Fermi-GBM GRBs with characteristics similar to GRB 170817A


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First EM Signal with a GW Counterpart

GW 170817 / GRB 170817A

- Temporal association: $\Delta t = 1.74 \pm 0.05$ s
- Spatial association

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

The main hard peak is best fit with by an exponentially cutoff power law (Comptonized model) with $E_{\text{pk}} = 185 \pm 62$ keV.

The soft tail is best fit by a black body with $kT = 10.3 \pm 1.5$ 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


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

- **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 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

The GBM GRB online catalog is updated within 1 hour:

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
13 Candidates

Properties of the final candidates → next slides!

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

<table>
<thead>
<tr>
<th>GRB Name</th>
<th>Trigger ID(^a)</th>
<th>Time (UTC)</th>
<th>T90 (s)</th>
<th>RA (deg.)</th>
<th>Dec. (deg.)</th>
<th>Localization Error (deg.)</th>
<th>Total Fluence (erg cm(^{-2})) (\times 10^{-7})</th>
<th>Peak Flux (ph cm(^{-2}) s(^{-1}))</th>
<th>Detect.(^d)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRB 081209A(^b)</td>
<td>bn081209981</td>
<td>23:41:56:39</td>
<td>0.192 ± 0.143</td>
<td>45.3</td>
<td>63.5</td>
<td>4.9</td>
<td>14.66 ± 1.49</td>
<td>25.4 ± 1.2</td>
<td>KW, S(^a), A</td>
<td>Golenetskii (2008a,b)</td>
</tr>
<tr>
<td>GRB 100328A(^b)</td>
<td>bn100328141</td>
<td>03:22:44:60</td>
<td>0.384 ± 0.143</td>
<td>155.9</td>
<td>47.0</td>
<td>4.8</td>
<td>10.01 ± 0.24</td>
<td>13.4 ± 0.8</td>
<td>S</td>
<td>Abadie et al. (2012)</td>
</tr>
<tr>
<td>GRB 101224A (^b)</td>
<td>bn101224227</td>
<td>05:27:13:36</td>
<td>1.728 ± 1.68</td>
<td>285.9</td>
<td>45.7</td>
<td>0.1(^f)</td>
<td>1.92 ± 0.27</td>
<td>6.7 ± 1.0</td>
<td>S</td>
<td>Krimm (2010); Nugent &amp; Bloom (2010); Xu (2010); Golovnya (2011)</td>
</tr>
<tr>
<td>GRB 110717A(^b)</td>
<td>bn110717180</td>
<td>04:19:50:66</td>
<td>0.112 ± 0.072</td>
<td>308.5</td>
<td>-7.9</td>
<td>7.5</td>
<td>2.51 ± 0.12</td>
<td>18.5 ± 1.8</td>
<td>KW, IA</td>
<td>Fermi-GBM Only</td>
</tr>
<tr>
<td>GRB 111024B(^b)</td>
<td>bn111024896</td>
<td>21:30:02:24</td>
<td>0.960 ± 1.032</td>
<td>91.2</td>
<td>-1.8</td>
<td>13.2</td>
<td>3.80 ± 0.16</td>
<td>7.4 ± 1.2</td>
<td>IA</td>
<td>Fermi-GBM Only</td>
</tr>
<tr>
<td>GRB 120302B(^b)</td>
<td>bn120302722</td>
<td>17:19:59:08</td>
<td>1.600 ± 0.779</td>
<td>24.1</td>
<td>9.7</td>
<td>13.9</td>
<td>1.19 ± 0.16</td>
<td>6.2 ± 1.5</td>
<td>IA</td>
<td>Fermi-GBM Only</td>
</tr>
<tr>
<td>GRB 120915A(^c)</td>
<td>bn120915000</td>
<td>00:00:41:64</td>
<td>0.576 ± 1.318</td>
<td>209.4</td>
<td>67.3</td>
<td>5.9</td>
<td>5.06 ± 0.26</td>
<td>6.0 ± 0.9</td>
<td>IA, SW</td>
<td>Fermi-GBM Only + LAT</td>
</tr>
<tr>
<td>GRB 130502A(^a)</td>
<td>bn130502743</td>
<td>17:50:30:74</td>
<td>3.328 ± 2.064</td>
<td>138.6</td>
<td>0.0</td>
<td>0.0(^f)</td>
<td>6.27 ± 0.35</td>
<td>6.6 ± 1.4</td>
<td>S, OT</td>
<td>Traja (2013); Malesani (2013); de Ugarte Postigo (2013); Gorosabel (2013); Breveveld (2013)</td>
</tr>
<tr>
<td>GRB 140511A(^b)</td>
<td>bn140511095</td>
<td>02:17:11:56</td>
<td>1.408 ± 0.889</td>
<td>329.8</td>
<td>-30.1</td>
<td>8.8</td>
<td>3.71 ± 0.32</td>
<td>9.4 ± 1.0</td>
<td>S, IA, C, X, z</td>
<td>Fermi-GBM Only</td>
</tr>
<tr>
<td>GRB 150101B(^c)</td>
<td>bn150101641</td>
<td>15:23:34:47</td>
<td>0.08 ± 0.928</td>
<td>188.0</td>
<td>-11.0</td>
<td>0.0(^f)</td>
<td>2.38 ± 0.15</td>
<td>10.5 ± 1.3</td>
<td>S, IA, C, X, z</td>
<td>Troja et al. (2018); Burns et al. (2018); Fong et al. (2016)</td>
</tr>
<tr>
<td>GRB 170711A(^b)</td>
<td>bn170711815</td>
<td>19:34:01:39</td>
<td>3.072 ± 1.318</td>
<td>270.9</td>
<td>63.7</td>
<td>6.7</td>
<td>5.96 ± 0.12</td>
<td>7.6 ± 1.0</td>
<td>L, z, C</td>
<td>Fermi-GBM Only</td>
</tr>
<tr>
<td>GRB 170817A(^a)</td>
<td>bn170817529</td>
<td>12:41:06:47</td>
<td>2.048 ± 0.466</td>
<td>197.5</td>
<td>-23.4</td>
<td>0.0(^f)</td>
<td>2.79 ± 0.17</td>
<td>3.7 ± 0.9</td>
<td>IA, HST and more</td>
<td>Abbott et al. (2017a)</td>
</tr>
<tr>
<td>GRB 180511A(^c)</td>
<td>bn180511364</td>
<td>08:43:35:79</td>
<td>0.128 ± 1.207</td>
<td>250.4</td>
<td>-8.2</td>
<td>15.1</td>
<td>1.53 ± 0.21</td>
<td>9.2 ± 1.0</td>
<td>IA</td>
<td>Fermi-GBM Only</td>
</tr>
</tbody>
</table>
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 $E_{\text{Peak}}$
  - 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 $d_{\text{min}}$
  - Method of Golkhou et al. (2015)
  - Describes the shortest coherent variation in the lightcurve
  - Radius emission region
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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.
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!

  - 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 \( \Rightarrow \sim 1.3/\text{year} \)
  - Short GRBs ranging in duration from \( \sim 0.1 \) to \( \sim 3 \) 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 \( \Rightarrow \) too weak to be observed?

- Only 170817A and 150101B have measured redshift

- GRB 170101B has an intriguing soft precursor