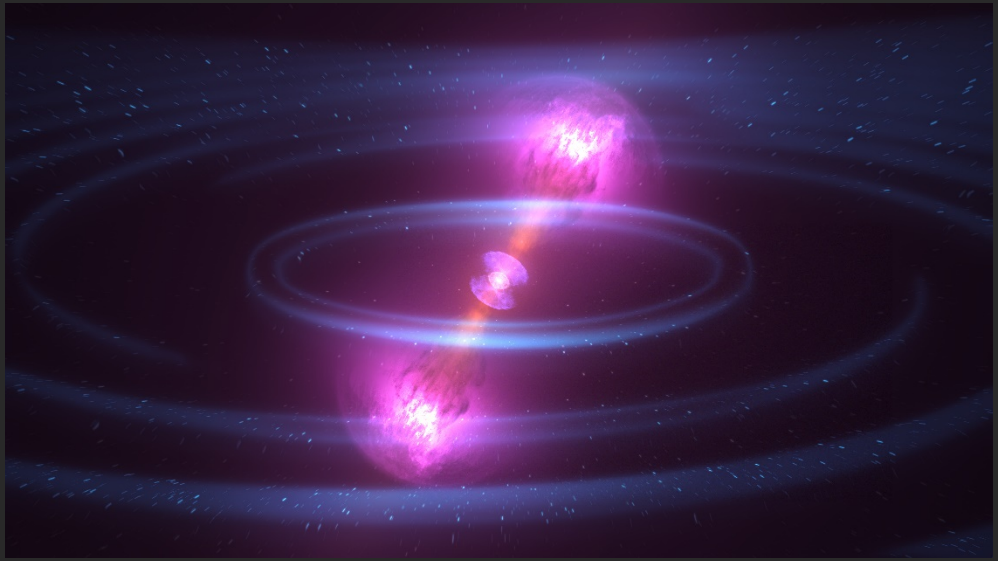
Fermi-GBM GRBs with characteristics similar to GRB 170817A

von Kienlin A. et al., 2019, ApJ, 876, 89



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First EM Signal with a GW Counterpart

