GRB Prompt Emission and Synergies Between Gamma-ray Observatories Multi-messenger Era

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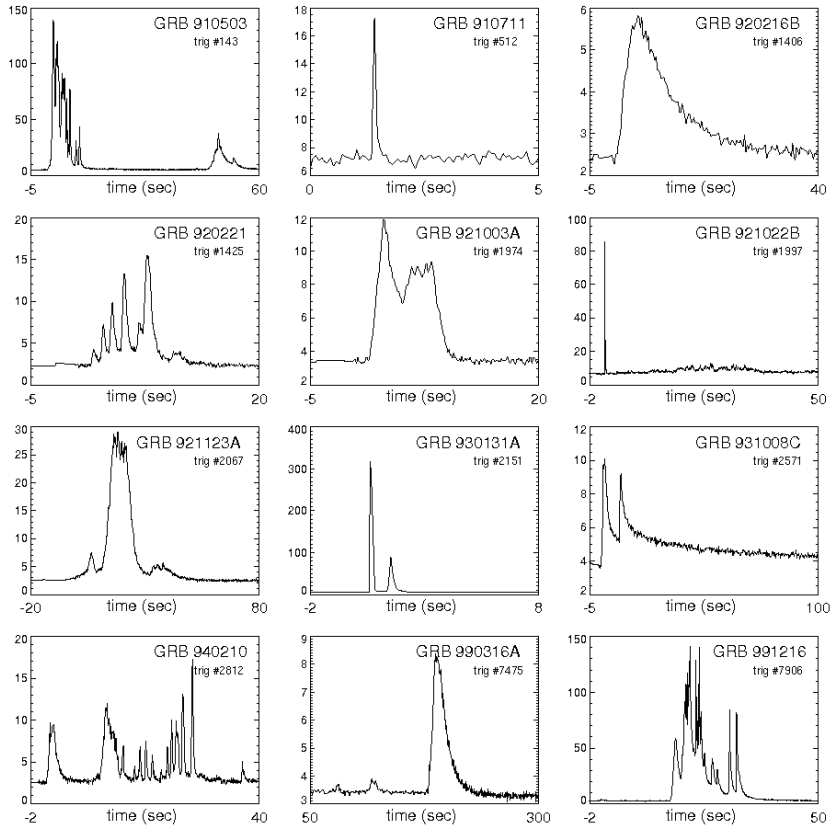
Fermi Gamma-ray Burst Monitor

on behalf of the *Fermi*-GBM Team

INTEGRAL LOOKS **AHEAD** TO MULTI-MESSENGER ASTROPHYSICS
12th INTEGRAL Conference - 1st AHEAD Gamma-ray Workshop
11-15 February 2019 - Campus Biotech, Geneva, Switzerland

Gamma-ray Bursts - Prompt emission

- Lightcurve/variability $\gtrsim$ 10 ms
- Short/long divide in duration
- Broad non-thermal spectrum: emerging complex picture
- Deduce: compact object, $\theta_{\rm jet} \approx$few $^\circ$, $E_{\rm iso} = 10^{49} - 10^{55}$ erg



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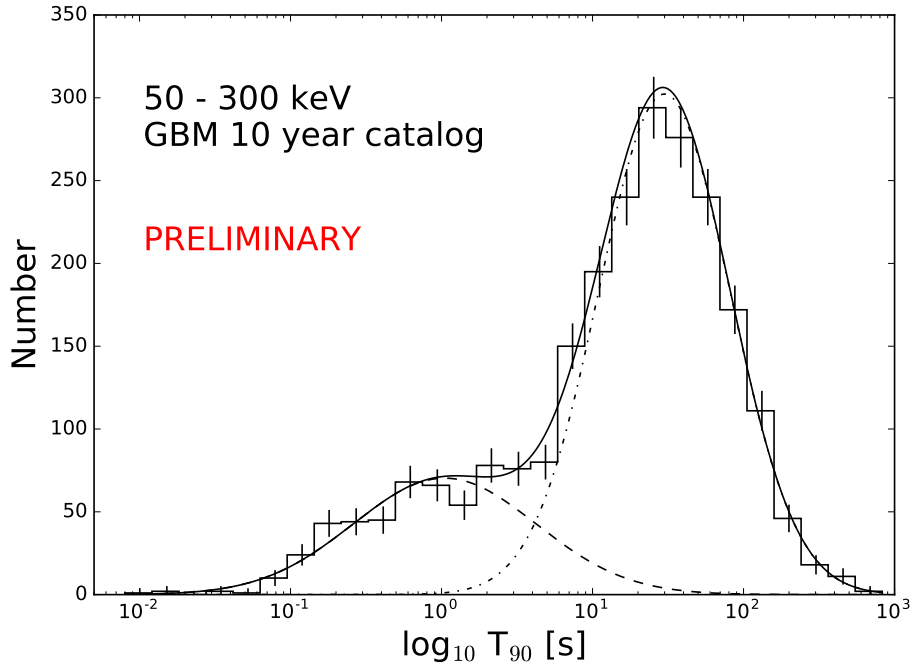

$4^{\rm th}$ GBM GRB catalog von Kienlin et al 2019 in prep

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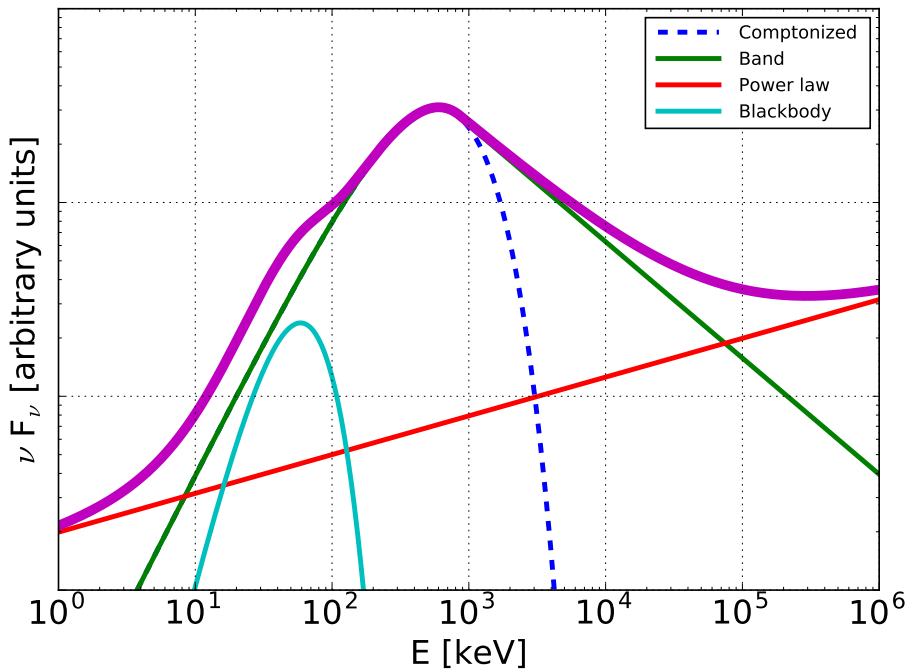

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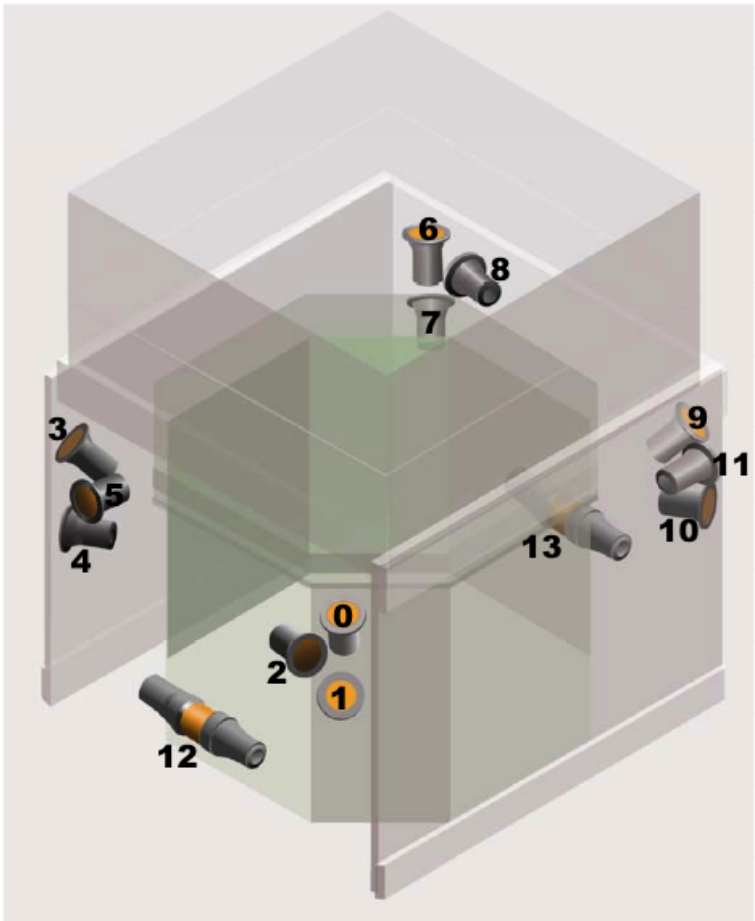
credit: NASA/Swift/deWilde

