Fermi GBM Status, Results, Plans

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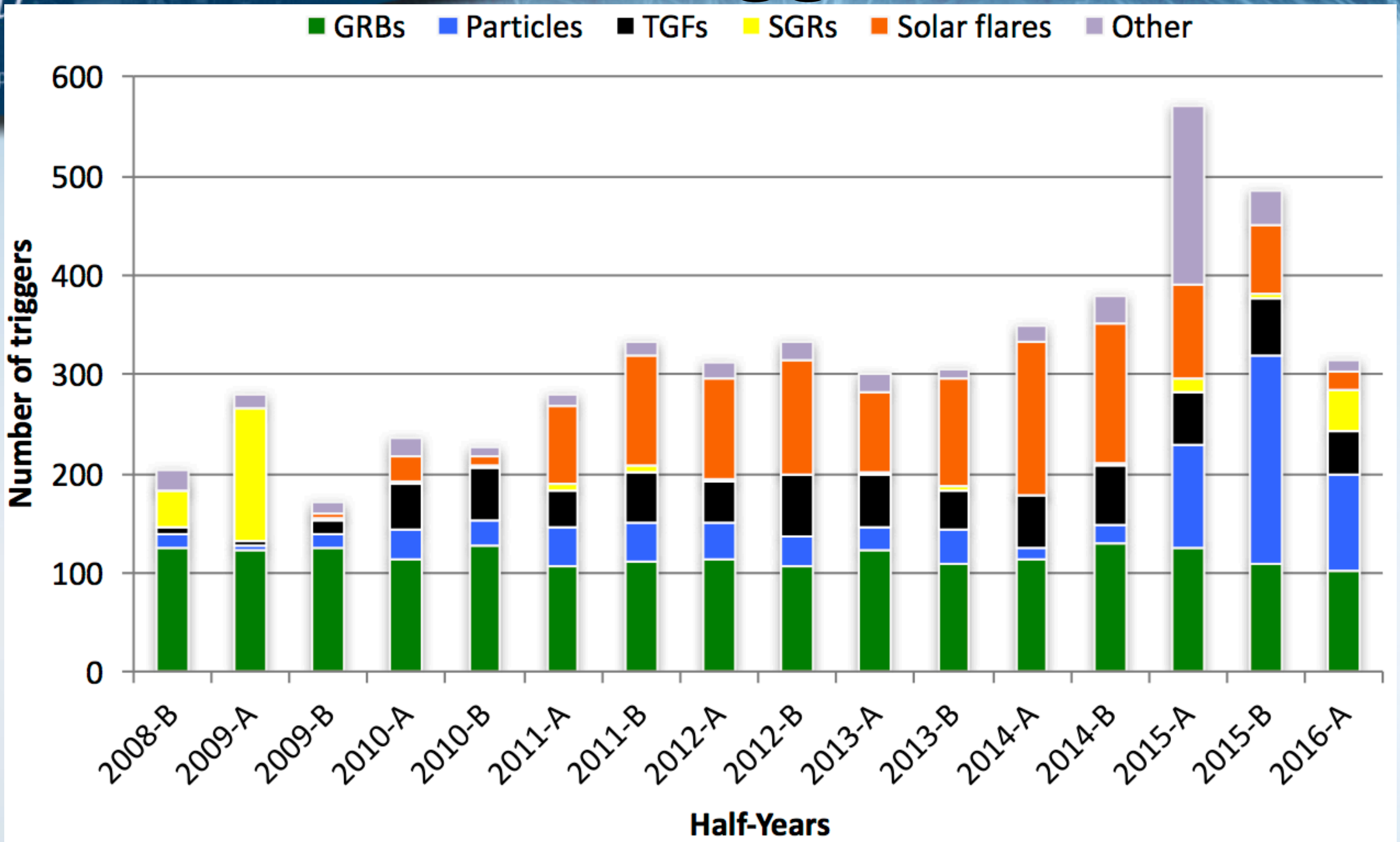
Fermi Users Group
18 August 2016

GBM Trigger Rate

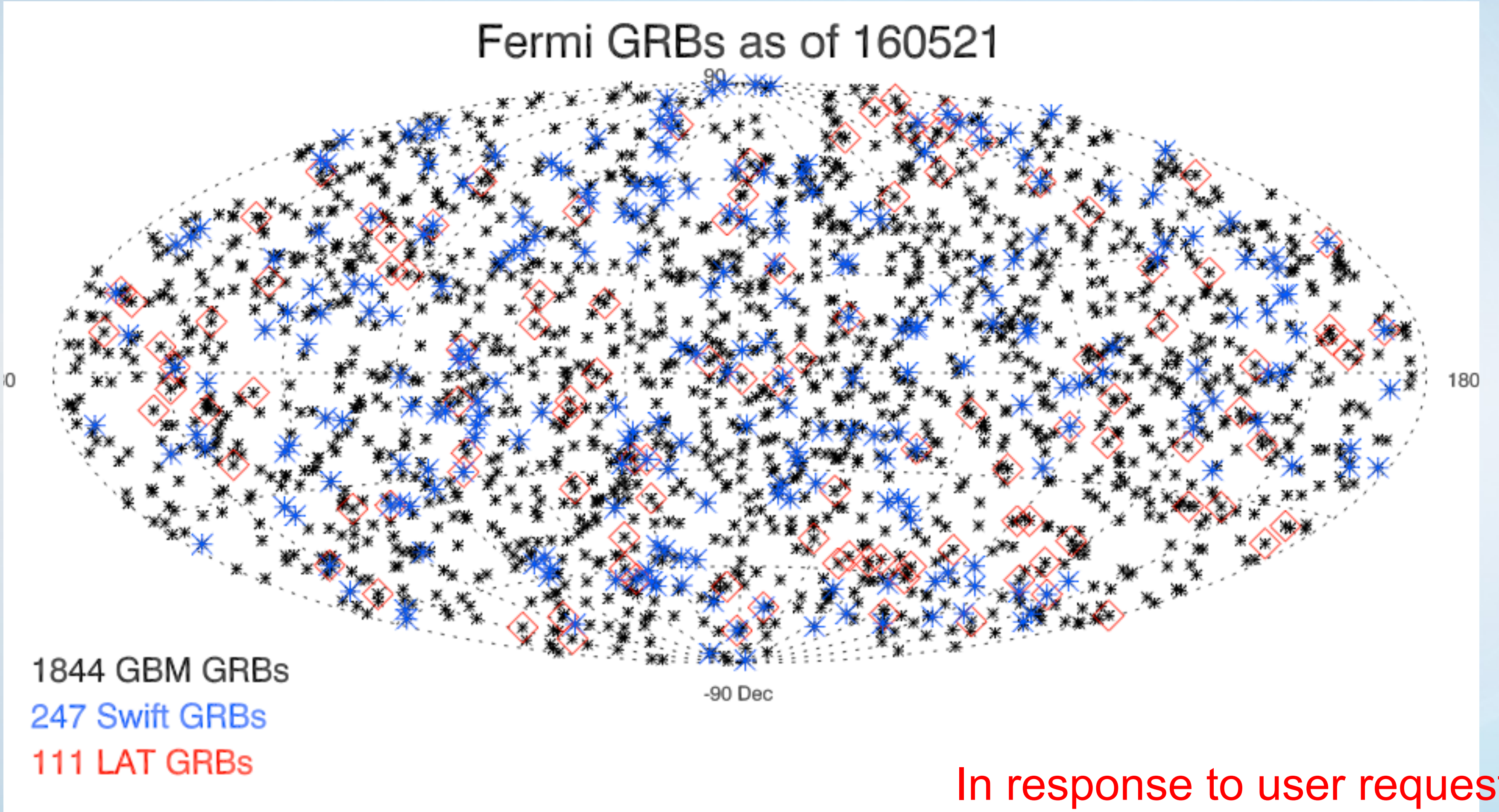


5138 triggers as of July 31, 2016

- Gamma-ray bursts (GRBs): 1879 (triggered twice on each of four long GRBs)
- Soft gamma repeaters (SGRs) aka magnetars: 267 (from 6 sources)
- Terrestrial gamma flashes (TGFs): 686 triggered, ~5x more untriggered
- Solar Flares: 1121
- Particles: 746
- Others (galactic XRBs, accidental, uncertain): 435 (169 from V404 Cygni)

