to 10 s), source type classification probabilities (GI funded)
- Revise GBM SAA definition to increase on-time
- Subthreshold onboard trigger – continued work
  - Develop new GCN type for subthreshold alerts and develop strategy for GRBs that would have triggered with standard trigger

# Summary

- GBM is operating nominally with no issues
- For the 6 goals/PMOs for GBM in the 2019 Senior review proposal, one has been completed, two have major progress, two are awaiting new detections of NS-NS mergers, one is in process
  - Automated joint GBM-LIGO/Virgo localization is COMPLETED
  - A detailed search for GBM counterparts to events in the LIGO/Virgo O3 catalog is expected to be submitted before the senior review proposal.
  - 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 and broadening its applications
  - Work to improve latency for sub-threshold triggers is in progress
  - Major progress in time-domain astrophysics (accreting pulsars 7 papers) and high risk/high return (magnetar physics – 4 papers)
- The GBM team is actively developing public user tools to improve access to and usability of GBM data.
- Future initiatives include new alert formats, improvements to and expansions of subthreshold searches, tool improvements, reduced SAA boundary