GRB observations with Konus-Wind experiment


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12th INTEGRAL conference and 1st AHEAD gamma-ray workshop
11-15 February 2019, Geneva, Switzerland
Contents

- Konus-\textit{Wind} observations: overview and capabilities for multi-messenger astronomy
- Recent results:
  - comprehensive study of GRBs with known redshifts
  - search for ultra-long GRBs in the KW archival data
Joint Russian-US Konus-Wind experiment

- Launched onboard WIND s/c on November 1, 1994: almost 25 years of continuous operation!
- Gamma-ray spectrometer aimed primarily at GRB and SGR studies
- Two NaI detectors (75x130 mm)
- Two modes: triggered (20 keV -15 MeV) and waiting (20 - 1500 keV)
- Orbiting near L1 point, up to 2.1 million km (~7 lt s) from Earth

Advantages
- Wide energy band (~20 keV – 15 MeV)
- Exceptionally stable background + no Earth occultation
- $4\pi$ FOV - continuous all-sky covering
- Triggers on almost all bright events ($>10^{-6}$erg cm$^{-2}$ s$^{-1}$)
KW and IPN capabilities for multi-messenger astronomy

- