FERMI-GBM IN THE MULTIMESSENGER ERA

C. Michelle Hui
NASA MSFC

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Since launching in 2008, GBM has detected over 3000 GRBs, ~490 are short GRBs.

4/14 Wednesday Exploring the Cosmos: GRB-1
A Decade of Gamma-ray Bursts Observed by Fermi-GBM — Andreas von Kienlin
FERMI GAMMA-RAY BURST MONITOR

12 NaI detectors (8keV—1MeV)

2 BGO detectors (200keV—40MeV)
Binary neutron star merger and short gamma-ray burst association confirmed!

- GRB 170817A detected by GBM 1.7s after GW170817
  - extensive electromagnetic followup resulting in detection of a kilonova.
  - two components:
    - initial GRB spike — best fit Comptonized model with $E_{\text{peak}}$ 185 keV
    - weak thermal tail — blackbody $kT \sim 10\text{keV}$
- joint science:
  - tightest constraint on speed of gravity: gravitational waves and gamma rays travelled 130 million light years and arrived within 2 seconds -> consistent with speed of light within 1e-15.
  - constraints on neutron star equation of state.
  - open questions: merger and jet geometry, intrinsic properties, population characteristics.
GRB 170817A / GW170817

Structured Jet
Cocoon
Ejecta

Neutron Star Merger
Polar Ejecta, Structured Jet, & Cocoon

Kilonova (UVOIR)

Classical SGRB

Off-Axis SGRB?

15°
30°

Structured Jet
Ejecta

Kilonova (UVOIR)

Classical SGRB

Off-Axis SGRB?

16°

Structured Jet
Ejecta

Kilonova (OIR)

Classical SGRB?

Top Hat Jet?

Neutron Star Merger
Equatorial Ejecta, Top Hat Jet, & No Cocoon

Kilonova (UVOIR)

Neutron Star Merger
Polar Ejecta, Structured Jet, & No Significant Cocoon

Kilonova (OIR)

Neutron Star Merger
Polar Ejecta, Structured Jet, & Cocoon
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

Targeted Search
Timescale: 4-5 hours
Seeded coherent search of continuous time tagged event data combing data from all detectors at a specific time.

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 Circular
Timescale: 5-6 hours

Sub-threshold Detection or Upper Limit Circular
Timescale: 1-2 days

Fermi-GBM followed up 46 of 55 un-retracted public alerts in O3.
JOINT GAMMA-RAY AND GRAVITATIONAL WAVE SEARCHES

GBM-LVC partnership for unique data sharing.
・GBM provides sub-threshold GRBs in low-latency for GW follow-up.
・LVC provides GW candidates below EM Follow-up threshold in low-latency for autonomous targeted searches with GBM.
・GBM detections would increase GW detection confidence, effectively increasing the volume of the Universe accessible.
・Similar GBM / Swift-BAT agreement to increase number and confidence of GRB detections.
・GBM targeted search increases gamma-ray horizon, 60% increase in maximum detection distance of GRB 170817A.
O1/O2 catalogs followup with Fermi-GBM targeted search for 21 out of 25 CBC triggers, remaining 4 did not have GBM data due to passage through the SAA.
O1/O2 catalogs followup with Fermi-GBM targeted search for 21 out of 25 CBC triggers, remaining 4 did not have GBM data due to passage through the SAA.

No other short GRB candidates were found in association with the CBC triggers.
SUB-THRESHOLD SEARCHES: GW O3A

- 39 Events in the O3a Catalog
- 1 possible BNS
- 1 possible NSBH
- No Coincident Events found in GBM

- Updated Ranking for O3 Events to include spatial association probability

$R = \frac{P_{astro} \times P_{vis} \times P_{assoc}}{|\Delta t| \times FAR_{GBM}}$
First joint sub-threshold alert sent on Aug 20 2019 (GCN 25406 / 25465):

- Fermi GBM-190816: A sub-threshold GRB candidate potentially associated with a sub-threshold LIGO/Virgo compact binary merger:
  - a candidate gamma-ray signal identified starting 1.5 s after the GW trigger time.
  - GBM-190816 is approximately 0.1 s in duration, consistent with a short GRB-like signal.
- Followed up observations by several gamma-ray, neutrino, and optical observatories
- Some optical candidates found but no firm association.

Both gamma-ray and gravitational events remain sub-threshold after further analyses.
• Extends the onboard trigger algorithms, with improved background model.
• Looks for signals in 2 NaI detectors with 2.5σ and 1.25σ excess above background.
• The 2 signal detectors must have valid geometry for a point source.
• Time delay for notice range from 0.5 to 6 hours, due to telemetry schedule.
• Available with the GCN notice: https://gcn.gsfc.nasa.gov/fermi_gbm_subthreshold.html
  > Localization FITS file
  > Contour sky map
  > Lightcurve
THE NEUTRINO-GRB CONNECTION

- GRBs are promising sources for high energy neutrino production based on energetics alone, but their connection remains elusive.

- High energy neutrino emission is constrained well below model expectations by IceCube measurements during the prompt emission phase of typical, bright GRBs.

- However, low luminosity and choked GRBs may produce neutrinos detectable by IceCube/IceCube-Gen2.

- Particularly interesting scenarios similar to GRB170817A/GW170817 could result in a BNS detection in GW, EM, and neutrinos.

- Weak EM emission may prove tricky to detect on-board Fermi-GBM → highlights importance of on-ground analysis.

IceCube’s 90% C.L. Upper Limits for Prompt Neutrino Emission


S. Kimura et al., Phys.Rev.D 2018
**STARBURST**

- ESPA-Grande SmallSat to detect SGRBs coincident with GW detections.
  - PI: Dan Kocevski, NASA/MSFC
- Selected for NASA's new Astrophysics Pioneers Program, currently in Phase A.
- Nominal launch in 2025 for a 1-2 year mission to coincide with LIGO A+.
- Instrument design based on the Glowbug ISS payload.
  - Sensitive to 30-2000 keV energy range.
  - Azimuth average effective area peak of ~3500 cm², compared to GBM @ ~600 cm² and Glowbug @ ~1100 cm²
- Detection Rate:
  - StarBurst: 200 SGRBs/yr
  - Swift: 10 SGRBs/yr, GBM: 40 SGRBs/yr
- Joint Detection Rate (based on model developed by E. Howell et al.)
  - Estimated rate of 3.7% of the A+ BNS detection rate
  - Estimated median rate of 9.8 GW-SGRBs/yr (2.6—25.2 @ 90% CL)
MOONBEAM
Moon Burst Energetics All-sky Monitor

- 2-year SmallSat mission concept to detect gamma-ray bursts, currently undergoing concept study funded by the 2019 Astrophysics Science SmallSat Studies.
- Science instrument is 5 detector modules (NaI/CsI phoswich + flat PMTs) positioned to maximize sky coverage.
- Cislunar orbit at >150,000 km from Earth majority of the time.
  ▶ Earth occults < 0.1% of sky at maximum.
  ▶ High duty cycle, no SAA passage.
  ▶ More stable background compared to Low Earth Orbit.
  ▶ Additional localization improvement with IPN-like timing triangulation.

SGRB rate up to 70/year
*assuming single-crystal detector
OUTLOOK

• New era for multi-messenger astronomy with joint GW-EM detection of a binary neutron star merger.
• Many open questions remain, looking forward to more joint detections with gamma-ray instruments that will enable deeper population studies of SGRBs.
• Subthreshold searches are crucial to increasing GRB sensitivity and the detection horizon
• Several future gamma-ray missions targeting multimessenger astronomy in different phases of development.
• More on GBM related work on Wednesday 4/14:
  Exploring Gamma-ray Data: Plenary-3:
  Fermi GBM Data Tools and GSpec — Adam Goldstein
  Exploring the Cosmos: GRB-1:
  A Decade of Gamma-ray Bursts Observed by Fermi-GBM — Andreas von Kienlin
  Photospheric emission in GRBs observed by Fermi/GBM — Felix Ryde
  Magnetar Giant Flares as Gamma-Ray Bursts — Rachel Hamburg
  Exploring Connections: Neutrinos and Gamma Rays:
  Multimessenger follow-up of high energy neutrino events using Fermi-GBM — Joshua Wood
  Gamma-ray Bursts/SN/Instrumentation-2:
  Fermi-GBM and Swift-BAT detection of an extragalactic magnetar giant flare — Peter Veres