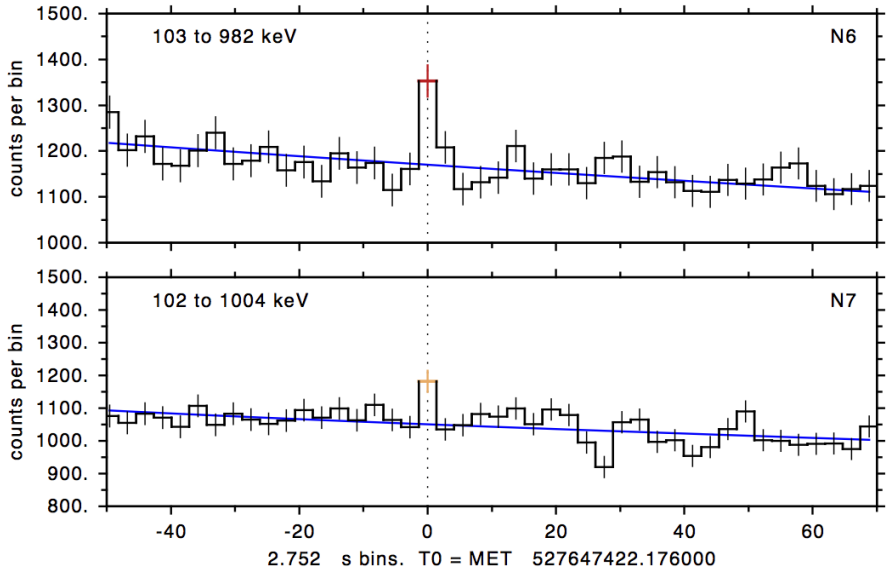
Fermi Gamma-ray burst Monitor (**GBM**)
An instrument for multi-messenger astronomy

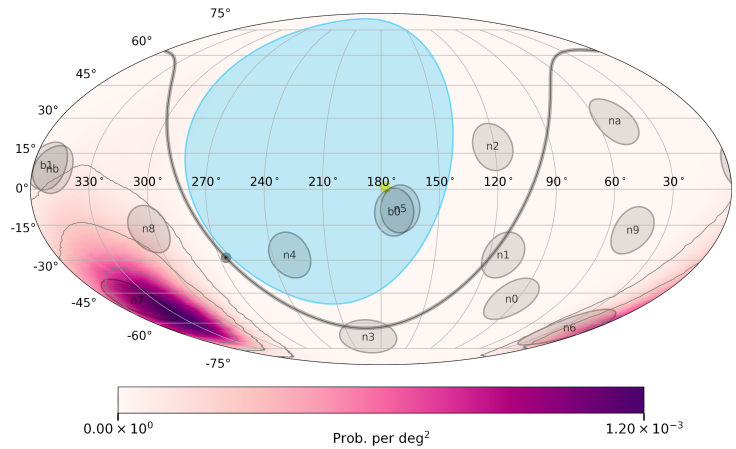
- 12 NaI (8-1000 keV),
  2 BGO (0.2-40 MeV)
- 87% uptime (SAA), 67% of the sky,
  any location: $\sim$ 60% of time
- Real-time **triggers**:
  in orbit detection of rate increase
- **Localization**:
  compare relative counts in detectors
- Short GRB: $\sim$ 40 per year
- Off-line searches increase sensitivity:
  Targeted, GW 150914-GBM
  comp. intensive $\rightarrow$outside targets
  Untargeted Briggs+19 in prep.
  extra 80 sGRBs



Sub-threshold search - **Untargeted** search

- Briggs et al. 2019 (in prep.)
- Improved background
- Excess signal in 2+ dets, lower than for triggers (e.g. 1.25 & 2.5 σ)
- Few hours latency - public GCN
- Confirmation by other instruments (mostly ACS)
- **Increase # of short GRBs by $\sim$ 80 yr^{-1}** (from 40 triggered yr^{-1})

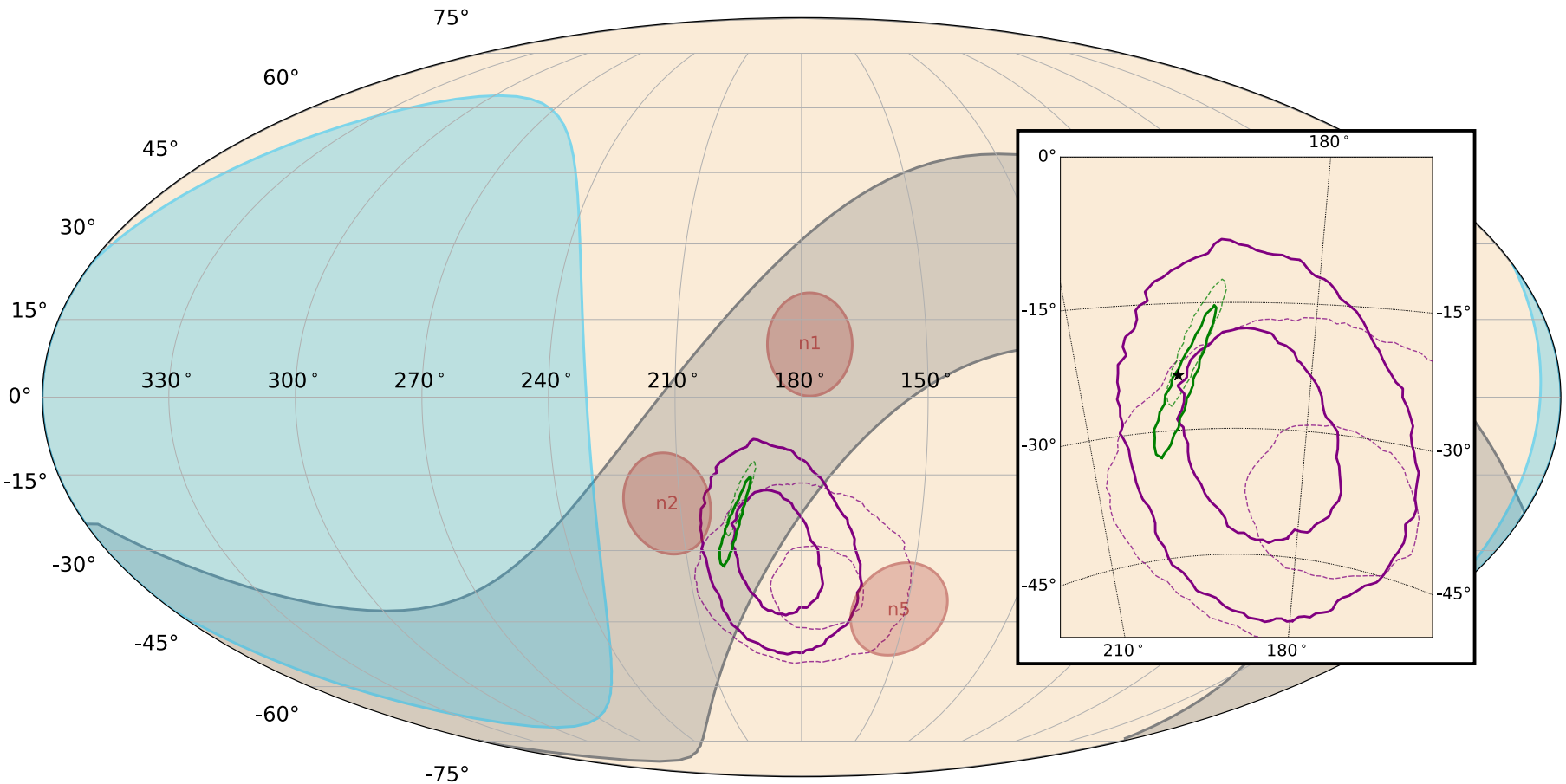




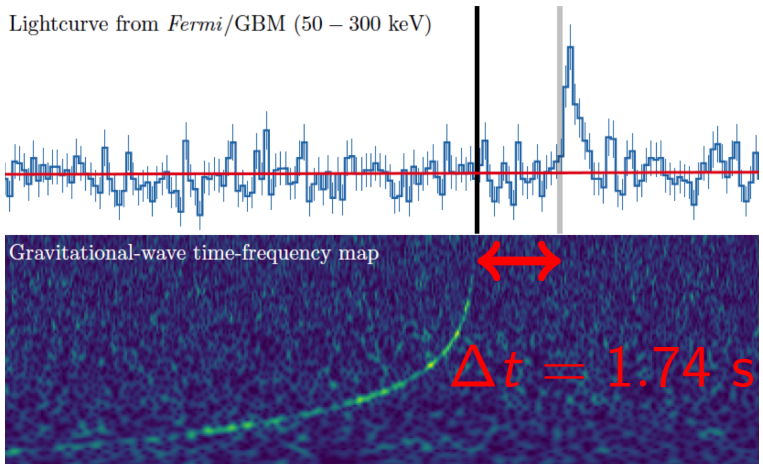
https://gcn.gsfc.nasa.gov/fermi_gbm_subthresh_archive.html