GW 170817 / GRB 170817A

Abbott+ 2017, ApJL, 848, L13

Goldstein+ 2017, ApJL, 848, L14

- Temporal association: Δt = 1.74 +/- 0.05 s
- Spatial association

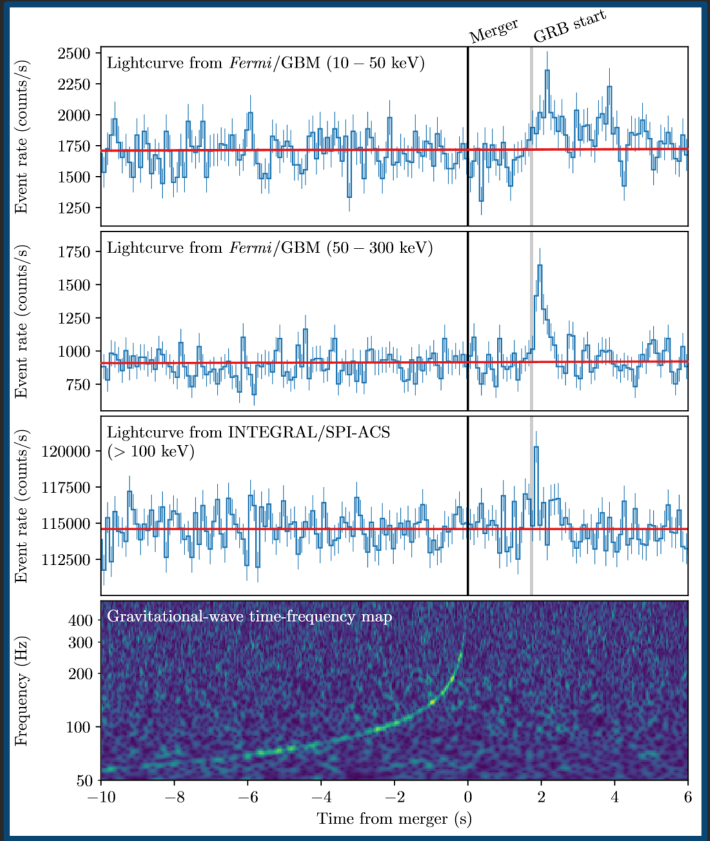
Association at 5.3 σ

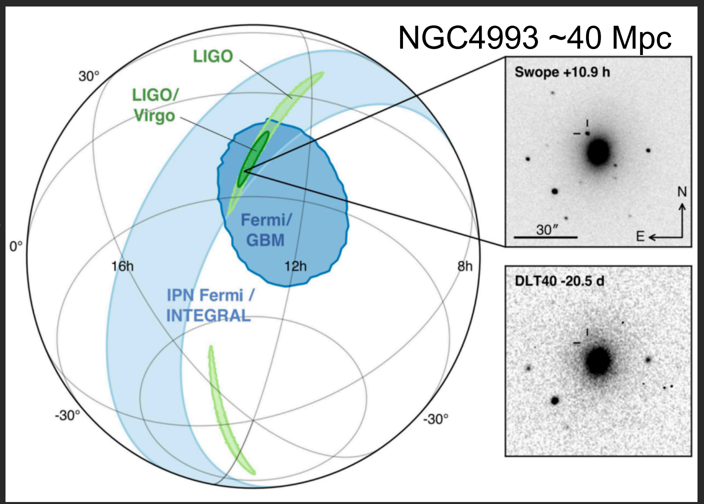
CONFIRMED → BNS – short GRB Association

Science

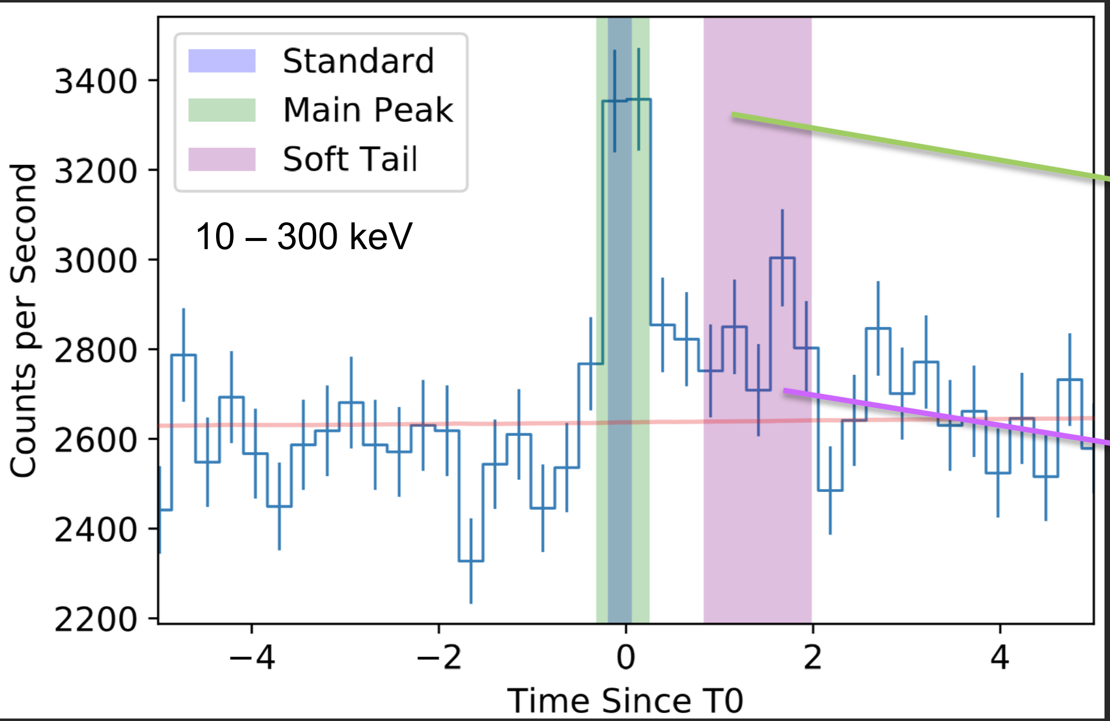
- Directly measured the speed of gravity
- Probed the neutron star (NS) equation of state: constrained the maximum mass of a NS
- Investigated the emission physics of relativistic jets and the engine that produces the short GRB
- Estimated the rate of joint detections, suggesting they should be reasonably common

Question: are there similar GRB events in the GBM GRB database?

