Multi-component emissions in GRBs
the case of GRB 090618

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In collaboration with

• Space and on-ground observations
• Morphological and spectral properties
• Analysis in the fireshell scenario
• Identification of two different episodes
• Possible implications and conclusions
Observations

- Swift
- Fermi-GBM
- RT-2
- AGILE
- Suzaku-WAM
- Konus-Wind

$t \sim 155$ s

Peculiar morphology...

Nal
8-440 keV

BGO
260-40000 keV
Observations

...confirmed by Swift and RT-2 Observations...

Hints for a strong spectral evolution.
Observations

Observed lag for each pulse

Base energy range 15-25 keV

Large delay for the first pulse (t₀, t₀ + 50 s)

Atypical for a GRB !!!

![Graph showing observed lag for each pulse across different energy ranges.](image)
Observations

Swift/XRT data of GRB 090618
blue: WT – red: PC

NH (intrinsic)
$2.24 \times 10^{21} \text{ cm}^{-2}$

Photon index
$2.01 \pm 0.05$

Flux (0.3-10 keV)
$3.3 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$
Extra signal in the soft X-ray due to prolonged activity
Observations

Complete optical and Radio coverage

Redshift $z = 0.54$ (Cenko et al.) from absorption lines

SN emission underlying the afterglow ??? (Cano et al. 2011)
Observations

LBT proposal to study the host galaxy, detected on archival images (courtesy Malesani)

\[ R \sim 23 \]
The first episode is less peaked and decays more smoothly than the other ones.

Norris profile:

\[ I(t) = A \exp \left[ -\left( \frac{|t - t_{\text{max}}|}{\sigma_r} \right)^\nu \right] \quad t < t_{\text{max}}, \]

\[ = A \exp \left[ -\left( \frac{|t - t_{\text{max}}|}{\sigma_d} \right)^\nu \right] \quad t > t_{\text{max}}, \]
Spectral properties

- Spectral analysis of the main pulses

\[ N_E(E) = A \left( \frac{E}{100 \text{ keV}} \right)^\alpha \exp \left( - \frac{E}{E_0} \right), \]

Band spectral model

\[ = A \left[ \frac{(\alpha - \beta)E_0}{100 \text{ keV}} \right]^{\alpha - \beta} \exp (\beta - \alpha) \left( \frac{E}{100 \text{ keV}} \right)^\beta, \]

\[(\alpha - \beta)E_0 \leq E \]

<table>
<thead>
<tr>
<th>Time Interval (MET)</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$E_0^{BAND}$ (keV)</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>508 - 559</td>
<td>-0.74 ± 0.10</td>
<td>-2.32 ± 0.16</td>
<td>119.0 ± 21.7</td>
<td>1.12</td>
</tr>
<tr>
<td>559 - 565</td>
<td>-1.14 ± 0.07</td>
<td>-3.53 ± 2.04</td>
<td>201.6 ± 35.5</td>
<td>1.15</td>
</tr>
<tr>
<td>565 - 576</td>
<td>-0.97 ± 0.02</td>
<td>-2.62 ± 0.11</td>
<td>305.3 ± 14.7</td>
<td>1.97</td>
</tr>
<tr>
<td>576 - 585</td>
<td>-1.04 ± 0.03</td>
<td>-2.40 ± 0.06</td>
<td>179.3 ± 11.9</td>
<td>1.62</td>
</tr>
<tr>
<td>585 - 612</td>
<td>-1.06 ± 0.03</td>
<td>-2.64 ± 0.09</td>
<td>124.3 ± 7.69</td>
<td>1.18</td>
</tr>
</tbody>
</table>

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GRB 090618

Pescara 2011

11/
Spectral properties

Hardness Ratio - Swift

HR1: 25-50 / 15-25 keV
HR2: 50-150 / 15-50 keV
Spectral properties

Hardness Ratio - Swift

HR1 : 25-50 / 15-25 keV
HR2 : 50-150 / 15-50 keV

...an other hint for 2 different episodes...
Mixed thermal – non thermal model: Blackbody + power-law