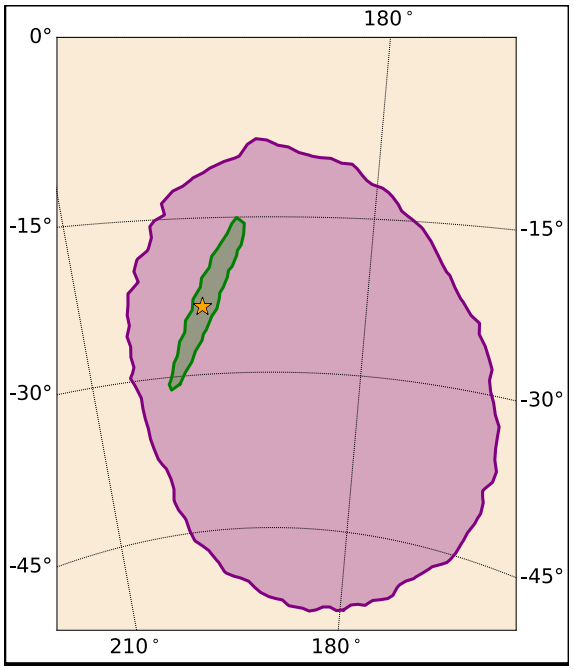
GRB 170817A - location - timeline

- $T_{GW} = T_{GRB}$ - 2.02 s
- T_{GW}+16 s: first **public** notice by flight software
- T_{GW}+27 s: on-board localization and classification
- T_{GW}+40 s: automatic on-ground localization
- T_{GW}+40 min: LVC reports GW trigger conc. w GRB
- T_{GW}+45 min: improved human-guided location
- Single IFO location consistent with GBM → good sign
- T_{GW}+67 min: report GRB properties
- T_{GW}+5 h: HLV map still consistent with GBM map (that was when we knew they are surely associated)



GRB 170817A - Significance of association



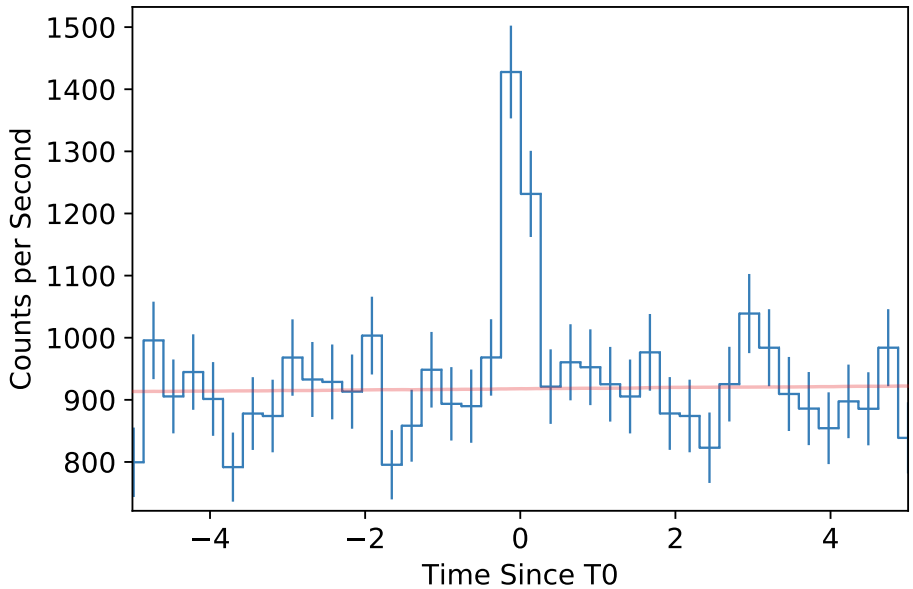


- $P_{\text{temporal}} = 5 \times 10^{-6}$
- $P_{\text{spatial}} = 10^{-2}$

$$P = 5 \times 10^{-8}\ (5.3\ \sigma)$$

GRB 170817A - Basic information

- GRBs brightest in 50-300 keV
- Triggered GBM: excess counts on 256 ms timescale
- Start: T_{GW}+1.7 s $\approx$ T_{GRB}-0.3 s
- Duration, T_{90}= 2.0$\pm$0.5 s
- "By eye" it's only 0.5 s long
- Main peak + soft component $\sim$ 1 to 2 s after trigger



50-300 keV lightcurve

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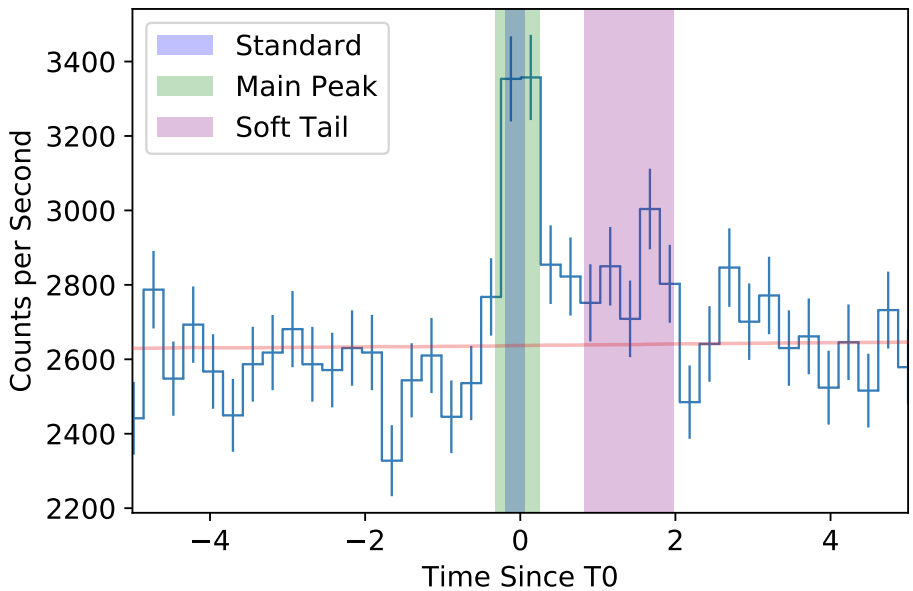


10-300 keV lightcurve

GRB 170817A - astrophysics - detectability

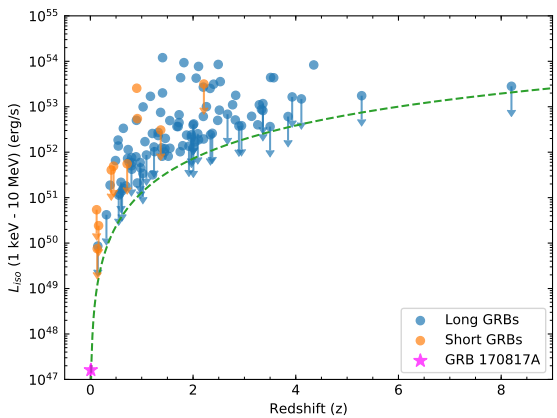
Observationally **ordinary** GRB. Redshift $\rightarrow$ subluminous by orders of magnitude.

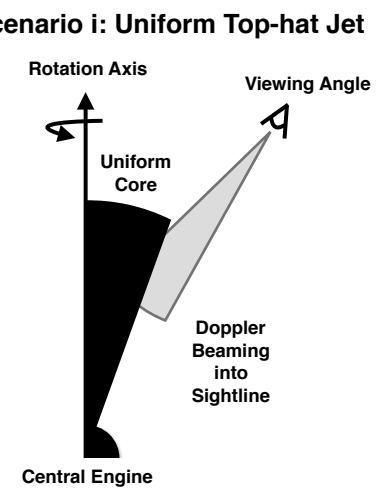
- On axis: sublum: sel. effect (?)
- Cocoon shock breakout (?)
- Off-axis structured jet

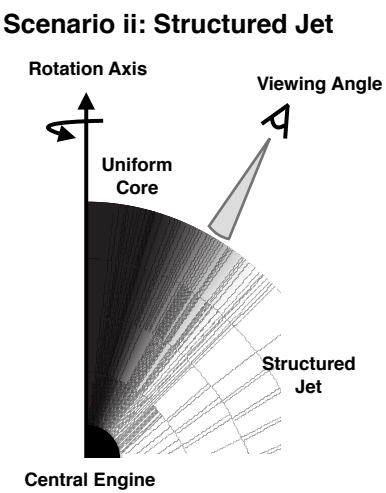
- Speed of gravity $\Delta v = v_g - v_{EM}$: -10 s $\leq$ dt $\leq$ 1.7 s
- $-3 \times 10^{-15} \leq \frac{\Delta v}{v_{\rm EM}} \leq 7 \times 10^{-16}$

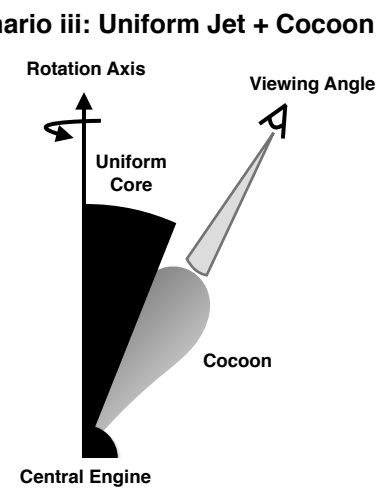
- O3: 1-50 BNS/year (0.1-1.4 joint)
- Design: 6-120 BNS/year (0.3-1.7 joint)