168 positive Autonomous Repoint Recommendations

GBM has now seen >1700 GRBs



In response to user requests,
GBM GRB catalog is now updated within 1 hour, spectral information ~weekly

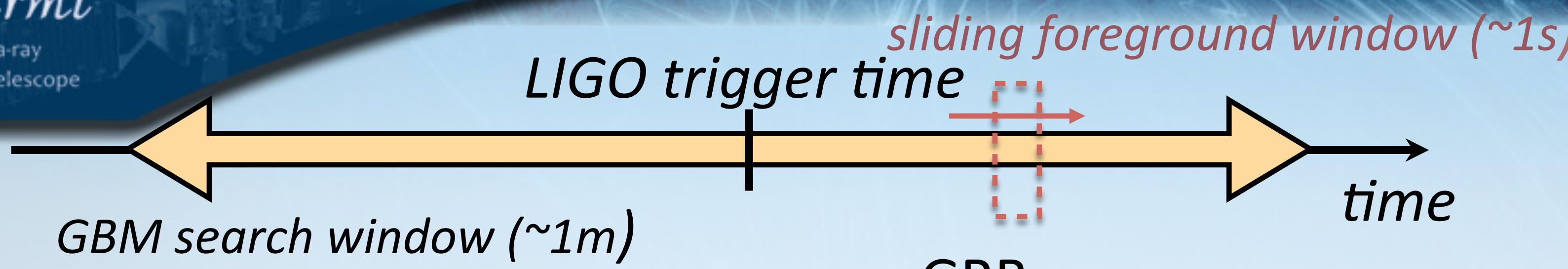
Operational Changes & Improvements

- RoboBA – automatic production and distribution of final GRB localizations (via GCN)
  - Notices distributed within 10 min for 80% of GRBs
  - Notifies human BA if fitting fails
  - Only for GRBs. Future mod planned for on-ground trigger classification
- Hourly CTTE data files
  - Currently being produced and tested. Will be delivered to FSSC when testing is complete.
  - Removes timing glitches and improves latency for untriggered searches.
  - Convenient: simpler to predict which file contains an event
- PMT Gain Balance Test
  - Performed on March 3, 2016, 12:20 UT to 23:50 UT
  - BGO data were non-standard and therefore not delivered to the FSSC.
  - PMTs found to be balanced for both BGO detectors, so no changes needed.

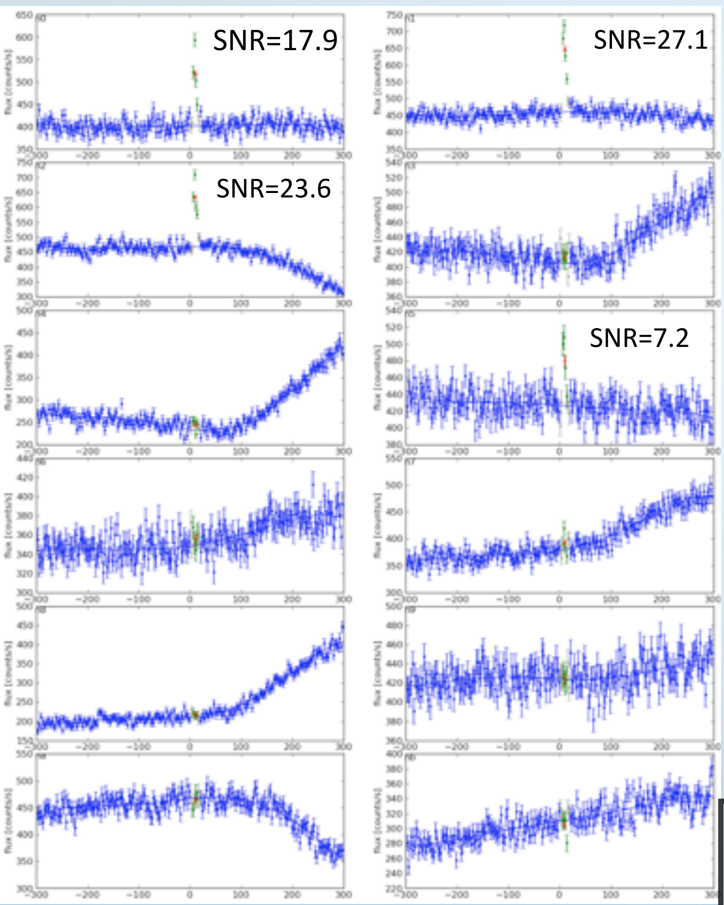
Searching GBM data for LIGO EM counterparts

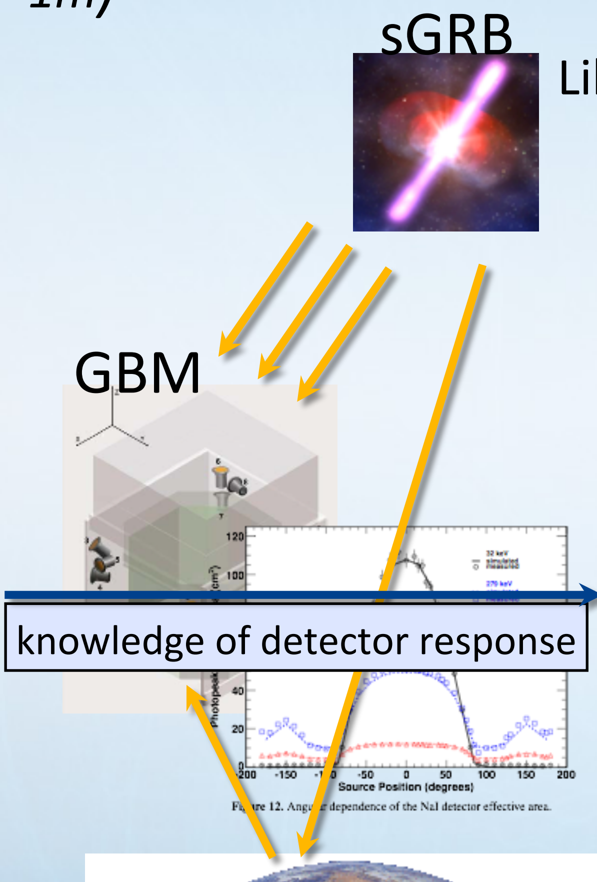
- Under an MOU with the LIGO consortium, GBM has implemented searches of GBM data for short GRB as counterparts of candidate gravitational wave (GW) events
  - A seeded search (Blackburn et al 2015, ApJS, 217,8) of GBM CTIME data for prompt emission
    - Uses count rate template matching, weighting 3 spectral models folded through the detector response
  - An unseeded search of CTTE data for sub-threshold short GRBs
    - http://gammaray.nsstc.nasa.gov/gbm/science/sgrb_search.html
  - A search for persistent emission using the Earth Occultation technique with CTIME data

