**Konus-Wind gamma-ray bursts: temporal characteristics, hardness, and classification**


Ioffe Workshop on GRBs and other transient sources: 20 Years of Konus-Wind Experiment
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Outline

- Physical classification
- Konus-Wind experiment
- Duration
- Hardness
- Lags
- Comparison of classifications
- Conclusions
# Physical classification

<table>
<thead>
<tr>
<th></th>
<th>Type I</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt emission (γ-rays)</td>
<td>short</td>
<td>long</td>
</tr>
<tr>
<td>X-ray afterglows</td>
<td>not always observed; about 10 times weaker;</td>
<td>always observed; X-ray flares</td>
</tr>
<tr>
<td></td>
<td>X-ray flares</td>
<td></td>
</tr>
<tr>
<td>Optical afterglows</td>
<td>rarely observed; weak</td>
<td>observed for most of bursts</td>
</tr>
<tr>
<td>Host galaxies</td>
<td>early- and late-type galaxies; large offsets from their host centers</td>
<td>late-type galaxies; burst sources reside in the most bright blue regions</td>
</tr>
<tr>
<td>Supernova</td>
<td>never observed; hard upper limits</td>
<td>observed (types Ib/c)</td>
</tr>
<tr>
<td>Redshift (median)</td>
<td>~0.3</td>
<td>~1.8</td>
</tr>
<tr>
<td>Suggested source</td>
<td>Coalescence of NS-NS or NS-BH</td>
<td>Collapse of massive stars ~&gt; 100 M_\text{sun}</td>
</tr>
</tbody>
</table>

Zhang et al., 2006, 2007, 2009
Konus-Wind

- Two detectors NaI(Tl) 4\pi FoV total, $S_{\text{eff}} \sim 80 \text{--} 160 \text{ cm}^2$
- Time history
  - recorded in 12 – 50 keV (G1), 50 – 200 keV (G2), 200 – 760 keV (G3)
  - Two modes: waiting (resolution 2.944 s) and triggered (2 ms –256 ms, from $T_0-0.512$ s to $T_0-230$ s)
- Spectral measurements in the 20 keV -15 MeV band
- Very stable background (up to few days)

- We have analyzed 1834 GRBs detected during 1994 – 2010.
- Among them 84 with measured redshift (Tsvelkova talk)
Duration

- Durations are calculated in 80-1400 keV (G2+G3) band
  - Energy of the most GRBs is hard $E_p$ (max $E_{F_E}$) >80 keV
  - in G1 (20-80 keV) background is less stable
  - onset of X-ray afterglow in G1 can bias a duration

- Burst begin ($t_0$) and end ($t_{100}$) are calculated at 5σ level.

- $T_{50}$ и $T_{90}$ – intervals of accumulation of 50% и 90% burst counts in a detector

  $$T_{50} = 2.6 \pm 0.2 \, \text{s}$$
  $$T_{90} = 6.7 \pm 0.4 \, \text{s}$$
Durations (systematic effects)

- Signal-to-noise ratio (S/N; Bonnell et al. 1997)
- Cosmological time dilation
- Energy band (Fenimore 1995)
- Trigger algorithm

Qin et al. (2013)
The burst sample contains 1834 GRBs (1994-2010)

Parameters of $T_{50}$ distribution is less sensitive to the search threshold.

$T_{50}$ was used for the classification.

The sample is biased: lack of weak short GRBs ($S/N<10$, $T_{50}<1$ s)

We used unbiased sample of 1168 GRBs with $S/N>10$. The boundary between long and short bursts is $T_{50} = 0.6$ s

The fraction of short GRBs ($T_{50} < 0.6$ s) in the unbiased sample - 22%, in the full sample – 15% (BATSE -32%; Swift-BAT -8%; Fermi-GBM – 15 %)

$\chi^2 = 9.3$ (13 d.o.f)
Short GRBs with EE

- Morphology: short initial pulse, long, low intensity tail up to ~100 s
  (Lazzati et al., 2001; Connaughton, 2002; Frederiks et al., 2004; Norris & Bonnell 2006; Norris et al., 2011)
- 23 candidates to short GRBs with EE found in KW data
- Fraction among short GRBs:
  Konus-Wind – 8% (23/296); BATSE – 25% (64/256); Swift – 23% (12/52).

GRB 950503 $T_0 = 66971.838$ s
Hardness

☐ Hardness – ratio of count accumulated during burst in G3 and G2 (HR_{32}=G3/G2)
☐ We have analyzed 1143 GRBs
☐ The log T_{50} – logHR_{32} distribution was fitted with two 2D Gaussian distributions.

☐ The fraction of short GRBs (T_{50} < 0.6 s) in long/soft GRB cluster is 13%.
☐ Among 23 short GRBs with EE, initial pulses of two bursts are in long/soft GRB cluster.