- 30 % dimmer : still triggered
- 50 % dimmer : untargeted search
- 60 % dimmer : targeted search





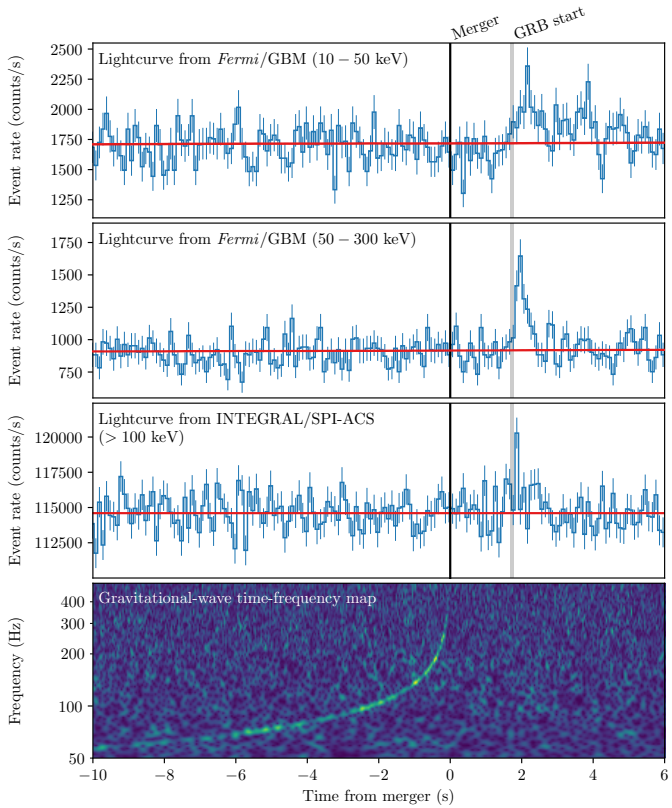




Twins of GRB 170817A - GRBs with likely BNS

Main question: "How do you define similarity based on one event?"

- 1 "gold plated" event: GRB 170817A
- 1 BNS - candidate: GRB 150101B kilonova(?), z∼0.13, 'regular' GRB
- Hard peak + soft tail
- **13 (11+2) candidates**, rate: 1+ /yr



Goldstein, PV et al, 2017, Abbott et al. 2017

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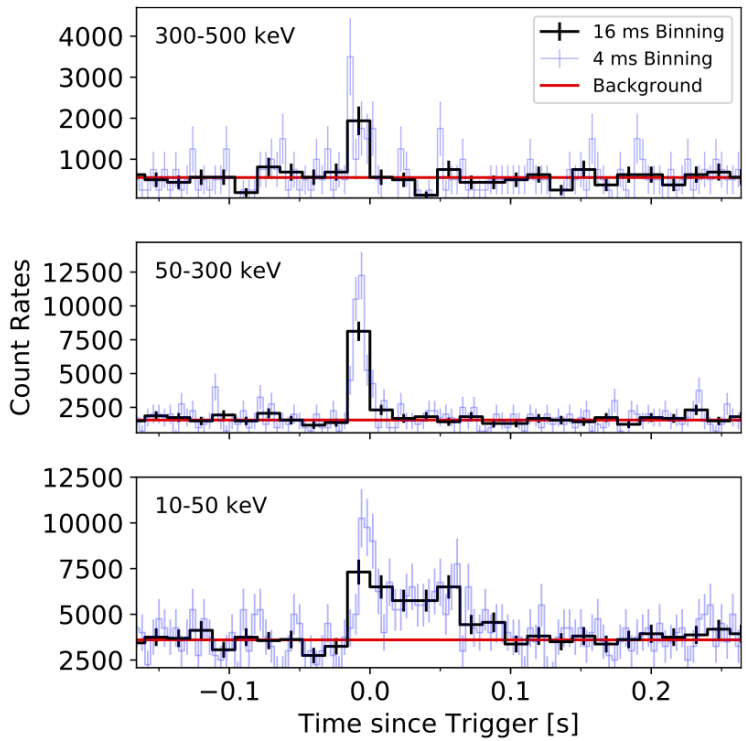

Burns, PV et al, 2018, Troja et al 2018

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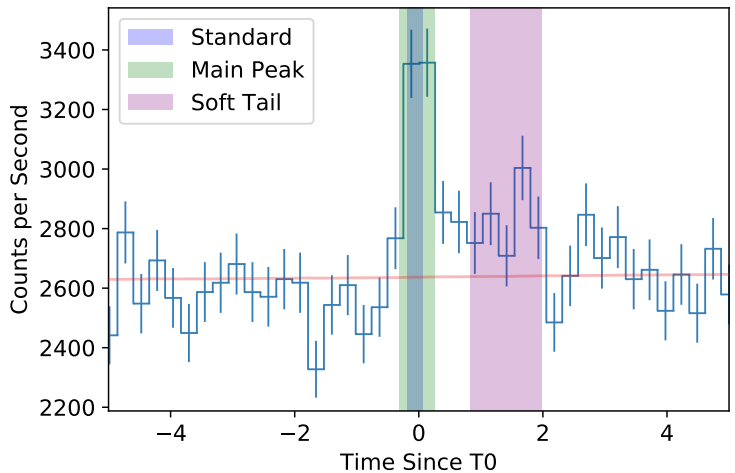

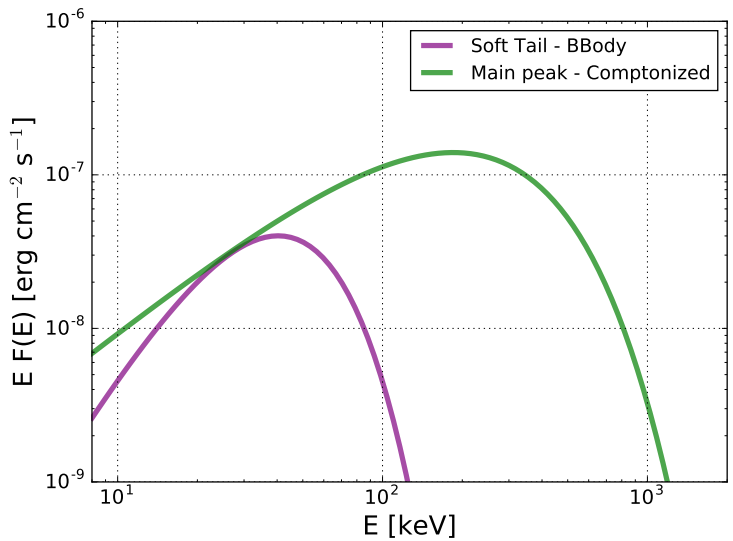

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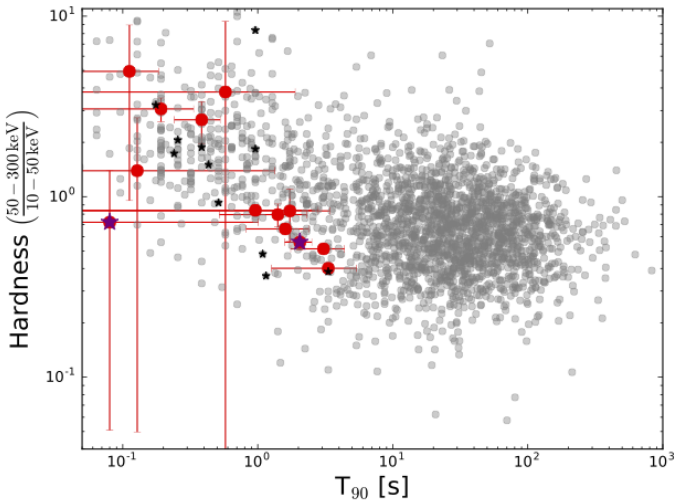


von Kienlin, PV et al, 2019 (arXiv:1901.06158)