GBM Seeded Search

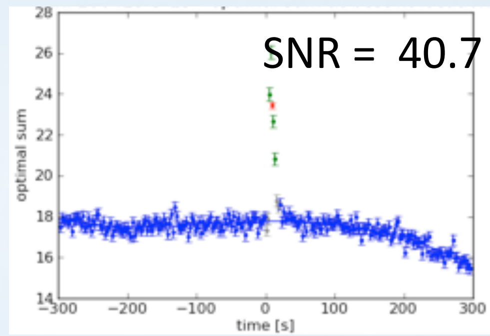


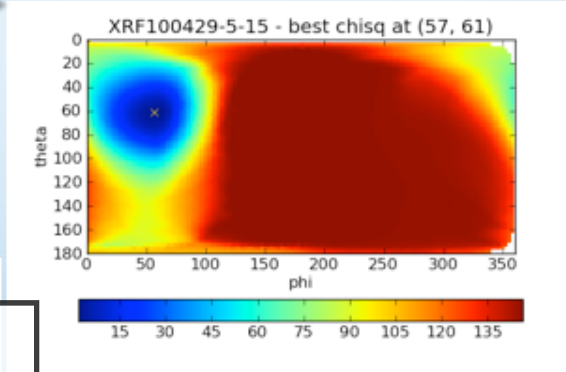
Individual GBM detector data





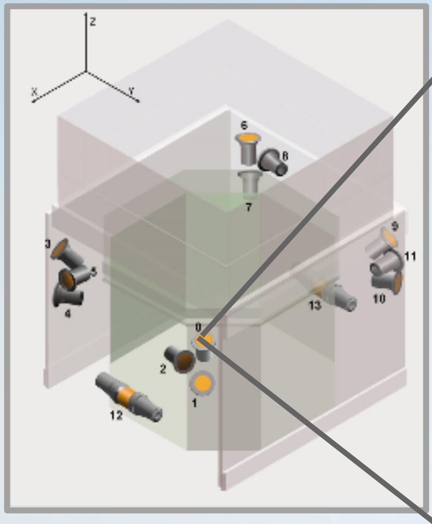
Likelihood-ratio characterizes event as originating from model vs noise alone

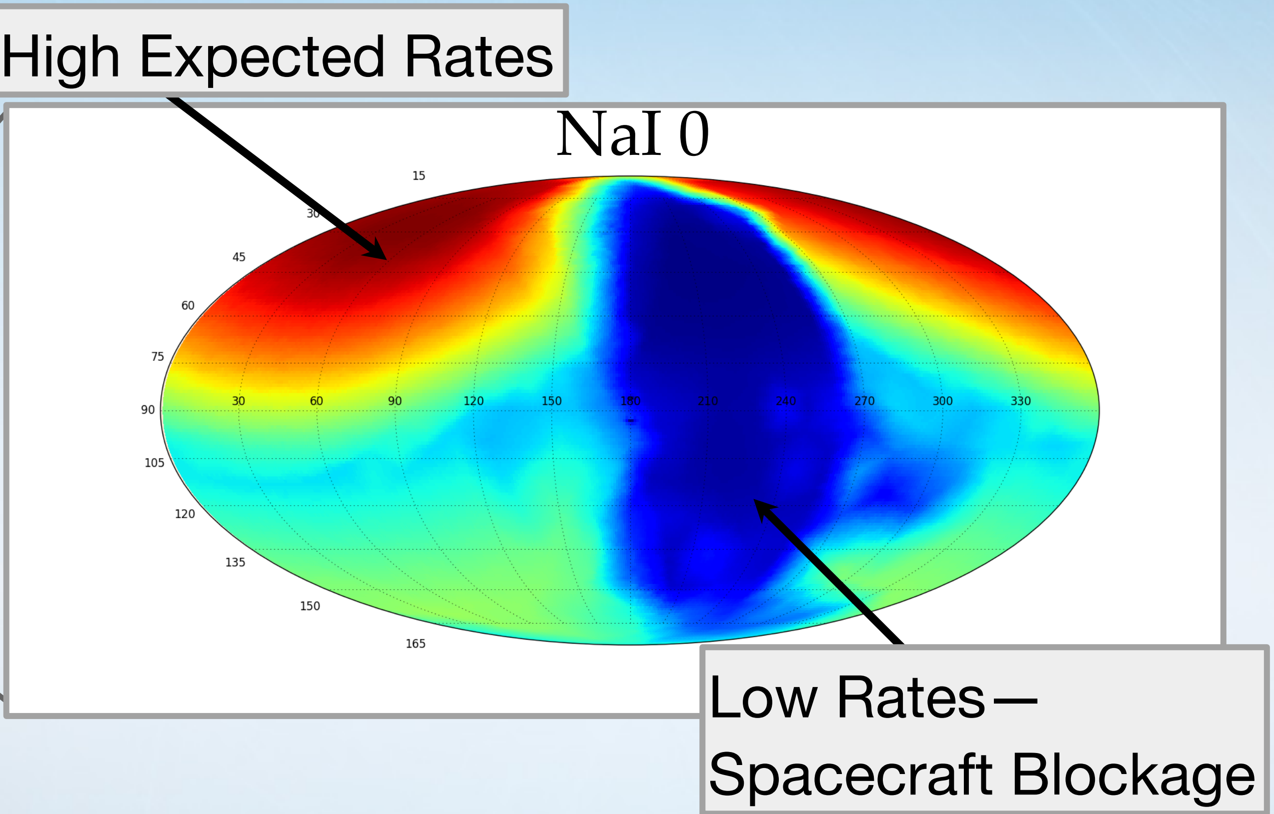




predicted counts depend on:
amplitude, light-curve, spectrum, source position, Earth position

Fermi GBM localization





- Localization is performed by comparing the relative observed rates from the GRB in each detector to the expected rates from a 1 degree grid
- This requires an assumption of the spectrum, and the sky grid limits to a statistical minimum uncertainty of 1 degree radius.

GBM Unseeded Search sGRB Candidate

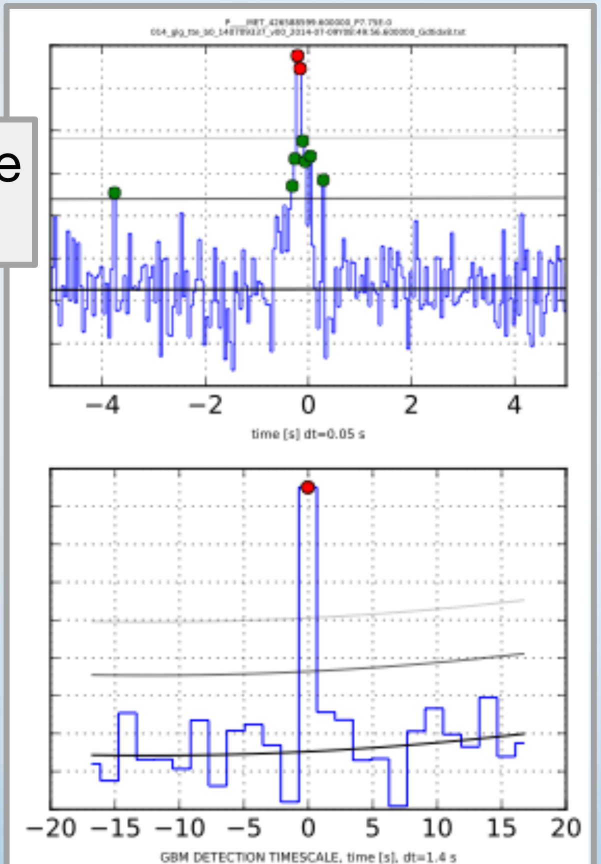
Fermi Gamma-ray Space Telescope

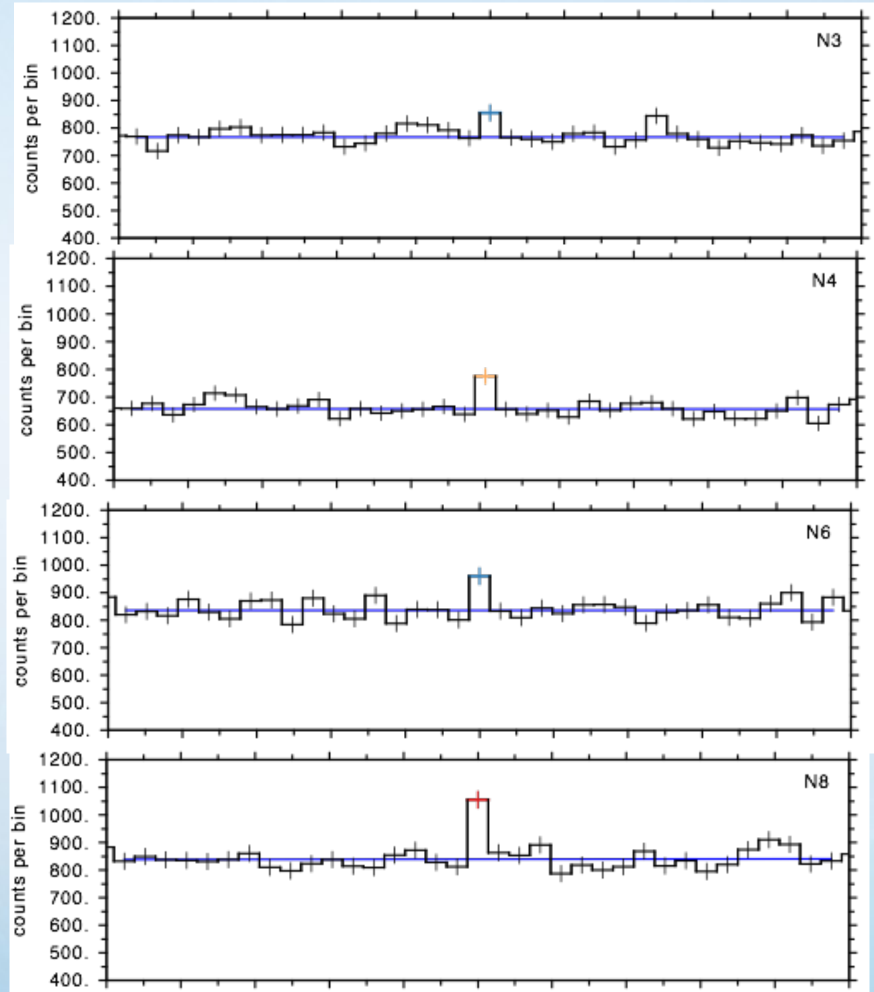
2014-07-09 08:49:56.600
Found in 1.40s time binning
25 - 494 keV energy range
P=7.75e-14

INTEGRAL ACS lightcurves

ACS native time bins

GBM timescale





3.18σ

4.60σ

4.31σ

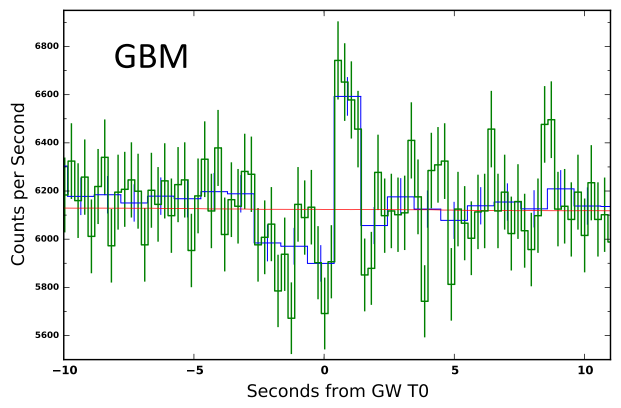
7.44σ

GBM Observations of GW Events

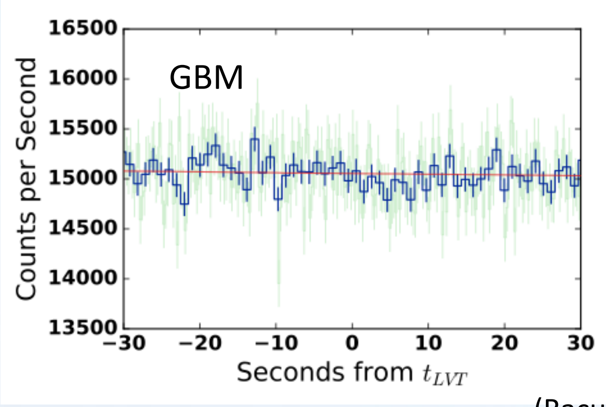
GW150914
(Abbot et al. 2016a)
- BH+BH Merger
- 36 and 29 M_{sun}
- 410 Mpc

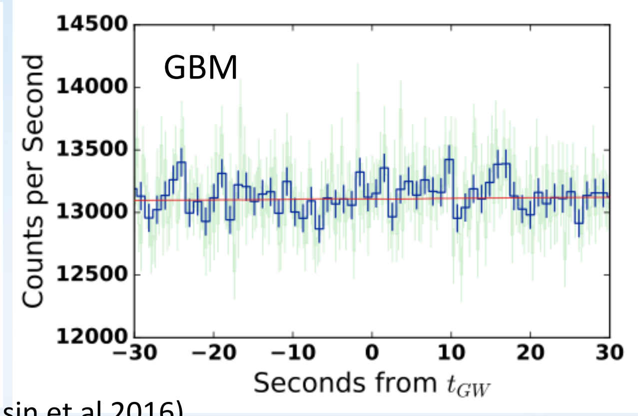
LVT151012
(Abbott et al 2016a)
- Candidate BH+BH
- 23 and 13 M_{sun}
- 1100 Mpc

GW151226
(Abbott et al. 2016b)
- BH+BH Merger
- 14 and 7.5 M_{sun}
- 440 Mpc



(Connaughton et al 2016)





(Racusin et al 2016)

- GW150914-GBM, a 2.9σ event consistent with a short GRB
  - Not predicted by theoretical models
- No gamma-ray detections for LVT151012 or GW151226 – not constraining
  - 32% and 17% of LIGO localization region blocked by Earth for GBM
  - Backgrounds were 18% and 3% higher in GBM
  - Distance for LVT151012 was 3x larger
  - If gamma-ray emission is in a jet, only 15-30% would be pointed toward Earth
- Need more events before we can say more!

