Konus-Wind observations of ultra-long GRBs

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Ioffe Workshop on GRBs and other transient sources: 25 Years of Konus-Wind Experiment
Known ultra-long GRBs observed by Konus-Wind

- GRB 971208
- GRB 020410
- GRB 060814
- GRB 080407
- GRB 091024
- GRB 111209A
- GRB 121027A
- GRB 130925A

Redshifts:
- \( z \approx 0.5 \)
- \( z = 1.1 \)
- \( z = 0.7 \)
- \( z = 1.8 \)
- \( z = 0.35 \)
## Very long GRB data

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Energy band*, keV</th>
<th>Number of bursts</th>
<th>$T_{90}&gt;250$ s</th>
<th>$T_{90} \sim 1000$ s</th>
</tr>
</thead>
<tbody>
<tr>
<td>CGRO-BATSE</td>
<td>50 - 300</td>
<td>22</td>
<td></td>
<td>1**</td>
</tr>
<tr>
<td>BeppoSAX-GRBM</td>
<td>40 - 700</td>
<td>7</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Swift-BAT</td>
<td>15 - 150</td>
<td>58</td>
<td></td>
<td>~20</td>
</tr>
<tr>
<td>Fermi-GBM</td>
<td>50 - 300</td>
<td>30</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Konus-Wind</td>
<td>50 - 1500</td>
<td>~100</td>
<td></td>
<td>~20 this work</td>
</tr>
</tbody>
</table>

* used for duration calculation  
** GRB 970315  
Meegan et al. BATSE current GRB cat.; Frontera et al., 2009; Lien et al., 2016; Bhat et al., 2016
Joint Russian-US
Konus-Wind experiment

- Launch 1994 - 24+ years of continuous operation;

- Waiting mode – continuous record of count rates in the 20-80 keV (G1), 80-350 keV (G2), and 300-1200 keV (G3) bands with 2.944 s resolution;

- Advantages:
  - stable background (up to a few days),
  - $2 \times 2 \pi$ FoV,
  - duty circle ~95%,
  - observes all bright transients;

- Extremely useful for a search of very long duration transients.
Konus-Wind triggered GRB classification

- The boundary between “short” and “long” GRBs was adopted to be $T_{50}=0.6$ s: 15% - short GRBs
- Hardness-duration distribution is well fitted with 2D Gaussians.

Classification using the fit:
- 18% - Type I (short/hard), 78% - Type II (long/soft), for 4% the type is uncertain (I or II).
Konus-Wind waiting mode event search

- Bayesian block decomposition of KW waiting mode time history 1994-2017;
- Selection of transients occurred in both detectors and/or at least in two energy bands;
- Preliminary event classification: GRB, Solar flare, hard X-ray transient (e.g. Cyg-X1, V404 Cyg), particle event (using Wind-3DP particle monitor), or instrument glitch;

KONUS-WIND V404Cyg 150615
$T_0 = 65304$ s UT (18:08:24)

KONUS-WIND GRB 130925A
$T_0 = 14968$ s UT (04:09:28)
KW waiting mode event search results

The confirmed and unconfirmed GRBs include \(~120\) events with \(T_{100} > 250\) s and \(S/N > 10\) (at \(T_{100}\)) which allow to analyze the tail of the KW GRB duration distribution.

<table>
<thead>
<tr>
<th>Event type</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Flares</td>
<td>~12 000</td>
</tr>
<tr>
<td>GRB candidates +</td>
<td>~9 000</td>
</tr>
<tr>
<td>Other transients</td>
<td>~5 000</td>
</tr>
<tr>
<td>Confirmed GRBs</td>
<td>~5 000</td>
</tr>
<tr>
<td>Total</td>
<td>~26 000</td>
</tr>
</tbody>
</table>

\(HR_{21} = 80\text{-}300\,\text{keV peak. rate}/20\text{-}80\,\text{keV peak. rate}\)
Confirmation of multi-episode GRBs

- Association of close in time events with a single source using detections by other instruments (Inter Planetary Network, IPN).