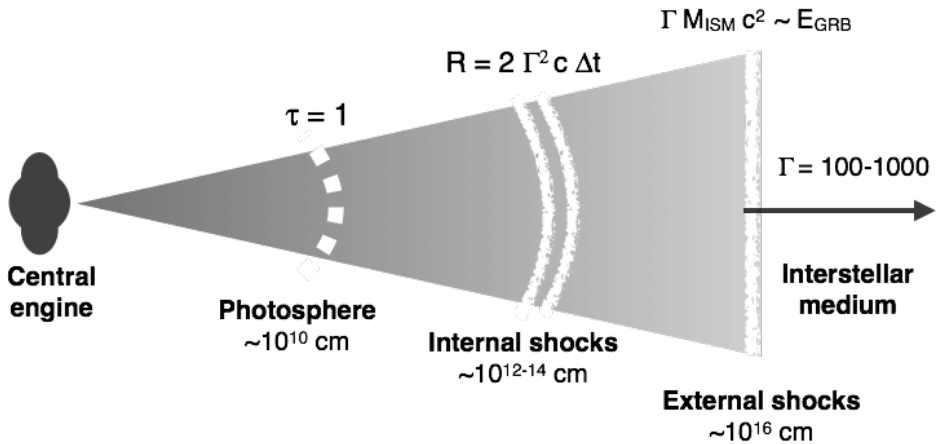
Twins of GRB 170817A

			Durations		Localization			Total Fluence	Peak Flux		
Trigger ID[a]	GRB Name	Time (UTC)	T90 (s)	T50 (s)	RA (deg.)	Dec. (deg.)	error (deg.)	(erg cm^{-2}) $\times 10^{-7}$	(64 ms) (ph cm^{-2} s^{-1})	Detect.[d]	References
bn081209981	GRB 081209A[b]	23:41:56.39	0.192 ± 0.143	0.128 ± 0.143	45.3	63.5	4.9	14.66 ± 1.49	25.4 ± 1.2	KW,S[e],A	Wilson-Hodge & Connaughton (2008); Pal'shin (2008); Golenetskii (2008)
bn100328141	GRB 100328A[b]	03:22:44.60	0.384 ±0.143	0.192 ± 0.091	155.9	47.0	4.8	10.01 ± 0.24	13.4 ± 0.8	IA	Abadie et al. (2012)
bn101224227[f]	GRB 101224A	05:27:13.86	1.728 ± 1.68	0.192 ± 0.286	285.9	45.7	0.1	1.92 ± 0.27	6.7 ± 1.6	S	Nugent & Bloom (2010); Xu (2010); Golovnya (2011)
bn110717180	GRB 110717A[b]	04:19:50.66	0.112 ± 0.072	0.032 ± 0.023	308.5	-7.9	7.5	2.51 ± 0.12	18.5 ± 1.8	KW	*Fermi*-GBM Only
bn111024896	GRB 111024C[b]	21:30:02.24	0.960 ± 1.032	0.256 ± 0.143	91.2	-1.8	13.2	3.80 ± 0.16	7.4 ± 1.2		*Fermi*-GBM Only
bn120302722	GRB 120302B[b]	17:19:59.08	1.600 ± 0.779	0.512 ± 0.466	24.1	9.7	13.9	1.19 ± 0.16	6.2 ± 1.5		*Fermi*-GBM Only
bn120915000	GRB 120915A[c]	00:00:41.64	0.576 ± 1.318	0.320 ± 0.091	209.4	67.3	5.9	5.06 ± 0.26	6.0 ± 0.9		*Fermi*-GBM Only
bn130502743[f]	GRB 130502A	17:50:30.74	3.328 ± 2.064	2.304 ± 0.572	138.6	-0.1	0.0	6.27 ± 0.35	6.6 ± 1.4	S	Troja (2013); Malesani (2013); de Ugarte Postigo (2013); Gorosabel (2013); Breeveld (2013)
bn140511095	GRB 140511A[c]	02:17:11.56	1.408 ± 0.889	0.256 ± 0.181	329.8	-30.1	8.8	3.71 ± 0.32	9.4 ± 1.0		*Fermi*-GBM Only
bn150101641[f]	GRB 150101B	15:23:34.47	0.08 ± 0.928	0.016 ± 0.023	188.0	-11.0	0.0	2.38 ± 0.15	10.5 ± 1.3	S, C, z, X	Troja et al. (2018); Burns et al. (2018); Fong et al. (2016)
bn170111815	GRB 170111B[c]	19:34:01.39	3.072 ± 1.318	0.32 ± 0.091	270.9	63.7	6.7	5.96 ± 0.12	7.6 ± 1.0		*Fermi*-GBM Only
bn170817529[f]	GRB 170817A	12:41:06.47	2.048 ± 0.466	1.28 ± 0.405	197.5	-23.4	0.0	2.79 ± 0.17	3.7 ± 0.5	L, z, C, IA, HST and more	Abbott et al. (2017a)
bn180511364	GRB 180511A[c]	08:43:35.79	0.128 ± 1.207	0.032 ± 0.045	250.4	-8.2	15.1	1.53 ± 0.21	9.2 ± 1.0	IA	*Fermi*-GBM Only

von Kienlin, PV et al, 2019 (arXiv:1901.06158)

Tests of theoretical models in the MM era

- (Dissipative) photosphere, internal/external(?) shocks
- GW provides viewing angle, structured jets
- Simple tests: peak energy limits
- $E_{peak}(t)$ (note the error bars)
- E_{peak} v. L (note the error bars)
- Simple modeling



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$$E_p \lesssim 3.92 k_B T_0 \approx 4.7 L_{52}^{1/4} R_{0,7}^{-1/2} \mathrm{MeV}$$

Zhang et al. 2013 ApJL, Veres et al. 2018

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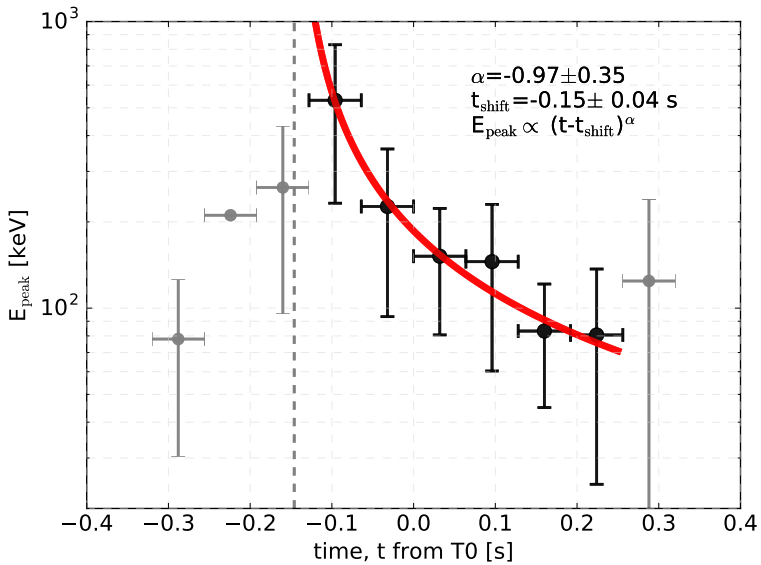

GRB 170817A, Veres et al. 2018

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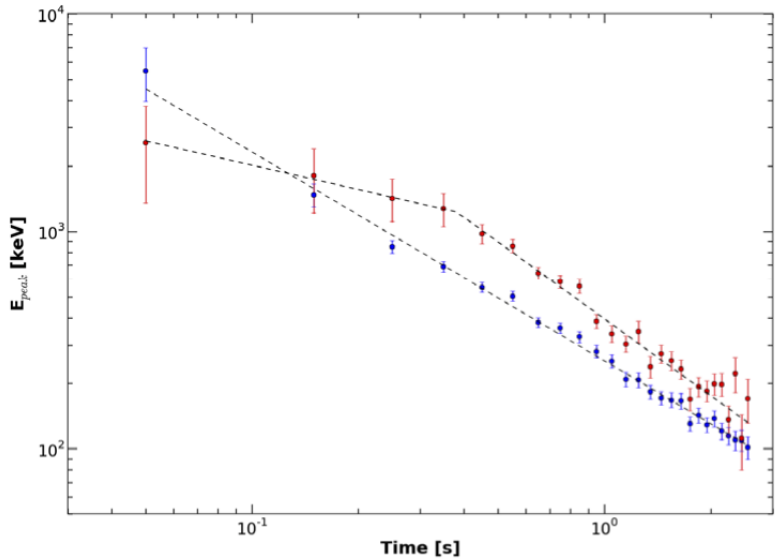

GRB 130427A, Preece et al. 2014

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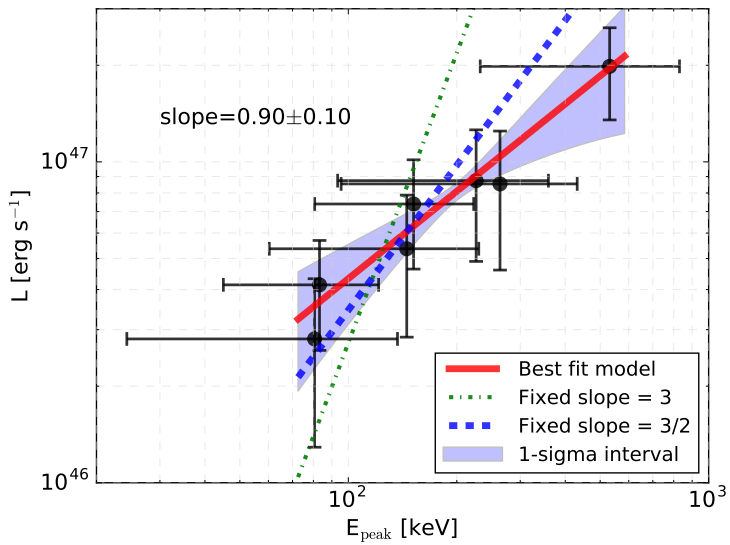