GBM Preparations for LIGO O2

- LIGO's next observing run (O2) expected to begin in late September. Creating automated search pipelines for GBM.
  - Seeded search
    - Now uses CTTE data to enable shorter timescales
    - Improved background estimate (unbinned Poisson maximum likelihood)
    - Joint statistic to account for spatial coincidence
    - Replacing hard template with Comptonized model with index -0.5 and Epeak = 1.5 MeV
  - Unseeded search
    - Automatic evaluation of background quality to reduce latency
    - Produce notices for communication with LIGO
    - Inter-comparisons with seeded search to internally validate candidates
    - Additional algorithms to increase sensitivity
  - Tool to inject simulated signals into data
  - Document our techniques on arXiv before the start of O2

Catalogs from GBM

- The Fermi-GBM Three-year X-ray Burst Catalog, P. Jenke et al. 2016, ApJ, 826, 22
  - 1084 events, including 752 thermonuclear X-ray bursts, 267 events from accretion flares and X-ray pulses, and 65 untriggered GRBs
- The 3rd Fermi GBM Gamma-ray Burst Catalog: The First Six Years: N. Bhat et al 2016, ApJS: 1403 bursts
- The Fermi GBM GRB time-resolved spectral catalog: the brightest bursts in the first 4 years, H. Yu et al 2016, A&A, 588, A135: 81 bursts
- First GBM TGF catalog: includes GBM and WWLLN data
  - http://fermi.gsfc.nasa.gov/ssc/data/access/gbm/tgf/
  - 3356 TGFs from 2008 Jul 11 – 2015 June 23; >80% untriggered

FERMI GBM OBSERVATIONS OF LIGO GRAVITATIONAL-WAVE EVENT GW150914

V. Connaughton[1], E. Burns[2], A. Goldstein[3,20], L. Blackburn[4,5], M. S. Briggs[6,7], B.-B. Zhang[7,8], J. Camp[9], N. Christensen[10], C. M. Hui[3], P. Jenke[7] Show full author list

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The Astrophysical Journal Letters, Volume 826, Number 1

Focus on Electromagnetic Counterparts to Binary Black Hole Mergers

Metrics

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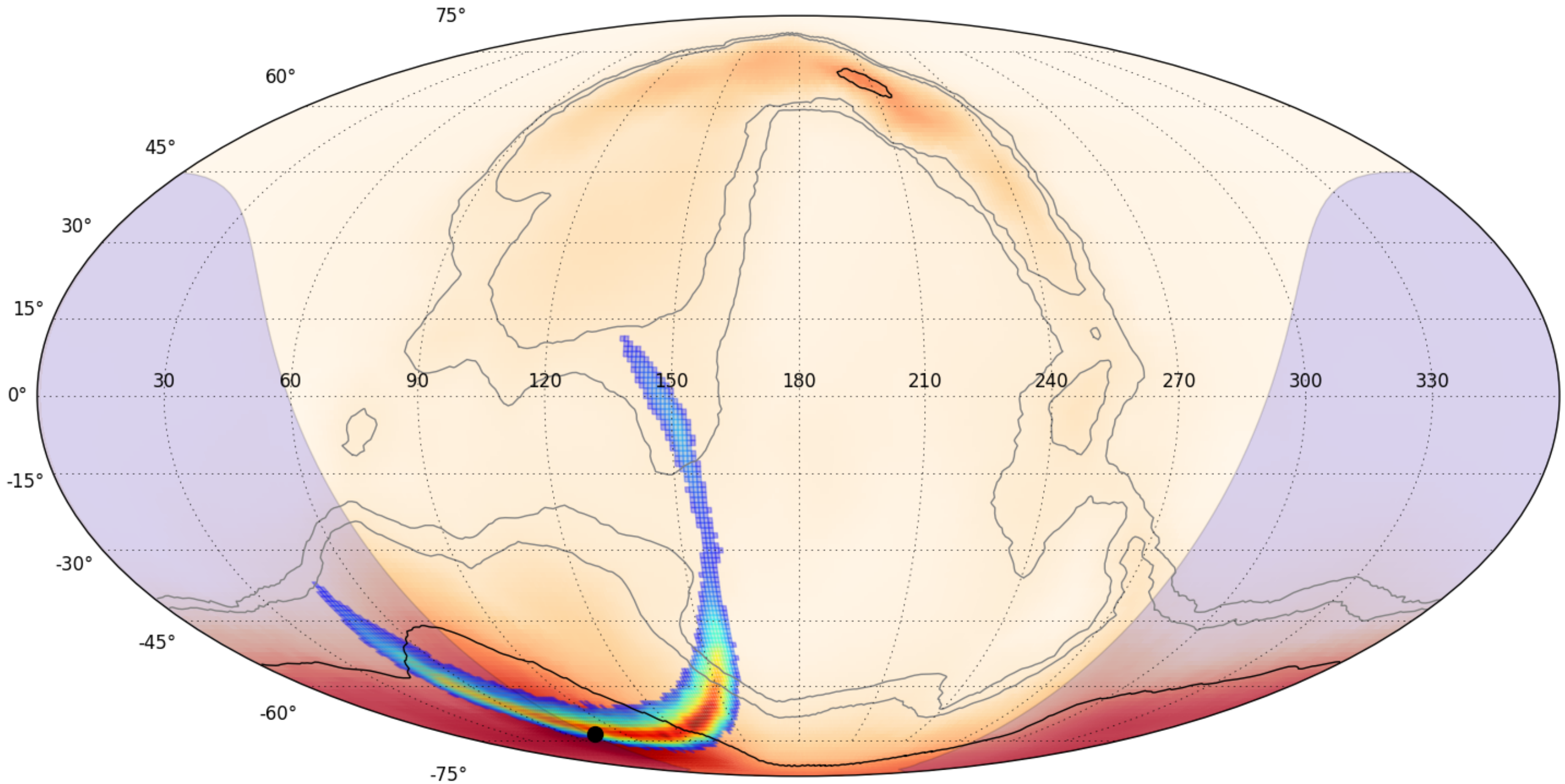
Abstract

With an instantaneous view of 70% of the sky, the *Fermi* Gamma-ray Burst Monitor (GBM) is an excellent partner in the search for electromagnetic counterparts to gravitational-wave (GW) events. GBM observations at the time of the Laser Interferometer Gravitational-wave Observatory (LIGO) event GW150914 reveal the presence of a weak transient above 50 keV, 0.4 s after the GW event, with a false-alarm probability of 0.0022 (2.9σ). This weak transient lasting 1 s was not detected by any other instrument and does not appear to be connected with other previously known astrophysical, solar, terrestrial, or magnetospheric activity. Its localization is ill-constrained but consistent with the direction of GW150914. The duration and spectrum of the transient event are consistent with a weak short gamma-ray burst (GRB) arriving at a large angle to the direction in which *Fermi* was pointing where the GBM detector response is not optimal. If the GBM transient is associated with GW150914, then this electromagnetic signal from a stellar mass black hole binary merger is unexpected. We calculate a luminosity in hard X-ray emission between 1 keV and 10 MeV of $1.8^{+1.5}_{-1.0} \times 10^{49}$ erg s^{-1}. Future joint observations of GW events by LIGO/Virgo and *Fermi* GBM could reveal whether the weak transient reported here is a plausible counterpart to GW150914 or a chance coincidence, and will further probe the connection between compact binary mergers and short GRBs.