Only two classes found
Hardness

- **2D Gaussian distribution** ($x=\log T_{50}$; $y=\log HR_{32}$)
  
  $$p(x, y|l) = \frac{1}{2\pi \sigma_x \sigma_y \sqrt{1 - r^2}} \times \exp \left[ -\frac{1}{2(1 - r^2)} \left( \frac{(x - a_x)^2}{\sigma_x^2} + \frac{(y - a_y)^2}{\sigma_y^2} - \frac{C}{\sigma_x \sigma_y} \right) \right],$$

  где
  
  $$C = 2r(x - a_x)(y - a_y)$$

- **Likelihood**
  
  $$L = \sum_i \ln p(x_i, y_i),$$

  $$p(x, y) = \sum_l p(x, y|l) p_l$$

- **Indicator function**
  
  $$I_l = \frac{p_l p(x, y|l)}{\sum_i p(x, y|l)}$$

- **Cluster parameters**

<table>
<thead>
<tr>
<th>$l$</th>
<th>$a_x$</th>
<th>$T_{50c}$, s</th>
<th>$a_y$</th>
<th>HR$_c$</th>
<th>$\sigma_x$</th>
<th>$\sigma_y$</th>
<th>$r$</th>
<th>$p_l$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$-0.940^{+0.032}_{-0.012}$</td>
<td>$0.115^{+0.009}_{-0.003}$</td>
<td>$-0.124^{+0.011}_{-0.019}$</td>
<td>$0.752^{+0.020}_{-0.032}$</td>
<td>$0.442^{+0.033}_{-0.015}$</td>
<td>$0.221^{+0.008}_{-0.010}$</td>
<td>$0.020^{+0.041}_{-0.056}$</td>
<td>$0.210^{+0.011}_{-0.003}$</td>
</tr>
<tr>
<td>2</td>
<td>$0.835^{+0.017}_{-0.005}$</td>
<td>$6.834^{+0.265}_{-0.081}$</td>
<td>$-0.499^{+0.001}_{-0.002}$</td>
<td>$0.317^{+0.001}_{-0.002}$</td>
<td>$0.560^{+0.003}_{-0.019}$</td>
<td>$0.216^{+0.003}_{-0.003}$</td>
<td>$0.176^{+0.006}_{-0.008}$</td>
<td>$0.791^{+0.002}_{-0.012}$</td>
</tr>
</tbody>
</table>
Spectral lags

- Spectral lag ($t_{\text{lag}}$) is a measure of spectral evolution
- $t_{\text{lag}}$ is calculated using a fit for cross correlation function (CCF) with 4th degree polynomial
- Confidence interval (68% CL) is calculated using bootstrap method

GRB 090618 $t_{\text{lag}} = 4.0 \pm 0.4$ s

GRB 120323A $t_{\text{lag}} = (5.4 \pm 1.3) \times 10^{-3}$ s
Spectral lags

- Most of the short GRBs have $|t_{\text{lag}}| < 50$ ms
- Long GRBs $t_{\text{lag}}$ distribution peaks at $\sim 75$ ms
- Among long GRBs $\sim 20\%$ have $|t_{\text{lag}}| < 50$ ms
Spectral lags

<table>
<thead>
<tr>
<th>parameter, p</th>
<th>channels</th>
<th>$D_{KS}$</th>
<th>$P_{KS}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{lag}$ (s)</td>
<td>G3-G1</td>
<td>0.678</td>
<td>8.5e-14</td>
</tr>
<tr>
<td>$\tau_{lag}/T_{50}$</td>
<td></td>
<td>0.297</td>
<td>5.5e-03</td>
</tr>
<tr>
<td>$\tau_{lag}$ (s)</td>
<td>G2-G1</td>
<td>0.566</td>
<td>1.1e-15</td>
</tr>
<tr>
<td>$\tau_{lag}/T_{50}$</td>
<td></td>
<td>0.245</td>
<td>2.7e-03</td>
</tr>
<tr>
<td>$\tau_{lag}$ (s)</td>
<td>G3-G2</td>
<td>0.568</td>
<td>2.2e-35</td>
</tr>
<tr>
<td>$\tau_{lag}/T_{50}$</td>
<td></td>
<td>0.307</td>
<td>1.3e-10</td>
</tr>
</tbody>
</table>
Spectral lags of short GRBs

- 5 soft GRBs with $T_{50} < 0.6$ s have significant lags ($t_{\text{lag}} > 100$ ms) and reside in the long/soft cluster.
- 2 GRBs classified as short GRB with EE reside in the long/soft cluster having $t_{\text{lag}} > 100$ ms.
- Softer and longer bursts tend to have longer lags.
Comparison of classifications

- Konus-Wind sample contains 84 GRBs with measured z (detected up to the end of 2010)
- Type I – 8 GRBs (7 short GRBs + GRB 060614)
- Type II – 48 GRBs (Zhang et al., 2009; Kann et al., 2010, 2011)
- 28 unclassified with measured redshift

Observer frame

$P_{KS}(\text{obs}, \text{HR}_{32}) = 0.3\%$

Source frame

$P_{KS}(\text{src}, \text{HR}_{32}) = 3\%$
Comparison of classifications

- Konus –Wind GRB redshifts
  - short \( < z > = 0.6 \)
  - long \( < z > = 1.5 \)
- Only one out of 6 short GRB has \( E_p > 1 \text{ MeV} \), while 16 out of 65 long GRBs have \( E_p > 1 \text{ MeV} \).

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**Observer frame**

**Source frame**
Conclusions

- Using the unbiased $T_{50}$ distribution we derived the boundary between short and long KW GRBs $T_{50} = 0.6$ s with a fraction of short GRBs of 22%. The total number of short GRBs – 296.

- Cluster analysis of KW GRBs suggests the existence of only two GRB classes: short/hard and long/soft.

- Spectral lag distributions of short and long GRBs differs significantly.

- Physical GRB types I and II corresponds to short/hard low-lag GRB and long/soft GRB classes, respectively.

- The hardness difference of the two GRB classes can be attributed to the difference of average source distances. Long bursts tend to be detected at large distances.

- The results were used in Pal’shin et al., Interplanetary Network Localizations of Konus Short Gamma-Ray Bursts, 2013 The second Konus catalog of short GRBs, in prep.
Thank you!