GRB 170817A, Veres et al. 2018

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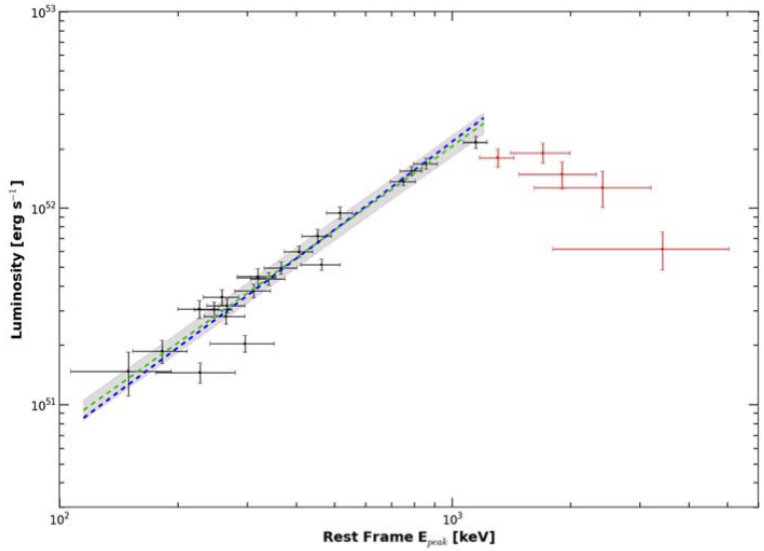

GRB 130427A, Preece et al. 2014

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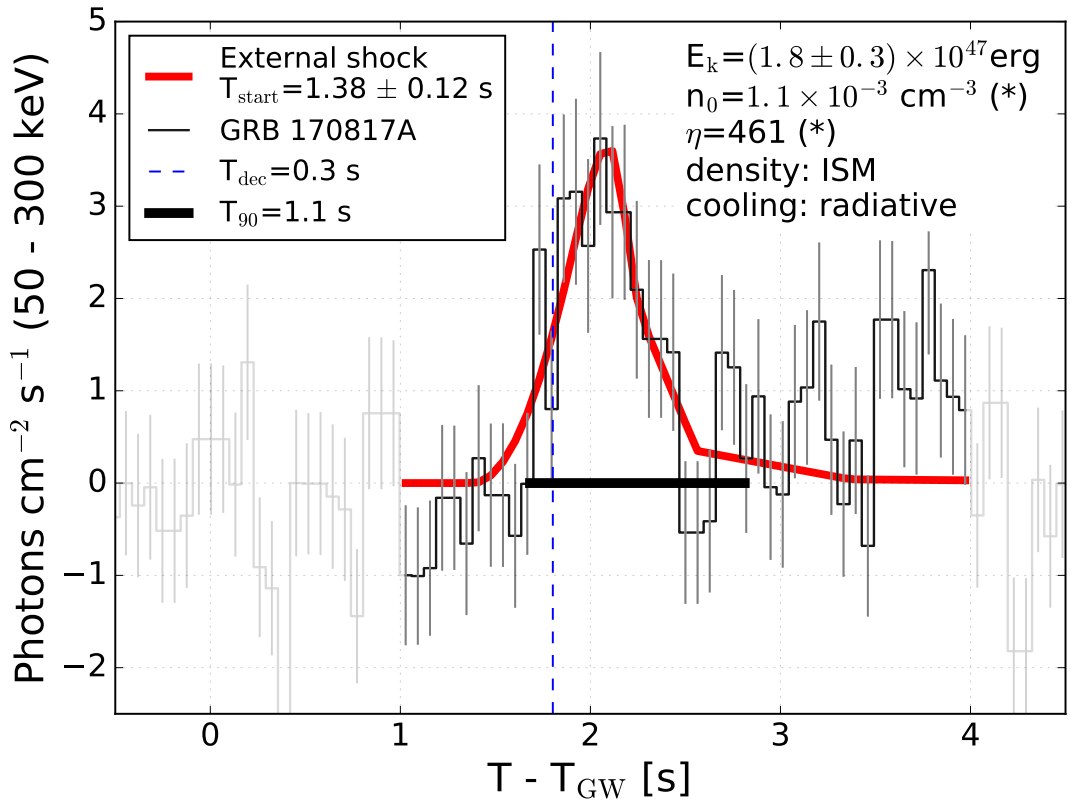
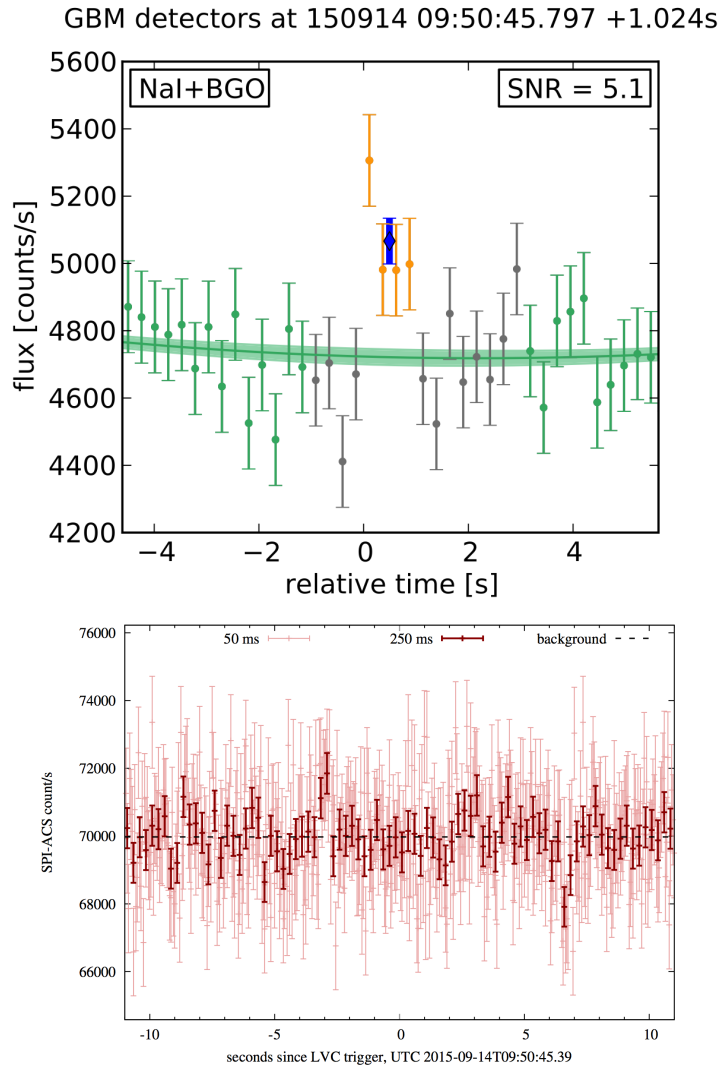


GRB 170817A, External shock (?) Veres et al. 2018

Binary black hole mergers, GW150914-GBM

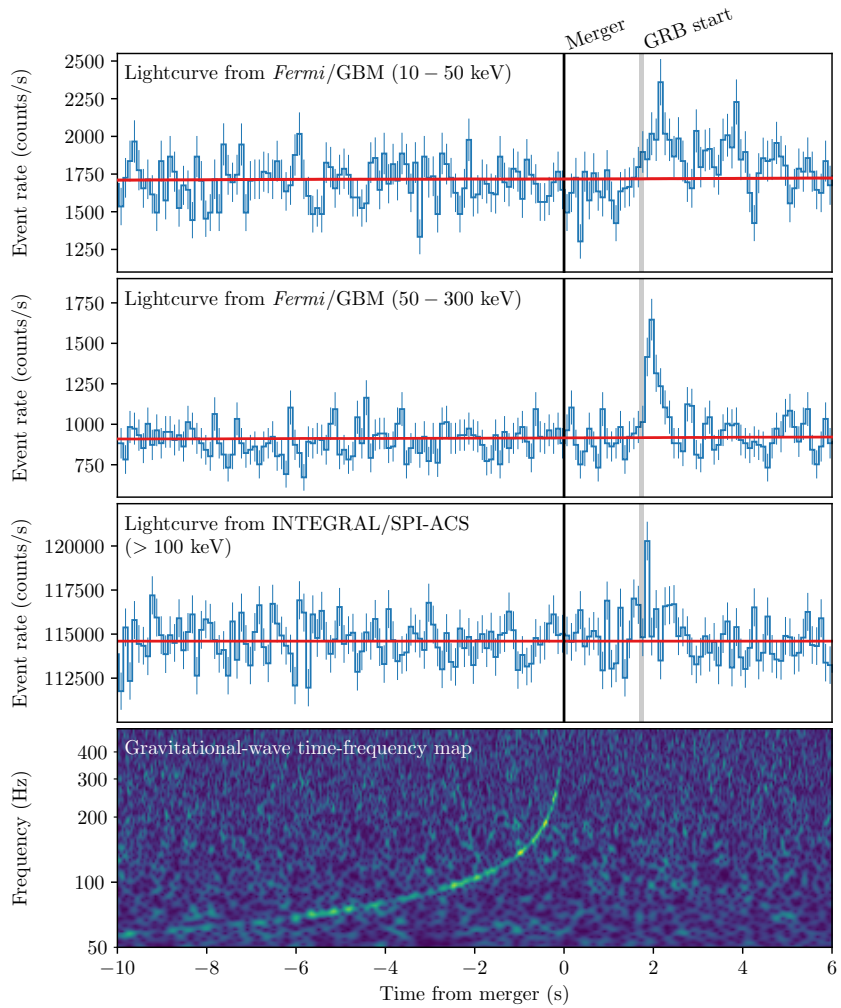
- A weak gamma-ray transient 0.4 s after GW150914, duration $\sim$ 1 s,
- Consistent with a short GRB
- Location: $\sim$ consistent with GW150914
- False Alarm Probability for association with GW150914: 0.0022
- Positive count rate in all dets., E$>$ 50 keV.
- Not seen in INTEGRAL-ACS