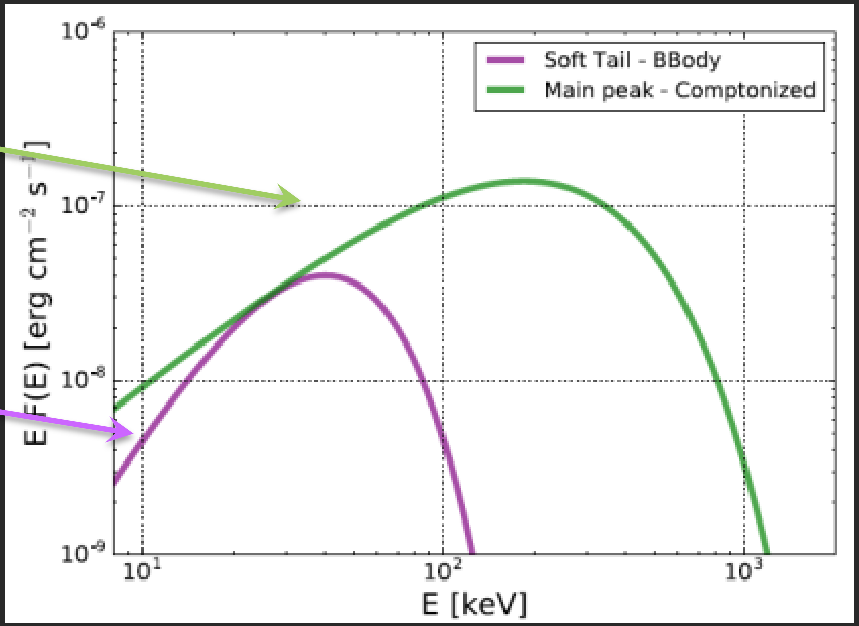




GRB 170817A: A short GRB with a low-energy tail



Goldstein+ 2017, ApJL, 848, L14

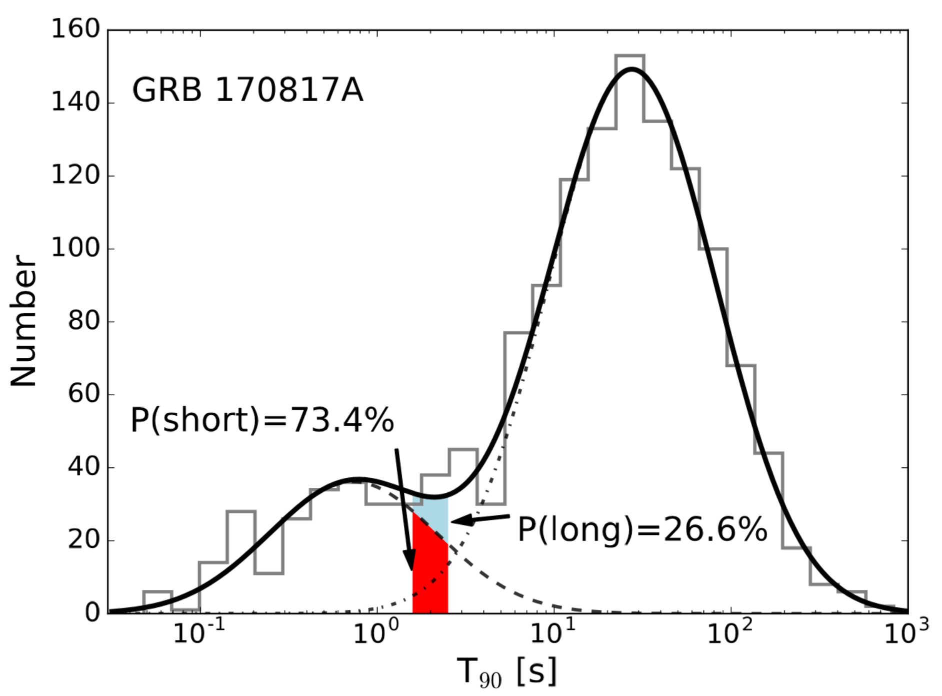


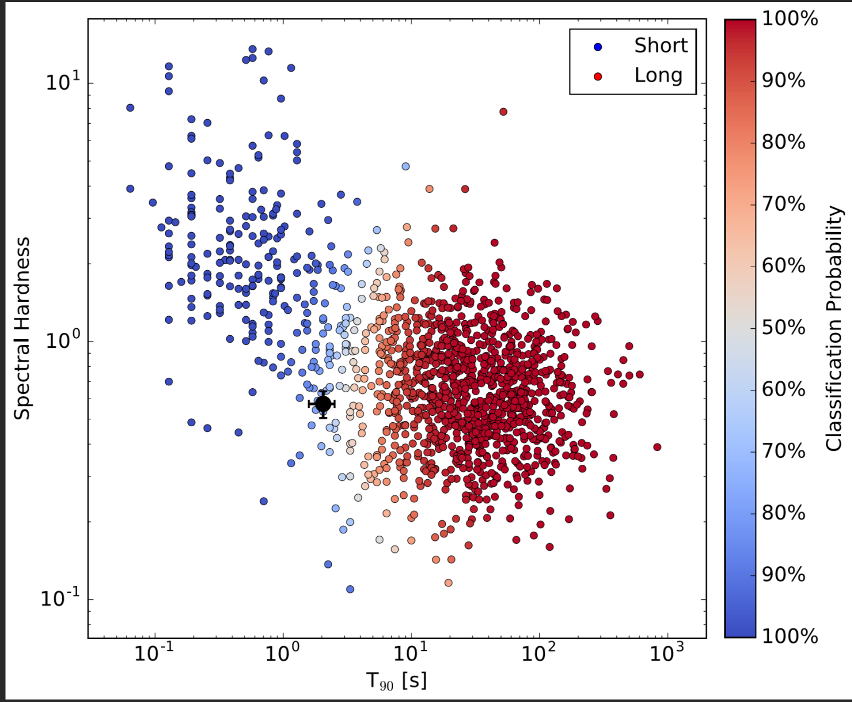
Goldstein+ 2017, ApJL, 848, L14

- The main hard peak is best fit with by a an exponentially cutoff power law (Comptonized model) with E_{pk} = 185 ± 62 keV
- The soft tail is best fit by a black body with kT = 10.3 ± 1.5 keV
- Spectra with photospheric components have been seen (e.g. Ryde,Guiriec), but not in this order

GRB 170817A: A short GRB with a low-energy tail

Goldstein+ 2017, ApJL, 848, L14

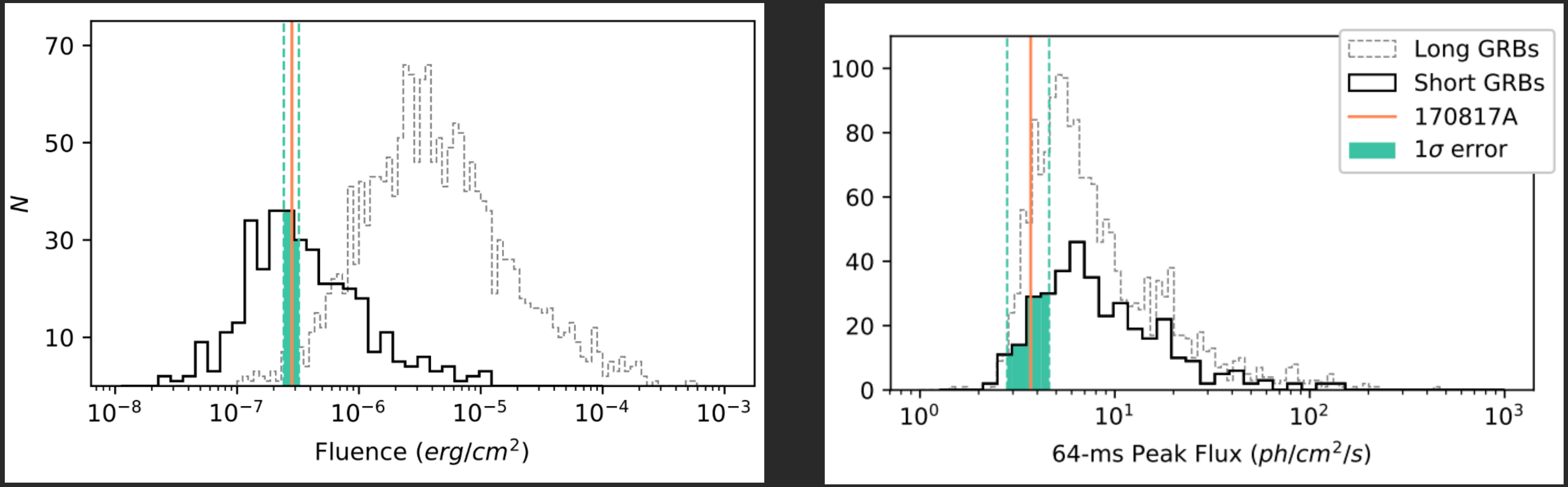




GBM temporal analysis results

- GRB 170817A is 3 times more like to be a short GRB than a long GRB, although it is spectrally softer than many sGRBs