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<tr>
<th>Time Interval (MET)</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$E_0(keV)$</th>
<th>$\tilde{\chi}^2_{BAND}$</th>
<th>$kT(keV)$</th>
<th>$\gamma$</th>
<th>$\tilde{\chi}^2_{BB+po}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>508 - 558</td>
<td>-0.75 ± 0.10</td>
<td>-2.33 ± 0.18</td>
<td>120.03 ± 22.0</td>
<td>1.19</td>
<td>29.13 ± 1.41</td>
<td>1.64 ± 0.04</td>
<td>1.34</td>
</tr>
<tr>
<td>559 - 565</td>
<td>-1.099 ± 0.10</td>
<td>-3.23 ± 6.32</td>
<td>174.012 ± 51.8</td>
<td>1.26</td>
<td>24.68 ± 2.16</td>
<td>1.62 ± 0.04</td>
<td>1.36</td>
</tr>
<tr>
<td>565 - 576</td>
<td>-0.81 ± 0.02</td>
<td>-2.21 ± 0.18</td>
<td>191.106 ± 15.73</td>
<td>1.79</td>
<td>46.38 ± 0.71</td>
<td>1.67 ± 0.08</td>
<td>6.24</td>
</tr>
<tr>
<td>576 - 585</td>
<td>-0.98 ± 0.02</td>
<td>-3.38 ± 1.83</td>
<td>170.4 ± 16.37</td>
<td>1.52</td>
<td>31.31 ± 0.57</td>
<td>1.76 ± 0.09</td>
<td>3.56</td>
</tr>
<tr>
<td>585 - 612</td>
<td>-1.01±0.02</td>
<td>-2.75 ± 0.02</td>
<td>118.62 ± 7.29</td>
<td>1.20</td>
<td>24.45 ± 0.42</td>
<td>1.86±0.01</td>
<td>2.36</td>
</tr>
<tr>
<td>612 - 659</td>
<td>-2.38 ± -1</td>
<td>-1.98 ± 0.01</td>
<td>999.28 ± -1</td>
<td>2.39</td>
<td>16.36 ± 0.84</td>
<td>2.23±0.05</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Counts

<table>
<thead>
<tr>
<th>BB+po</th>
<th>Band</th>
<th>Power-law</th>
</tr>
</thead>
</table>

Counts vs Time (s)
Spectral properties

Two different emission episodes

Each of them satisfies the Amati relation
Analysis in the fireshell scenario

- Opt thick and spherical sym plasma originated from the formation of a black hole
- Thermal equilibrium with the engulfed baryonic matter
- Relativistic expansion until the transparency condition
- First flash of radiation (Proper-GRB) whose SED should be thermal
- Following observed prompt emission due to collisions of the residual baryonic and leptonic matter shell with the CBM around the burst site (extended afterglow)

We need only 2 parameters, the total energy and the baryon loading, and the structure of the circumburst density around the GRB
For each couple of Edya and B it is possible to:

- Determine the energy emitted in the P-GRB
- Estimate the observed temperature $kT$ of the transparency
- Obtain the Lorentz Gamma factor at the transparency

For more information see C.L. Bianco talk

- Distinct emission in the first seconds of the light curve
- Observed $kT$ of the BB+po
- Total energy emitted
Episode 1 as P-GRB of GRB 090618?  NO

\[ E_{ep1} = 3.87 \times 10^{52} \text{ ergs} = 16 \% \ E_{iso} \]

\[ B = 1.5 \times 10^{-4} \]

\[ kT_{th} = 460 \text{ keV} \]
Episode 1 as P-GRB of GRB 090618? **NO**

\[ E_{\text{ep 1}} = 3.87 \times 10^{52} \text{ ergs} = 16 \% E_{\text{iso}} \]

\[ B = 1.5 \times 10^{-4} \rightarrow kT_{\text{th}} = 460 \text{ keV} \]

Episode 2 as a single GRB? **YES**

P-GRB episode in the first 6 s

\[ B = 1.5 \times 10^{-3} \rightarrow kT_{\text{th}} = 22 \text{ keV} \]

\[ \Gamma_0 = 352 \]

\[ \langle n \rangle = 1 \text{ \#/cm}^3 \]

\[ Edya = 5 \times 10^{53} \text{ ergs} \]
Discussions

Multiple collapse ???

Rees Ruffini Wheeler 1974

See Penacchioni talk
 Discussions

- BB and power-law spectral model origin
- Is the power-law the correct non-thermal component?

The case of GRB 090902B
• Two different episodes confirmed

• More analysis are needed on the first episode

• => talk Penacchioni