GW150914-GBM Localization

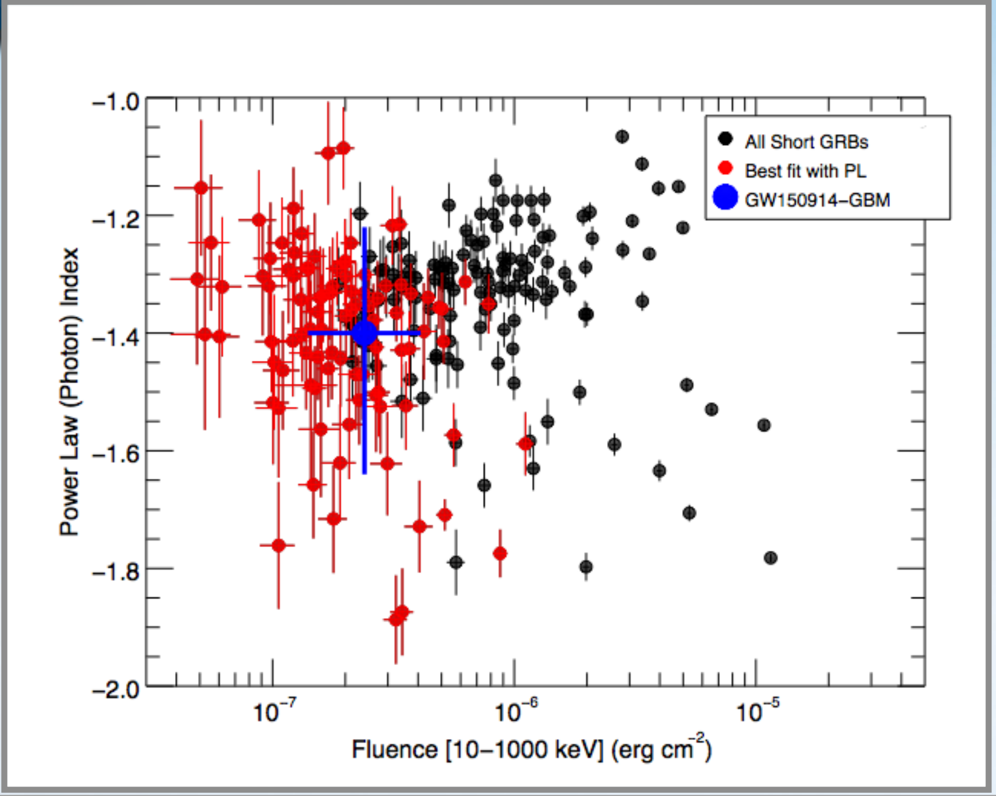


- GBM highest probability region coincides with LIGO highest probability region
- Some probability in the “North” - localization mirror point resulting from event underneath spacecraft

Spectrum & Fluence

- Only used detector NaI 5 & BGO 0: smallest source angles - standard GBM analysis
- Background fit with a 1st-order polynomial using a 2-pass linear least-squares minimization (background livetime is ~30 s for 1 s signal)
- Spectral fitting is performed using a forward-folding Levenberg-Marquardt algorithm, minimizing the Castor C-statistic (Poisson likelihood), assuming the background model variance is negligible compared to the Poisson rate variance.
- For each of the 10 points, perform a joint fit of a PL to the signal in the two detectors
- At each point, simulated 1e4 deviates of the fitted spectrum using the background livetime, signal livetime, and responses. These synthetic spectra were then fit, producing an estimate of the spectral PDF at each point.
- The spectral PDFs were marginalized over the sky points to produce the spectrum estimate over the LIGO arc.

GW150914-GBM Spectral Comparison



- All short GBM-triggered short GRBs fit with a PL compared to **best** fit with a PL
- Weaker short GRBs can only be fit by a PL because curvature cannot be constrained
- Almost all short GRBs where we can fit curvature have an exponential cutoff near the peak spectral density.

On the GBM event seen 0.4 sec after GW 150914

J. Greiner, J.M. Burgess, V. Savchenko, H.-F. Yu

(Submitted on 1 Jun 2016 (v1), last revised 10 Jun 2016 (this version, v2))

In view of the recent report by Connaughton we analyse continuous TTE data of Fermi-GBM around the time of the gravitational wave event GW 150914. We find that after proper accounting for low count statistics, the GBM transient event at 0.4 s after GW 150914 is likely not due to an astrophysical source, but consistent with a background fluctuation, removing the tension between the INTEGRAL/ACS non-detection and GBM. Additionally, reanalysis of other short GRBs shows that without proper statistical modeling the fluence of faint events is over-predicted, as verified for some joint GBM-ACS detections of short GRBs. We detail the statistical procedure to correct these biases. As a result, faint short GRBs, verified by ACS detections, with significances in the broad-band light curve even smaller than that of the GBM-GW150914 event are recovered as proper non-zero source, while the GBM-GW150914 event is consistent with zero fluence.

Comments: 13 pages, 12 figures, ApJL (acc.); subm. 2016 March 10, Apr 21 (1st rev.), May 13 (2nd rev), Jun 1 (3rd rev), and editorial changes by Jun 2 (4th rev), Jun 8 (5th rev): Our manuscript refers exclusively to arXiv:1602.03920.v3 since we had no prior access to arXiv:1602.03920.v4/5 (2016 May 31). Note that JG and HFY are not co-authors on arXiv:1602.03920.v4/5

Subjects: **High Energy Astrophysical Phenomena (astro-ph.HE)**

Cite as: **arXiv:1606.00314 [astro-ph.HE]**

(or **arXiv:1606.00314v2 [astro-ph.HE]** for this version)

- Independent analysis of GBM data for GW150914-GBM from which the authors conclude the event we report in VC+ 2016 is more consistent with background than with the presence of a source.

Summary of Issues with Greiner et al paper

- User only 2 detectors to determine the statistical significance using spectral analysis, which does not challenge the statistical significance reported by VC+2016, found in count space by combining coherently the data from 14 detectors in a seeded search, based on an empirically-derived FAR
- Incorrect and excluded single source position results in a much higher effective area in NaI 5 than used in VC+2016, resulting in an overestimate of counts predicted using the fluence reported in VC+2016.
- Use 128-channel TTE data; VC+ use 8-channel CTIME data, coarser binning which does not suffer from low-count statistical problems.
- Lower fluence with MLEfit implies consistency with non-detection by SPI-ACS

A single position along the LIGO arc is used to test the deconvolution from rmfit and MLEfit against the observed count rates in a single detector.

Table 1 of Greiner et al.

RA (deg)	DEC (deg)	RMFIT-based analysis Amplitude (ph/cm^2/s) (@100 keV)	Index	Fluence (10^{-7} erg/cm^2) (10–1000 keV)	PGStat-based analysis Amplitude (ph/cm^2/s) (@100 keV)	Index	Fluence (10^{-7} erg/cm^2) (10–1000 keV)
84.0	-72.8	0.0043±0.0020	−1.44 ± 0.14	4.3±1.5	0.0035±0.0031	−1.85 ± 0.86	2.7±2.6
155.3	-43.2	0.0019±0.0006	−1.26 ± 0.11	2.1±0.6	0.0008±0.0005	−1.50 ± 0.25	0.8±0.5
102.0	-73.9	0.0039±0.0016	−1.42 ± 0.13	3.9±1.2	0.0025±0.0020	−1.93 ± 0.43	1.9±1.6
118.3	-72.9	0.0034±0.0013	−1.39 ± 0.12	3.5±1.0	0.0018±0.0019	−1.79 ± 0.42	1.4±1.3
132.0	-70.4	0.0030±0.0011	−1.36 ± 0.12	3.2±0.9	0.0014±0.0014	−1.72 ± 0.39	1.1±1.0
140.9	-66.6	0.0026±0.0009	−1.33 ± 0.11	2.9±0.8	0.0014±0.0011	−1.69 ± 0.32	1.1±0.9
147.5	-62.5	0.0024±0.0008	−1.31 ± 0.11	2.7±0.7	0.0009±0.0007	−1.57 ± 0.32	0.8±0.6
151.2	-58.0	0.0022±0.0007	−1.29 ± 0.11	2.5±0.7	0.0009±0.0006	−1.54 ± 0.28	0.8±0.6
153.4	-53.1	0.0020±0.0007	−1.28 ± 0.11	2.4±0.6	0.0009±0.0006	−1.50 ± 0.26	0.8±0.6
153.9	-48.2	0.0019±0.0006	−1.27 ± 0.11	2.2±0.6	0.0009±0.0005	−1.49 ± 0.25	0.8±0.5