GRB 170817A: Standard GBM Catalog analysis



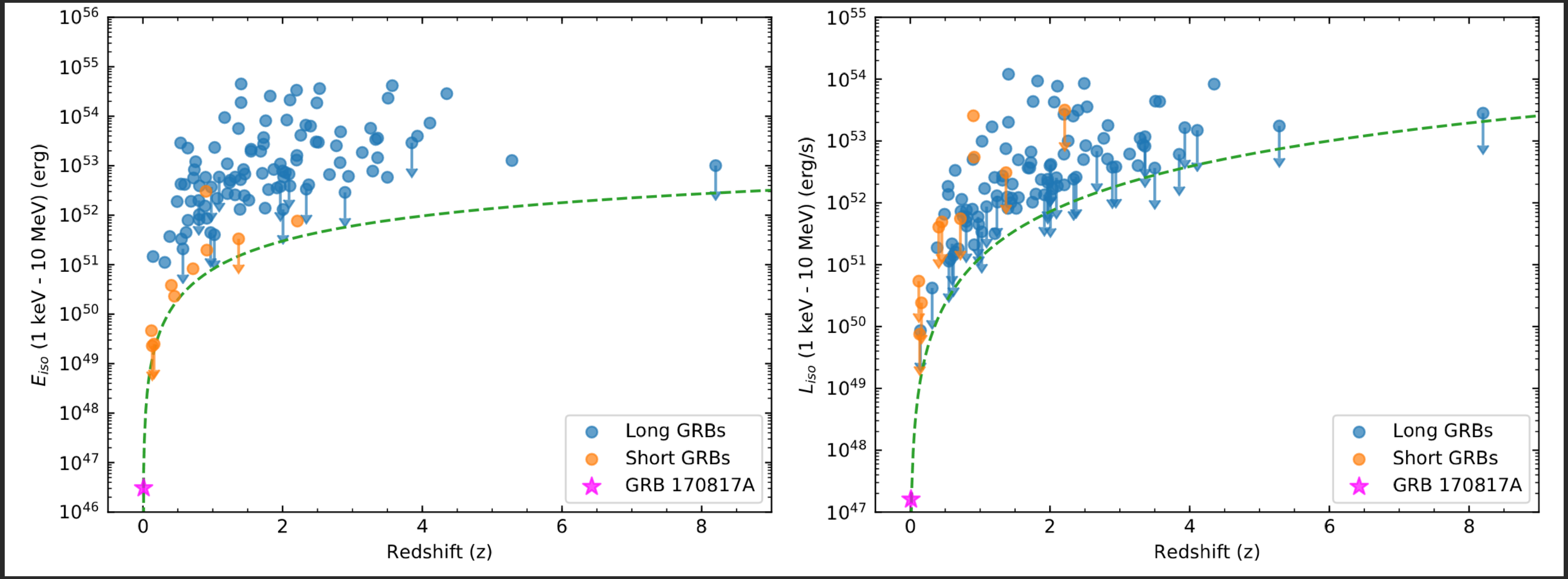
Goldstein+ 2017, ApJL, 848, L14

- Average fluence for a short GRB compared to the catalog distribution
- Relatively weak in peak flux - in the lower third in the 64ms peak flux distribution

➢ It appears as a typical sGRB in the observer frame

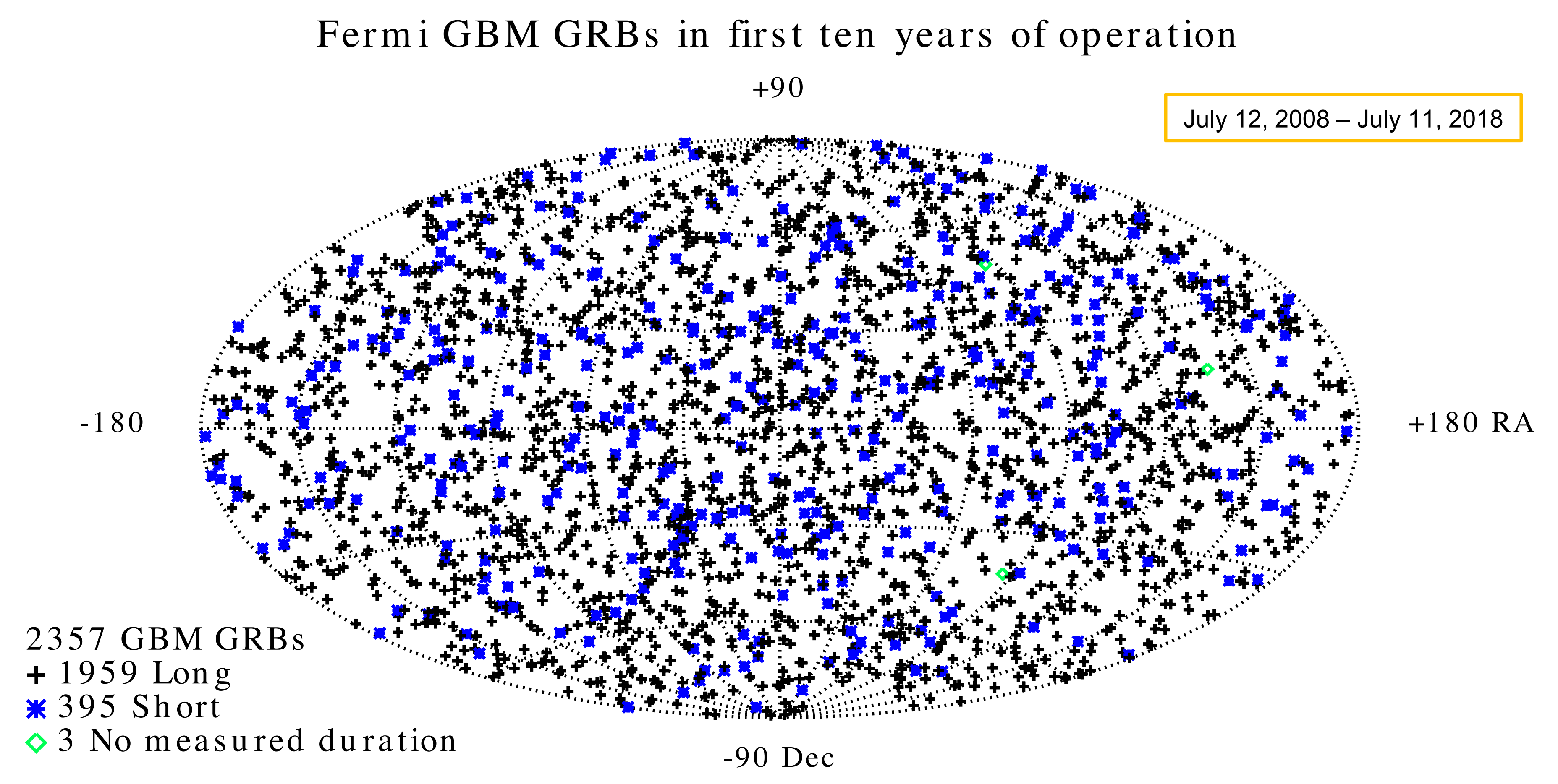
GRB 170817A: Source Frame Energetics

Abbott+ 2017, ApJL, 848, L13



- GRB 170817A was extremely under luminous compared to other GRBs
  - It was the closest (of GRBs with measured redshift) and least luminous GRB ever detected
  - Estimated isotropic-equivalent energy is ~2-3 orders of magnitude lower than previous observations

Search for GRBs with Similar Characteristics



A. von Kienlin et al. 2019, in preparation

The **GBM GRB online catalog** is updated **within 1 hour**:
➔ http://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html

Selection of Candidates

1. Significantly luminous initial peak, brighter over 50 - 300 keV than in 8 - 50 keV
2. Weak tail, bright over the 8 - 50 keV energy range and disappears at higher energies
3. Discernible change of the lightcurve (avoiding GRBs with hard-to-soft spectral evolution)

◆ Verification

- ➢ Localization of the main and soft emission episodes must coincide
- ➢ Spectral characteristics of the soft tail must be similar to that of GRB 170817A