Connaughton et al. 2016 ApJL, Veres et al. 2017 ApJ

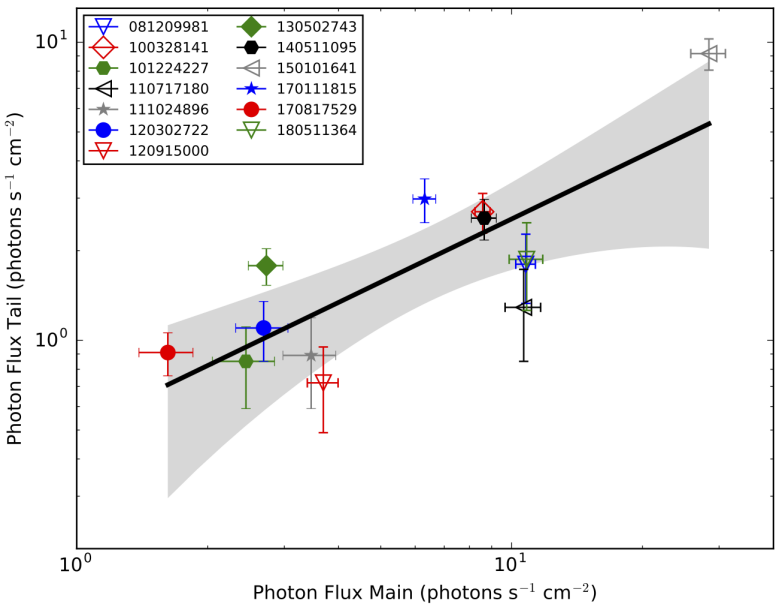
Conclusions

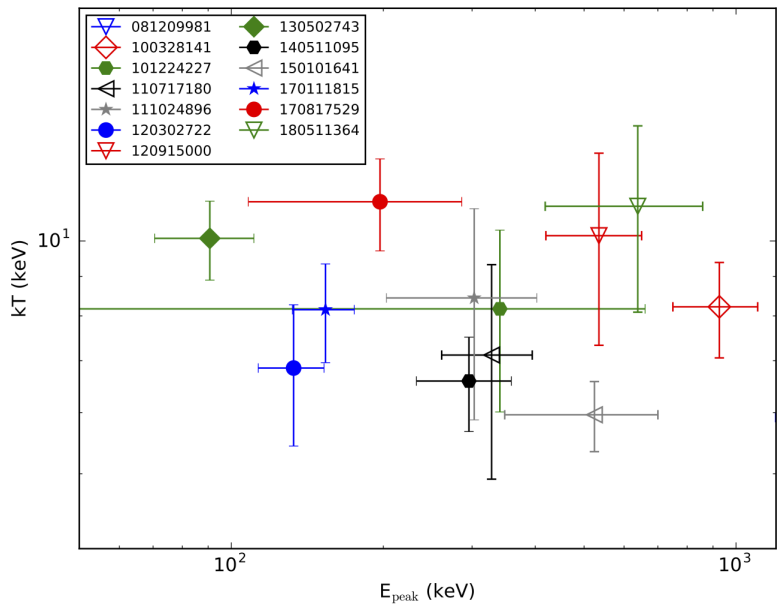
- Lots of interesting joint GBM/ACS science
- Maximize output: sub-threshold events
- GRB 170817A: an ordinary GRB with extraordinary implications
- Emerging signature: hard peak+soft tail structure
- Future tests of prompt emission models
- BBH counterparts?