- **The IPN instruments used:** CGRO-BATSE, Fermi-GBM, Swift-BAT (at low earth orbit); INTEGRAL-SPI-ACS (at the elongated orbit up to 0.5 lt-s); Ulysses-GRB (670 -3180 lt-s); Mars Odyssey-HEND (Mars, up to 1200 lt-s); MESSENGER-GRNS (Mercury, up to 700 lt-s)

- **Confirmed:** 99 GRB candidates (single and multi-episode) $T_{100} > 250$ s, 17 u-long GRB – $T_{100} > 1000$ s (including 8 known KW u-long GRBs and 9 new candidates).

GRB 080407; Pal’shin et al., 2012

GRB 961029 - detected by KW, BATSE, and Ulysses
U-long GRBs.
Duration and hardness.

- The $T_{90}$ distribution of the GRBs with $250 \, s < T_{90} < 1000 \, s$ is consistent with a tail of the triggered GRB population with $P_{KS}=30\%$.
- There is an excess of bursts in the tail ($T_{90} > 1000 \, s$) with $P_{chance}=3\times10^{-6}$.
- Ultra-long GRBs extend the softer/longer part of the long GRB distribution.

![Histogram and scatter plot diagram](image)
KW waiting mode is a continuous 3-channel spectrum in the ~20–1500 keV band.

Up to 3 model parameters (including normalization) may be estimated: PL (1 d.o.f.), Cutoff PL, Band function with one fixed parameter (i.e., beta).

Ultra-long GRB 130925A; Frederiks et al., 2014
Spectral analysis results

- 17 GRBs with $T_{100} > 1000$ s
- Most of $E_{\text{peak}}$ are in the ~100-300 keV range with 2 hard (~1 MeV) and 1 soft (~40 keV) outliers.
- U-long GRBs are consistent with other bursts in terms of fluence and peak flux.
Discovered KW ultra-long GRBs

The hardest and the softest discovered burst

KONUS-WIND GRB 161103
$T_0 = 81691 \text{ s UT (22:41:31)}$

S1

KONUS-WIND GRB 130527
$T_0 = 39662 \text{ s UT (11:01:02)}$

S2

$T_{100} = 4380 \text{ s (25-1470 keV)}$

$T_{90} = 4001 \pm 164 \text{ s; } T_{50} = 3053 \pm 134 \text{ s}$

time averaged: $E_p = 1.06 (-0.27,+0.68) \text{ MeV}$

$T_{100} = 1348 \text{ s; (25-1470 keV)}$

$T_{90} = 824 \pm 38 \text{ s; } T_{50} = 306 \pm 7 \text{ s}$

time averaged: $E_p = 36 (-21,+24) \text{ keV}$
KW Ulong GRBs in the rest frame: Hardness-duration distribution

- Konus-Wind has detected 337 GRBs with known redshifts (Anastasia Tsvetkova talk on Wednesday)
- U-long GRBs are still the longest bursts in the rest frame.

References:

KW Ulong GRBs in the rest frame: Amati and Yonetoku relations

U-long GRBs nicely follow the Amati relation for ‘classic’ long GRBs and reside on the low luminosity side of the Yonetoku relation.
KW Ulong GRBs in the rest frame

There are 12 u-long GRB candidates with unknown z. What we can learn about them?

- Most of the found u-rights may originate at a broad range of $z > \sim 0.2$
- U-long GRBs seem to be inhomogeneous in hardness also in the rest frame.

![Graphs showing the relationship between $E_{\text{iso}}$ (erg) and $L_{\text{iso}}$ (erg s$^{-1}$) with color-coded points at different redshifts ($z$)]
Summary

KW provides an excellent opportunity to observe prompt emission of ultra-long GRBs for their whole duration.

We have found 9 new u-long GRB candidates with durations in the range ~1000 – 4500 s.

A hint of excess was found in the \( T_{90} \) distribution at \( T_{90} > \sim 1000 \) s above the log-normal fit derived for classical long GRBs.

Spectral analysis of KW u-long GRBs shows that most of the events have \( E_{\text{peak}} \) in the range of 100-300 keV with one soft and two hard outliers.

The u-long GRBs with unknown redshifts nicely follow the Amati relation for ‘classic’ long GRBs and reside on the low luminosity side of the Yonetoku relation.

U-long GRBs seem to be inhomogeneous in hardness also in the rest frame.

Thank you!