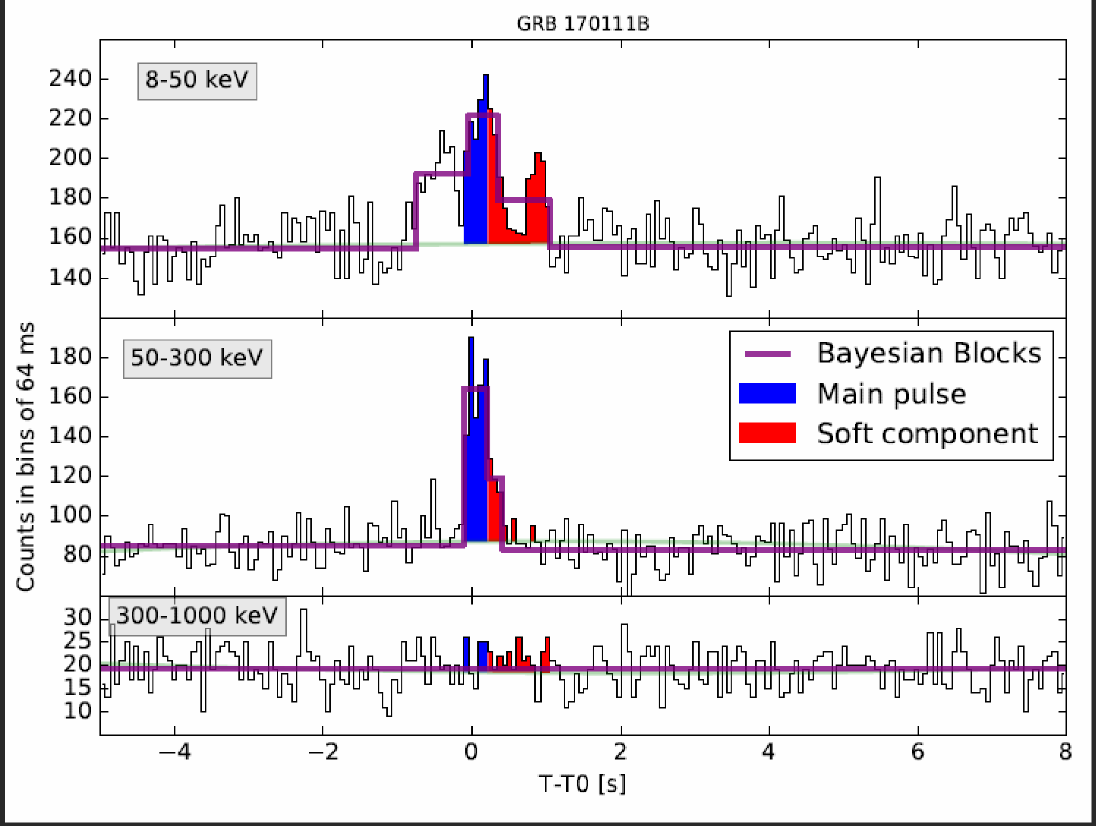
→ 13 Candidates

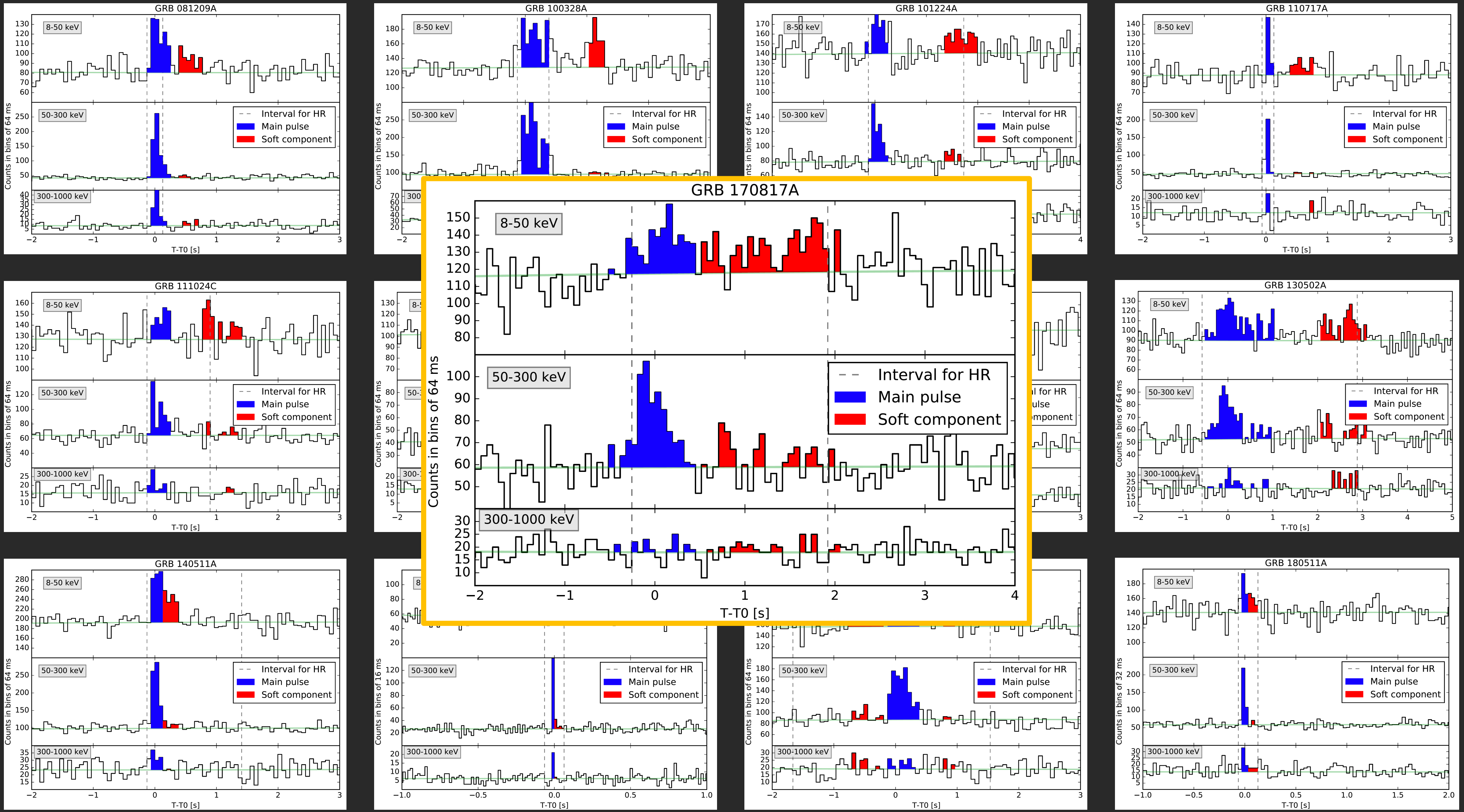
→ Including GRB 170817A

→ and GRB 150101B,

- A second Nearby Event with a Short Hard Spike and a Soft Tail (Burns+ 2018, Troja+ 2018)

not claiming for completeness




GRB 081209A
GRB 100328A
GRB 101224A
GRB 110717A
GRB 111024C
GRB 130502A
GRB 140511A
GRB 180511A
GRB 170817A
8-50 keV
50-300 keV
300-1000 keV
Interval for HR
Main pulse
Soft component
Counts in bins of 64 ms
T-T0 [s]