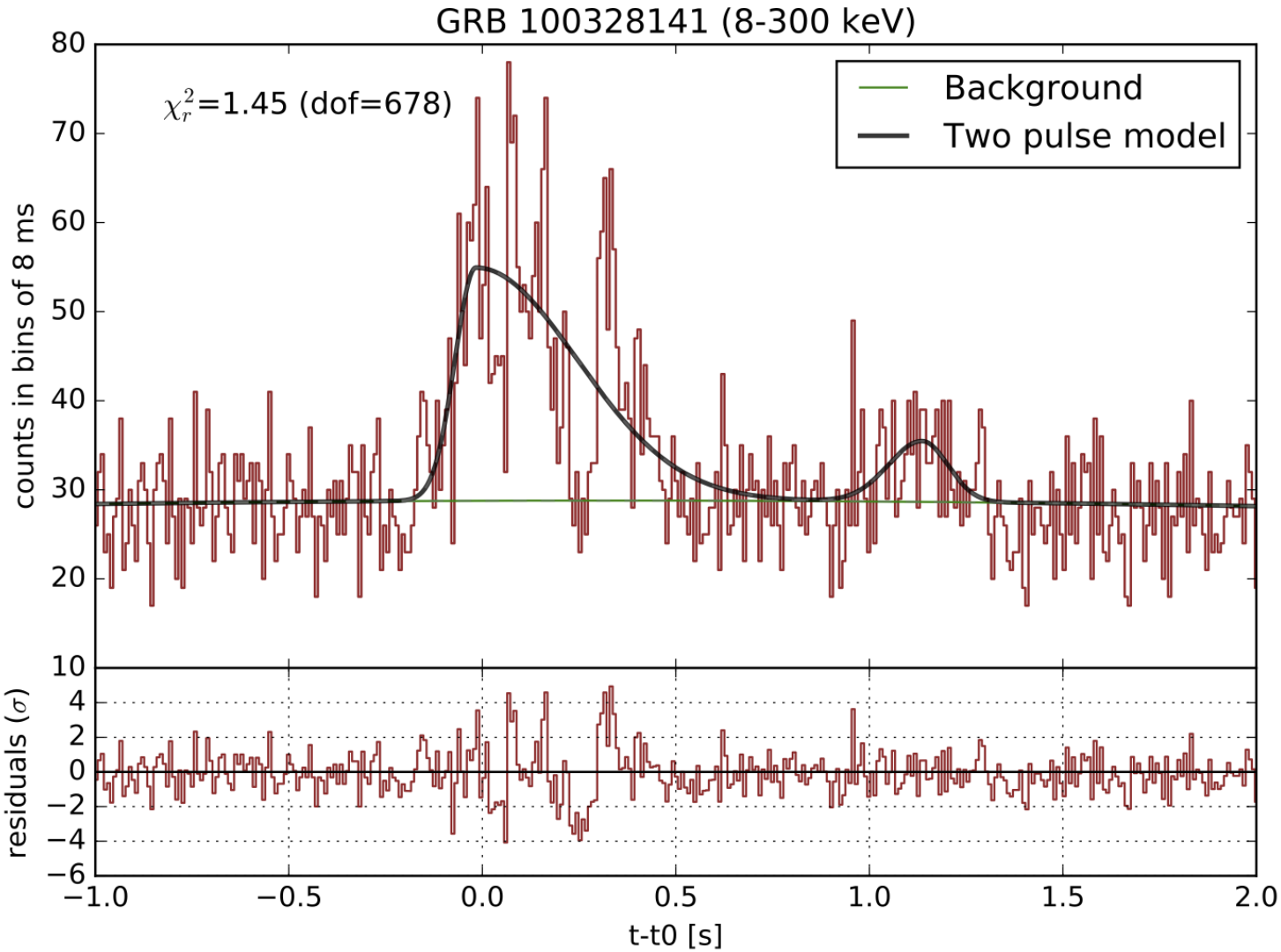
Backup slides

Correlations





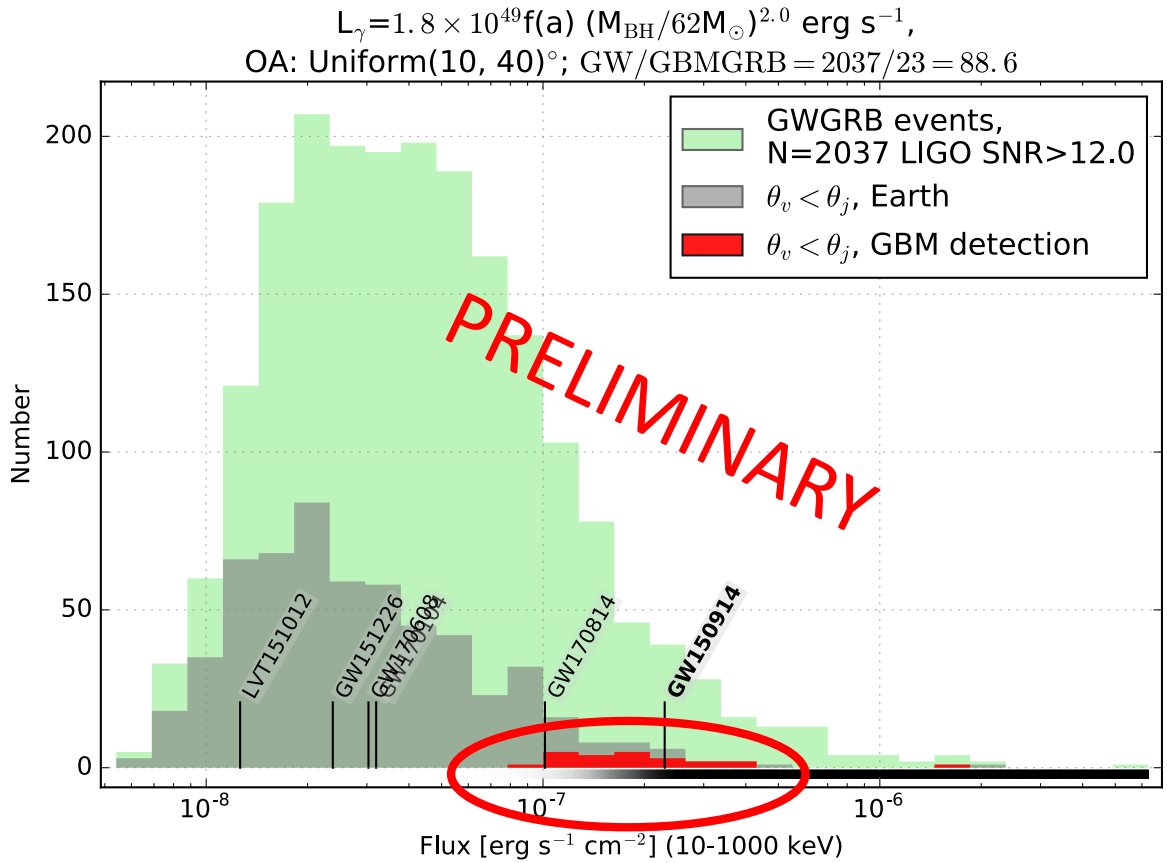
BNS counterpart GRB with high variability



How many BBHs to follow up with GBM to rule out GW150914-GBM association?

Next gamma-ray counterpart for a binary BH merger in O3 (?):

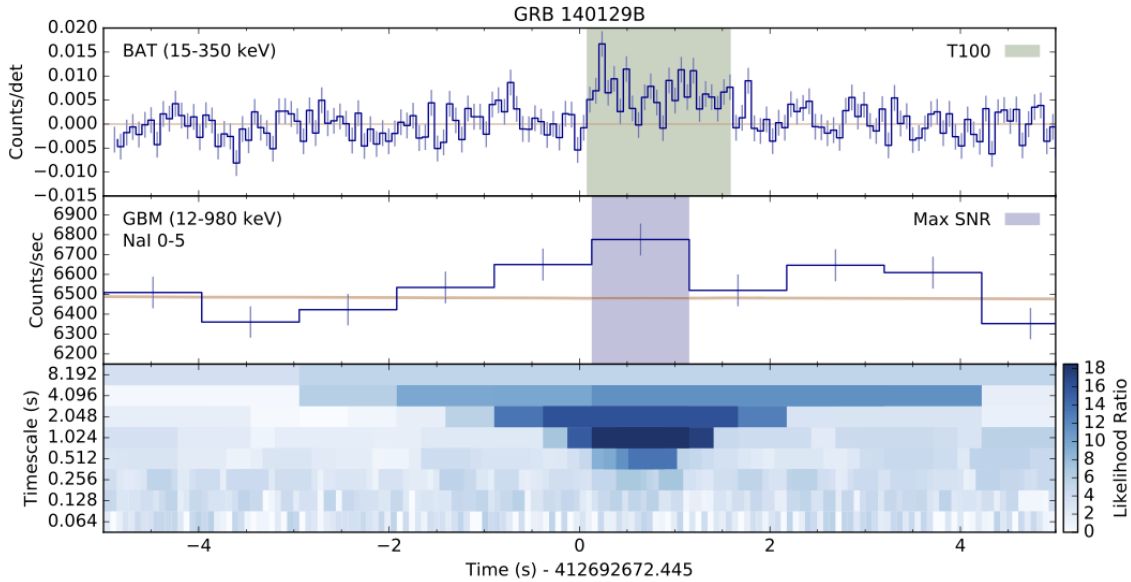
- Generate BBH population (green)
  - Calculate LIGO SNR>12
- Adopt scenario to generate gamma-rays from GW (Blandford-Znajek, neutrino wind, charged BH)
- Normalize flux to GW150914-GBM
- Assume an opening angle
- Calculate # of observed by GBM (red)
- Veres et al. (2018 in prep)
- Result (preliminary):
  - **BBH-to-GRB ratio:** 3 to >100 depending on assumed scenario



Example: BZ, opening angles random uniform (10 to 40 deg.)
BBH-to-GRB ratio (#green/#red) ~ 90

Sub-threshold searches - **Targeted** search

- Independent seed time (e.g. GW, ν, FRB etc.)
- 3 template spectra (soft, normal, hard)
- Assumes point source
- Scans the whole sky
- 64 ms to 8 s, $\pm$30 s (**1 run** $\mathcal{O}(1)$ **minutes**)
- Significance based on false alarm probability from background runs

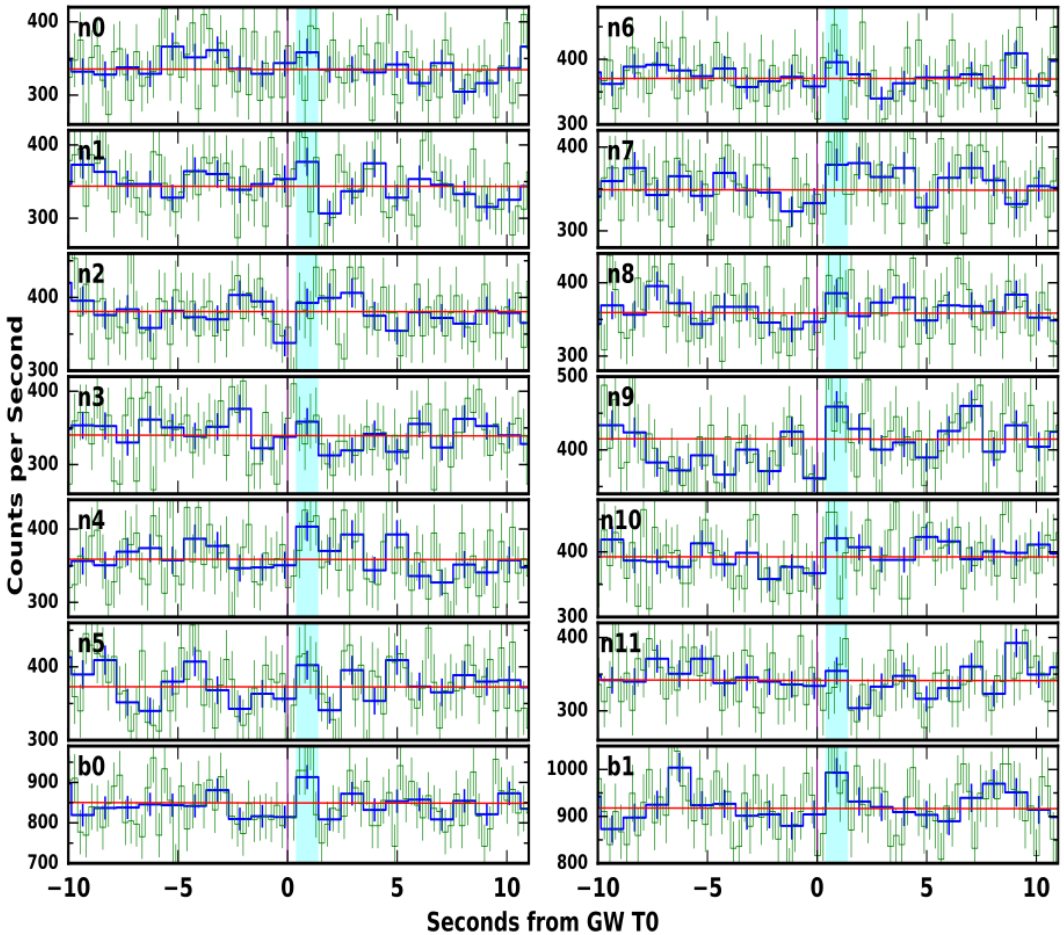


Example: recovery of a Swift GRB that didn't trigger GBM

Blackburn et al., ApJ, 2015; Goldstein et al., 2016, arXiv:1612.02395, Kocevski et al., ApJ, 2018

Binary black hole mergers, GW150914-GBM

- A weak gamma-ray transient 0.4 s after GW150914, duration $\sim$ 1 s,
- Consistent with a short GRB
- Positive counts rate in all dets., E$>$ 50 keV.
- Location: $\sim$ consistent with GW150914
- Not seen in INTEGRAL-ACS
- False Alarm Probability for association with GW150914: 0.0022



Connaughton et al. 2016 ApJL, Veres et al. 2017 ApJ

GRB 170817A - Is this a short GRB?

- Short - long divide (2 s ?)
- 3^{rd} GBM GRB catalog
- $T_{90} = 2.0 \pm 0.5$ s $\rightarrow$conservative ($\sim$ 0.5 s + soft episode)
- 2 log-normals describe the duration distribution
- Answer:
  YES, short more likely ($\sim$ 3:1)