Table 2 of VC+

RA	Dec	SC ϕ	SC θ	NaI 0	1	2	3	4	5	6	7	8	9	10	11	BGO 0	1	Prob. %
83.98	-72.85	342	160	144.8	122.0	83.1	117.8	76.1	71.2	161.5	142.0	97.3	149.2	103.3	108.6	70.8	109.2	12.1
101.99	-73.87	349	156	139.9	117.1	79.2	115.2	75.4	66.5	161.6	145.5	101.3	149.4	104.1	113.4	66.1	113.9	10.0
118.31	-72.94	354	151	134.9	112.3	75.6	112.0	74.2	61.6	159.9	148.3	105.0	149.3	105.4	118.3	61.3	118.7	10.3
132.04	-70.44	357	147	129.9	107.6	72.4	108.5	72.8	56.7	157.0	150.1	108.3	149.0	106.9	123.2	56.5	123.5	11.2
140.85	-66.63	358	142	125.2	103.3	69.9	104.4	70.7	51.7	153.1	150.5	110.9	148.7	109.0	128.2	51.5	128.5	10.3
147.53	-62.51	359	137	120.3	98.8	67.4	100.3	68.9	46.7	148.8	150.2	113.5	147.5	110.9	133.2	46.5	133.5	7.4
151.18	-57.97	358	132	115.5	94.5	65.5	96.0	66.9	41.7	144.3	148.8	115.6	146.2	113.0	138.2	41.5	138.5	5.8
153.363	-53.091	360	127	111.2	90.8	64.7	91.2	64.0	37.0	139.4	145.9	116.5	145.2	115.9	142.9	36.7	143.3	3.7
153.933	-48.239	359	122	106.7	87.1	64.0	86.6	61.6	32.2	134.5	142.8	117.4	143.5	118.4	147.7	31.8	148.2	1.8
155.331	-43.208	358	116	102.5	83.7	64.1	81.7	58.6	27.7	129.5	138.9	117.4	141.9	121.4	152.1	27.1	152.9	2.0
151.172	-7.256	342	84	75.4	66.7	76.2	45.6	39.5	21.9	93.6	105.2	105.6	124.1	141.1	157.9	18.7	161.3	4.8
75.	-73.	348.	163.	147.	124.	84.	120.	78.	74.	162.	141.	96.	148.	102.	106.	73.4	106.6	N/A (

rmfit fit with 128 channel data convolved with response for same incorrect source position.

Purple point assumes single source position excluded by GBM and joint GBM/LIGO localization, with 27 deg angle to NaI 5 vs ~70 deg for favored source position (i.e., ~3x more expected counts).

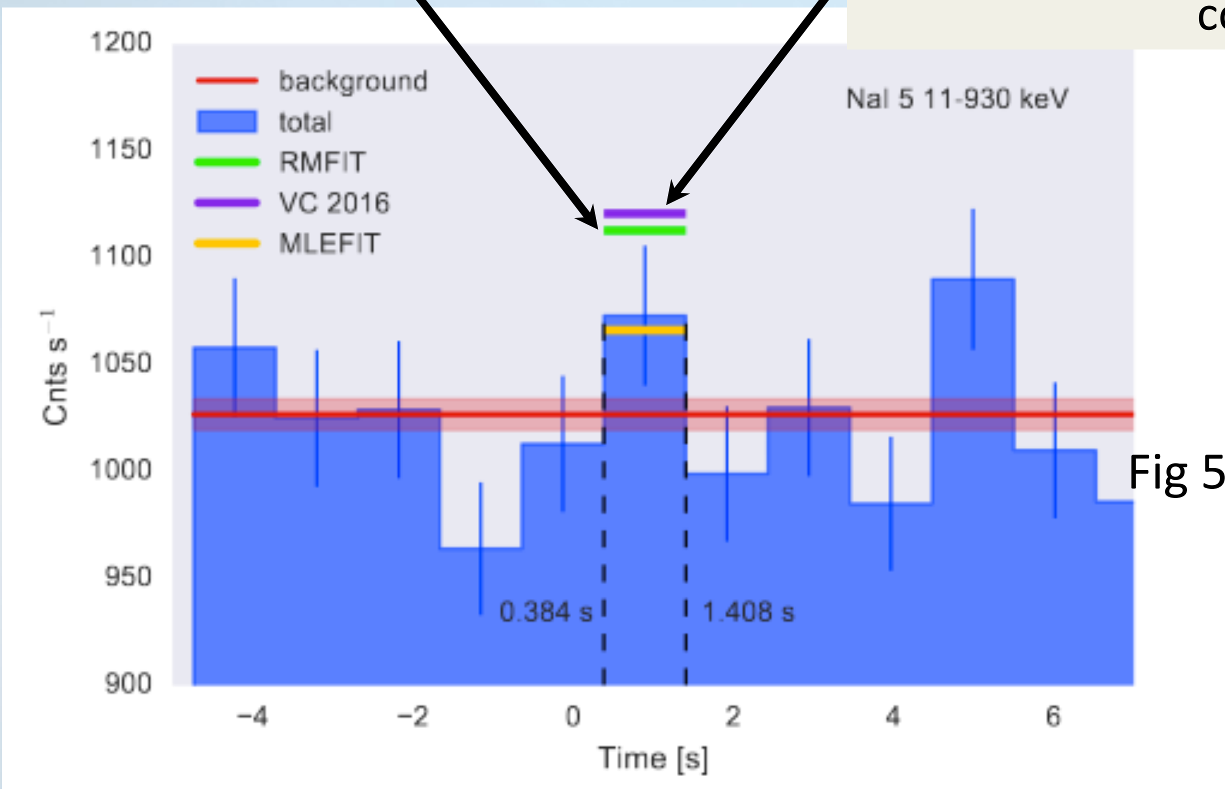
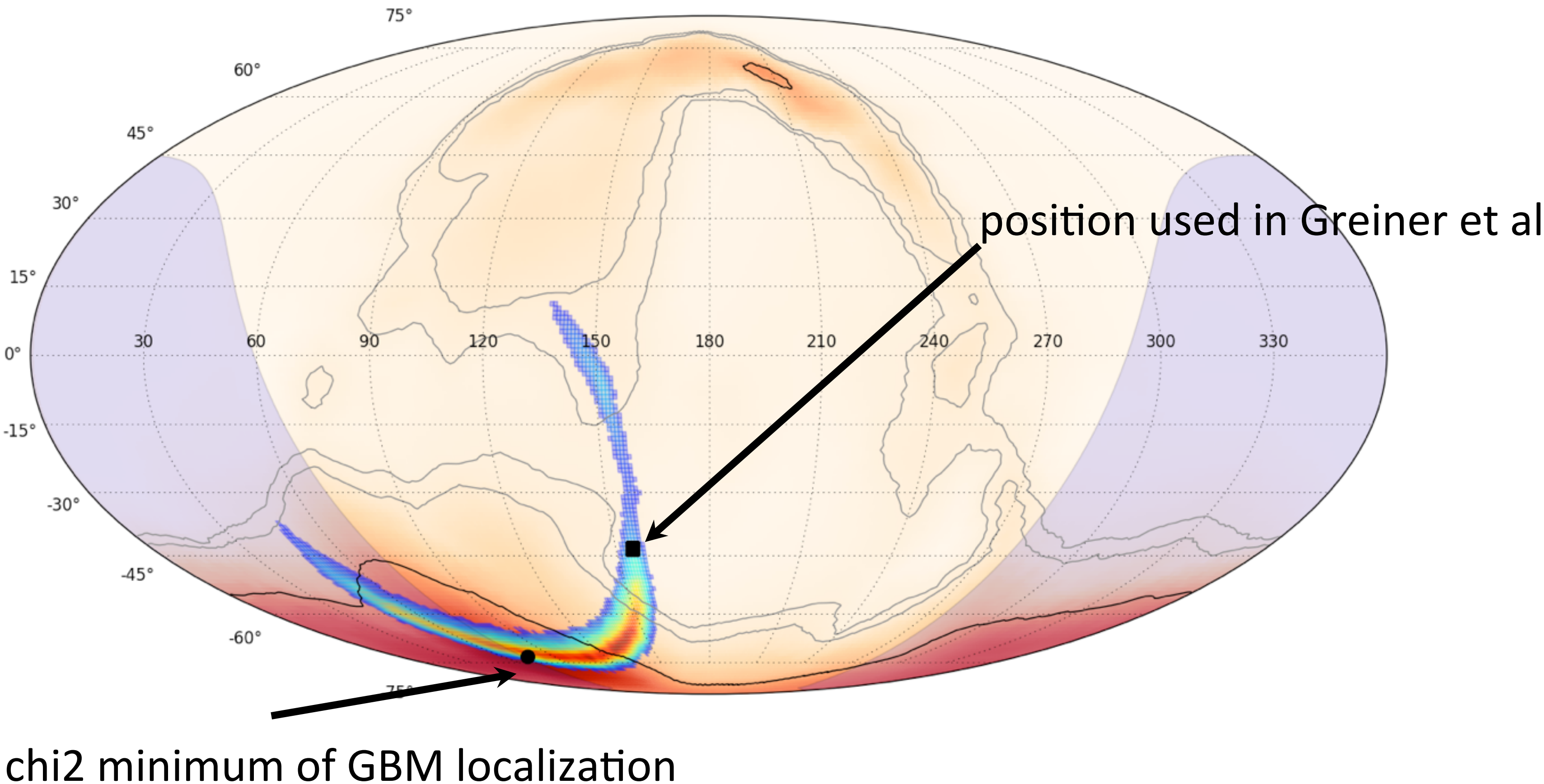