13 Candidates

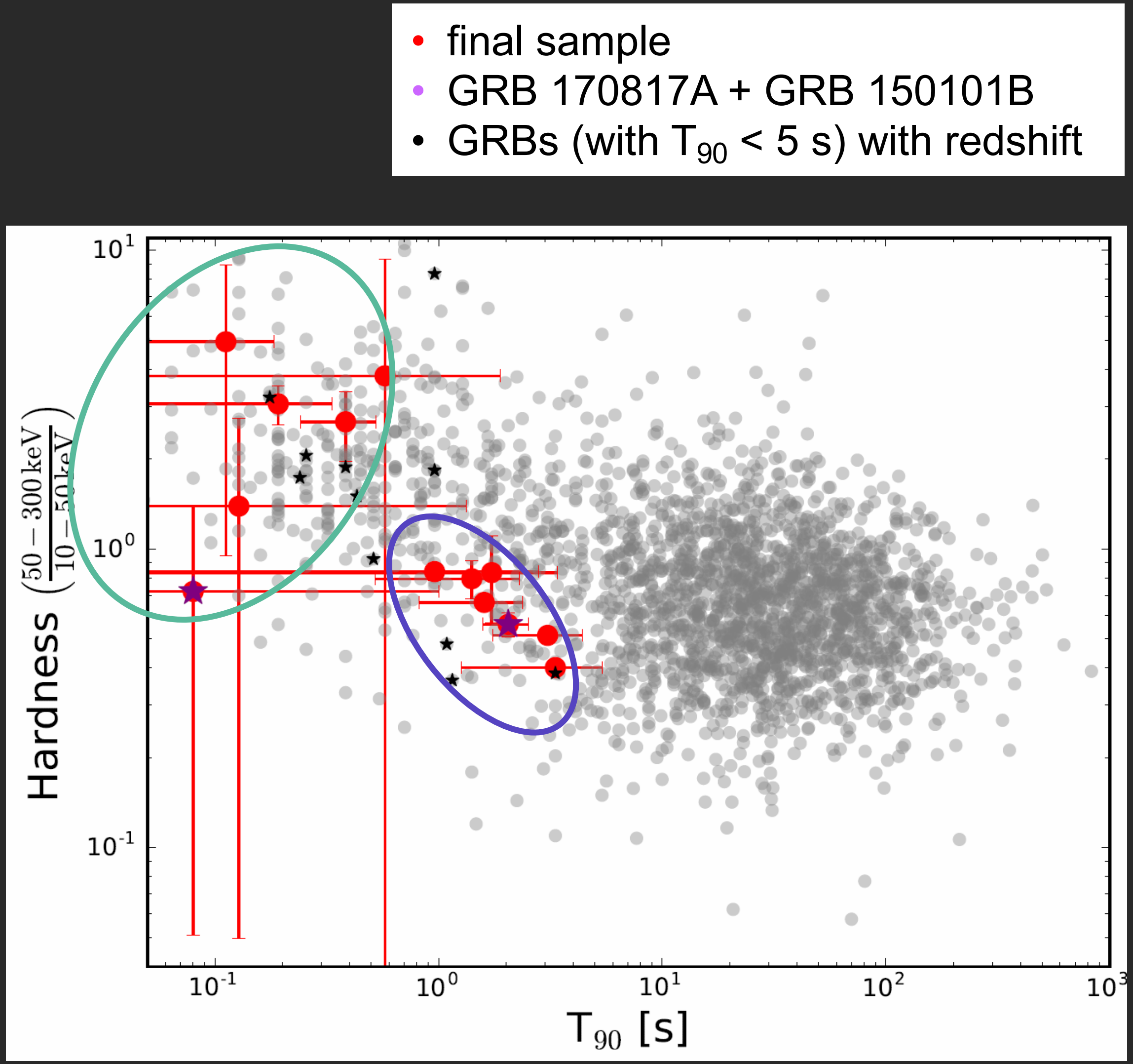
Table 2. Standard *Fermi*-GBM burst catalog parameters of the final sample of 13 candidate GRBs, which is including the reference GRB 170817A.

GRB Name	Trigger ID[a]	Time (UTC)	Durations T90 (s)	Durations T50 (s)	Localization RA (deg.)	Localization Dec. (deg.)	Localization error (deg.)	Total Fluence (erg cm^{-2}) $\times 10^{-7}$	Peak Flux (64 ms) (ph cm^{-2} s^{-1})	Detect.[d]	References
GRB 081209A[b]	bn081209981	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	Golenetskii (2008a,b)
GRB 100328A[b]	bn100328141	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		Abadie et al. (2012)
GRB 101224A	bn101224227	05:27:13.86	1.728 ± 1.68	0.192 ± 0.286	285.9	45.7	0.1[f]	1.92 ± 0.27	6.7 ± 1.0	S	Krimm (2010); Nugent & Bloom (2010); Xu (2010); Golovnya (2011)
GRB 110717A[b]	bn110717180	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, IA	*Fermi*-GBM Only
GRB 111024C[b]	bn111024896	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	IA	*Fermi*-GBM Only
GRB 120302B[b]	bn120302722	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
GRB 120915A[c]	bn120915000	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	IA, SW	*Fermi*-GBM Only + LAT
GRB 130502A	bn130502743	17:50:30.74	3.328 ± 2.064	2.304 ± 0.572	138.6	-0.1	0.0[f]	6.27 ± 0.35	6.6 ± 1.4	S, OT	Troja (2013); Malesani (2013); de Ugarte Postigo (2013); Gorosabel (2013); Breeveld (2013)
GRB 140511A[c]	bn140511095	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
GRB 150101B	bn150101641	15:23:34.47	0.08 ± 0.928	0.016 ± 0.023	188.0	-11.0	0.0[f]	2.38 ± 0.15	10.5 ± 1.3	S, IA, C, X, z	Troja et al. (2018); Burns et al. (2018); Fong et al. (2016)
GRB 170111B[c]	bn170111815	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
GRB 170817A	bn170817529	12:41:06.47	2.048 ± 0.466	1.28 ± 0.405	197.5	-23.4	0.0[f]	2.79 ± 0.17	3.7 ± 0.9	L, z, C, IA, HST and more	Abbott et al. (2017a)
GRB 180511A[c]	bn180511364	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

- Properties of the final candidates → next slides!