Work is supported by RSF (grant 17-12-01378)
Discovered KW ultra-long GRBs

KONUS-WIND GRB 080806
$T_0 = 64284 \text{ s UT (17:51:24)}$

$T_{100} = 1007 \text{ s (25-1470 keV)}$
$T_{90} = 830 \pm 116 \text{ s}$; $T_{50} = 277 \pm 51 \text{ s}$

time averaged: $E_p = 1.06 (-0.4,+1) \text{ MeV}$
# Konus-Wind ultra long GRBs

<table>
<thead>
<tr>
<th>GRB</th>
<th>z</th>
<th>dT (s)</th>
<th>LC shape</th>
<th>$E_{\text{peak}}$ (keV)</th>
<th>Fluence (erg cm$^{-2}$)</th>
<th>$E_{\text{iso}}$ (erg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>971208$^a$</td>
<td>--</td>
<td>~2500</td>
<td>FRED</td>
<td>~144</td>
<td>~2.6x10$^{-4}$</td>
<td>~6.9x10$^{53}$$^*$</td>
</tr>
<tr>
<td>020410$^b$</td>
<td>~0.5$^f$</td>
<td>~1600</td>
<td>Multi-episode</td>
<td>~180</td>
<td>~2.8x10$^{-5}$</td>
<td>~1.8x10$^{52}$</td>
</tr>
<tr>
<td>060814B$^a$</td>
<td>--</td>
<td>~2700</td>
<td>FRED</td>
<td>~340</td>
<td>~2.4x10$^{-4}$</td>
<td>~6.4x10$^{53}$$^*$</td>
</tr>
<tr>
<td>080407$^c$</td>
<td>--</td>
<td>~2100</td>
<td>Multi-episode</td>
<td>~290*</td>
<td>~4.5x10$^{-4}$</td>
<td>~1.2x10$^{54}$$^*$</td>
</tr>
<tr>
<td>091024$^d$</td>
<td>1.1$^d$</td>
<td>~1200</td>
<td>Multi-episode</td>
<td>~280</td>
<td>~1.3x10$^{-4}$</td>
<td>~4.5x10$^{53}$</td>
</tr>
<tr>
<td>111209A$^e$</td>
<td>0.7$^g$</td>
<td>~10000</td>
<td>Multi-episode</td>
<td>~310</td>
<td>~4.9x10$^{-4}$</td>
<td>~5.8x10$^{53}$</td>
</tr>
<tr>
<td>121027A</td>
<td>1.8$^h$</td>
<td>&gt;3500</td>
<td>Multi-episode</td>
<td>~300</td>
<td>~7.4x10$^{-5}$</td>
<td>~5.9x10$^{53}$</td>
</tr>
<tr>
<td>130925A</td>
<td>0.35$^e$</td>
<td>~5000</td>
<td>Multi-episode</td>
<td>~152</td>
<td>~6.2x10$^{-4}$</td>
<td>~1.9x10$^{53}$</td>
</tr>
</tbody>
</table>

* 1st pulse
** at z=1

\[ a \text{Pal’shin+2008, } b \text{Nicastro+2004, } c \text{Pal’shin+2013, } d \text{Virgili+2013, } e \text{Golenetskii+2011, } f \text{Levan+2005, } \\
\text{gVreeswijk+2011, } h \text{Tanvir+2012, } e \text{Vreeswijk+2011} \]
The 3rd IPN is in operation since 1990

At present time consists of 7 s/c: AGILE, Fermi, RHESSI, and Swift (at low earth orbits); INTEGRAL (at the elongated orbit up to 0.5 lt-s); Wind (up to 7 lt-s) and Mars Odyssey (Mars, up to 1200 lt-s)

Included also: MESSENGER, Suzaku, BATSE, Ulysses, etc.

Continuous full sky monitor with sensitivity of $\sim 10^{-6}$ erg cm$^{-2}$ (1 phot. cm$^{-2}$ s$^{-1}$)

K. Hurley,
http://www.ssl.berkeley.edu/ipn3/
IPN detections

GRB 121217A, observed by Fermi and Swift

\[ T_{100} = 748 \text{ s}; \]
\[ T_{90} = 741 \pm 7 \text{ s}; T_{50} = 730 \pm 12 \text{ s} \]
IPN detections