Fig 5 of Greiner et al.

This error appears to be propagated throughout the rest of the analysis - using the amplitude from VC+ but for a source at a single location.

However, this position in Fig 5 is excluded by the GBM localization and contains only 2% of the LIGO probability - completely excluded by joint GBM-LIGO localization



This error appears to be propagated throughout the rest of the analysis - using the amplitude from VC+ but for a source at a single location, excluded by the GBM detector rates.

Exploring INTEGRAL SPI-ACS non-detection: power-law fit (unphysic

rmfit fit to 128-channel data in tension with non-detection of GW150914-GBM by INTEGRAL SPI-ACS (red crosses) (Values don't match Table 1 of JG+)

MLEfit consistent with non-detection of GW150914-GBM by INTEGRAL SPI-ACS (green crosses)

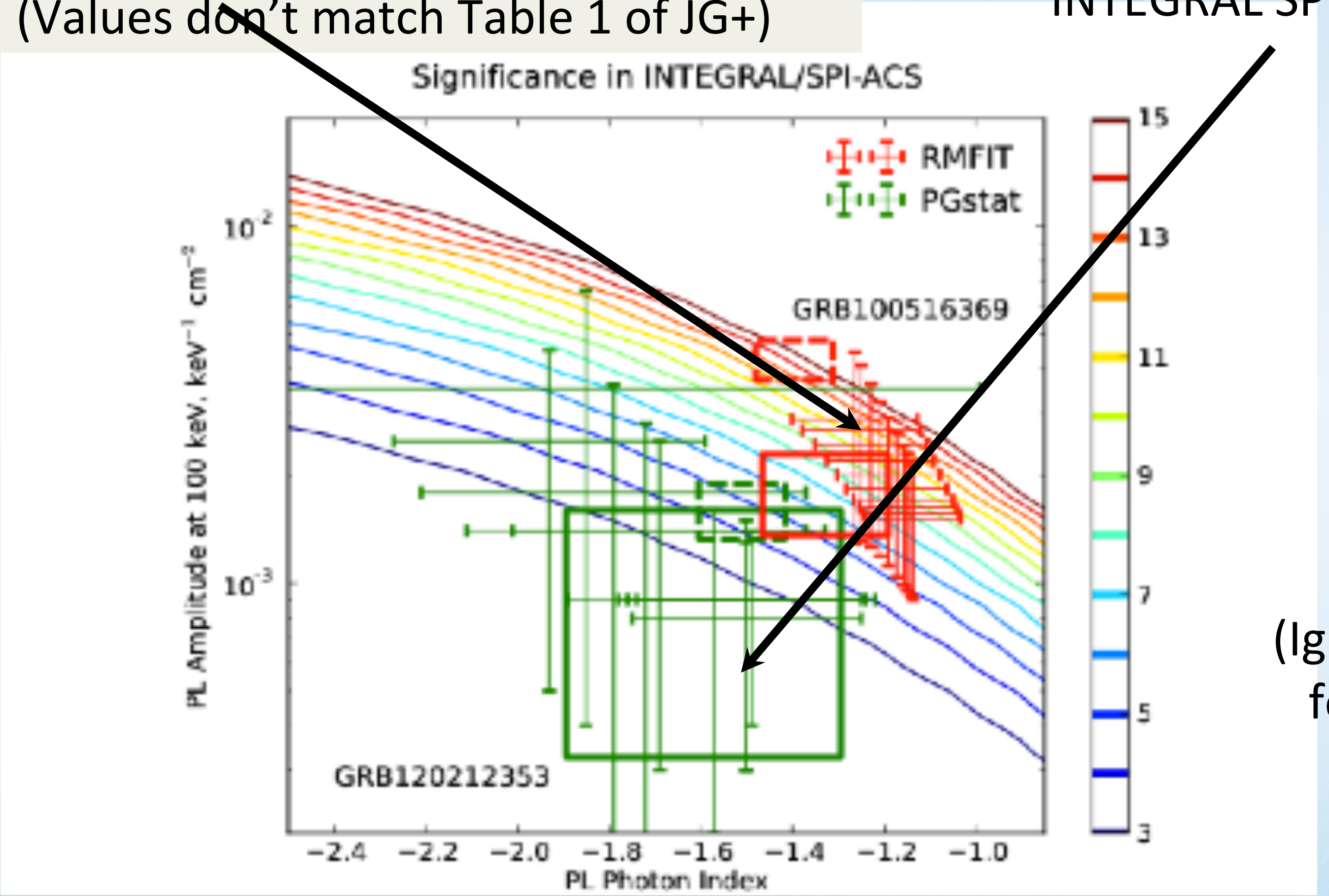


Fig 12 of Greiner et al.

(Ignore boxes: they are for unrelated GRBs)

GBM and INTEGRAL SPI-ACS teams are collaborating on joint analysis of short GRBs to understand how the instruments complement one another.

GBM Summary

- GBM operations and performance are nominal
  - RoboBA has improved latency for distribution of localizations for most GRBs
  - The BGO PMT balance test shows that the PMTs are still very stable after 8 years.
- Searches for LIGO EM counterparts
  - Automated pipelines and improvements to our seeded and unseeded searches are being implemented and documented for O2
  - VC et al. paper about GW150914-GBM has been published in ApJ Letters.
  - Two other GW events in O1 show no detectable gamma-ray signal, but do not constrain GW150914-GBM