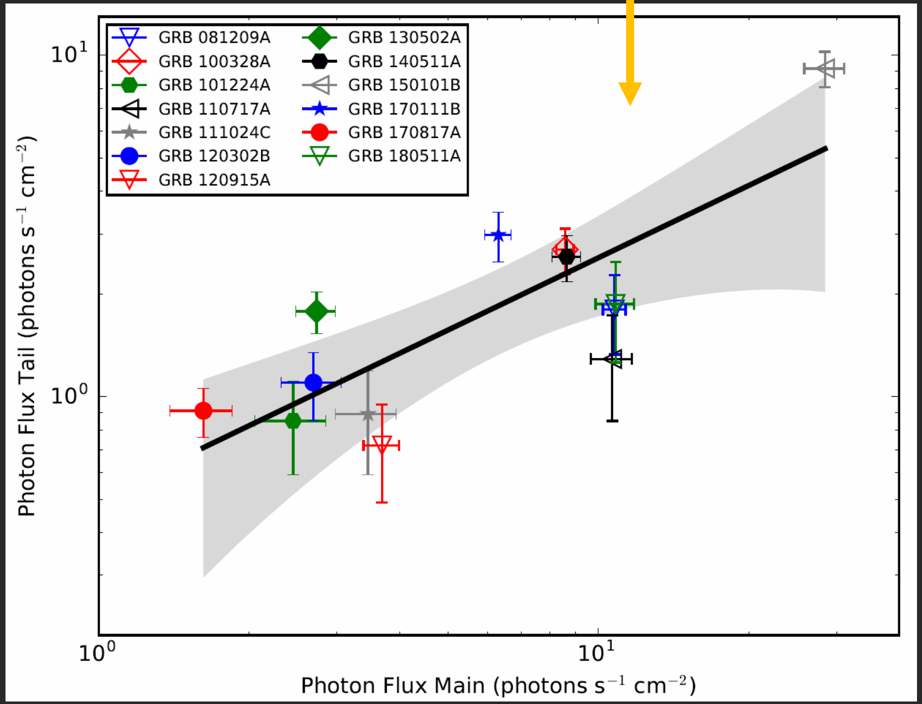
Candidate Properties: Spectral Hardness vs. Duration

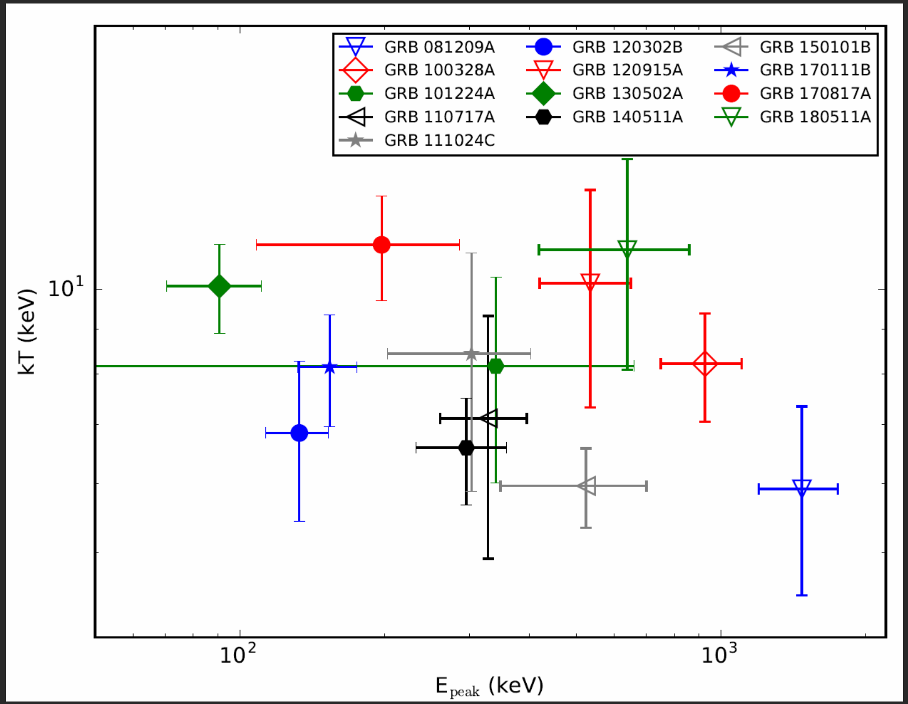
- Hardness-duration plot
  - From 10-year GBM GRB catalog
- 1st group:
  - Soft tail below a hardness value of 1
  - T_{90}: 1 - 4 s,
  - 7 GRBs including GRB 170817A
- 2nd group:
  - T_{90} < 0.6 s / hardness: 0.7 – 6 / large errors
  - 6 GRBs, including GRB 150101B
  - + Peak energy as proxy for hardness
  - Main pulse of the short group has systematically higher peak energies compared to the longer population!



Candidate Properties: Correlation Analysis

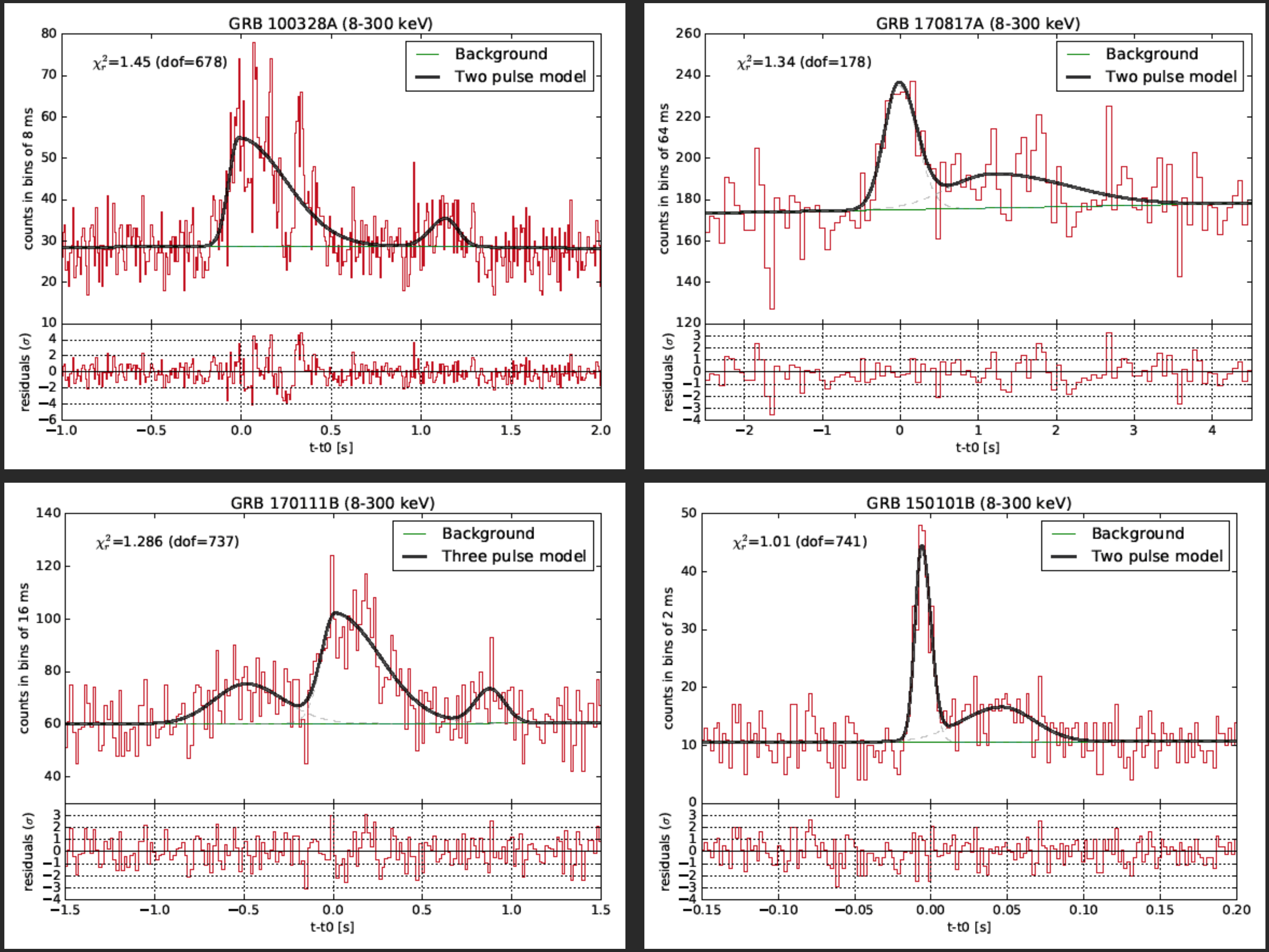
- between parameters of the main pulse and soft tail
  - Photon- and energy-fluxes, fluence and characteristic energies: kT and E_{Peak}
  - Derived from spectral analysis
- No significant correlation between the fluence and characteristic energies
- Significant correlation in Photon Fluxes





Candidate Properties: Pulse Fitting and Variability

- Inspection of lightcurves using pulse-fitting techniques
- Fit function composed of two pulses
  - Relation main pulse / tail
  - Analytical functions:
    → Norris et al. (1996, 2005)
- Cases where the two episodes
  - clearly separated
  - overlap
- Determination of minimum variability timescale dt_{min}
  - Method of Golkhou et al. (2015)
  - Describes the shortest coherent variation in the lightcurve
  - Radius emission region



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GRB name	$\sigma_{t_{rise,main}}$	dt_{min}	$t_{peak,soft} - t_{peak,main}$	Main/Tail relation
GRB 081209A (v)	25 ± 3	< 14.9	133 ± 14	joined
GRB 100328A (v)	77 ± 21	< 10.6	1153 ± 65	separated
GRB 101224A	23 ± 23	47.4 ± 7.6	1360 ± 625	separated
GRB 110717A (v)	36 ± 11	11.4 ± 3.0	712 ± 2097	separated
GRB 111024C	33 ± 17	40.7 ± 8.8	106 ± 20	separated
GRB 120302B	16 ± 19	< 119.6	1545 ± 134	separated
GRB 120915A (v)	312 ± 75	40.6 ± 13.2	632 ± 717	separated
GRB 130502A	169 ± 63	220.7 ± 34.0	2092 ± 765	separated
GRB 140511A	23 ± 7	<94.4	385 ± 424	joined
GRB 150101B	6 ± 1	7.9 ± 0.7	52 ± 11	joined
GRB 170111B	110 ± 36	<63.4	865 ± 71	separated
			-502 ± 104 [a]	separated
GRB 170817A	263 ± 103	124.6 ± 6.4	1201 ± 774	joined
GRB 180511A (v)	15 ± 4	<5.3	94 ± 65	joined

(v): candidates, where the variability timescale is less than the rise time with more than 2 sigma significance, indicating pulse sub-structure

⇨ We find that short-hard candidates with the exception of GRB 150101B have significant variation within the main pulse, i.e they are composed of multiple overlapping pulses

Discussion

- Sample of GRBs that show similarities to GRB 170817A
  - Soft emission episode with a BB spectrum that follows the main peak
  - Soft emission separate from the main peak - reported for the first time
- Two emerging groups of candidates in hardness duration diagram plot
  - Viewing angle effect? ⇨ similar GRBs viewed off-axis will become softer and of longer duration.
  - Short timescale structures present in on-axis lightcurves will be smoothed out for an off-axis observer

Discussion

- Proposed model (e.g. Lazzati et al. 2017)
  - Main peak: successful GRB jet, with lateral angular structure that is viewed off-axis
  - Soft emission: from the photosphere of a wide angled cocoon
  - Could explain both, the highly-variable main emission and the soft tail
- Cocoon shock breakout model (Gottlieb et al. 2018) ⟶ from candidate sample:
  - Strong variability could not come from the shock breakout emission!
  - Unclear how to account for the soft tails, temporally clearly separated from the main pulse!
- Matsumoto & Piran: arXiv:1909.03049, Sept 9, 2019
  - Study of similarity of our candidate sample and GRB 170817A
  - Two of them could be a cocoon shock-breakout events
  - Sample GRBs can be associated with a wing emission scenario

Conclusion

- 12 GRBs similar to 170817A (including 150101B) over 10 years ⇨ ~1.3/year
  - Short GRBs ranging in duration from ~0.1 to ~3 s
  - All seem to have a similar soft (blackbody?) tail
  - Tail not part of natural hard-to-soft spectral evolution observed in many GRBs
- Could be signatures of low-z binary neutron star mergers
  - Most short GRBs do not have this observed tail, far away ⇨ too weak to be observed?
- Only 170817A and 150101B have measured redshift
- GRB 170101B has an intriguing soft precursor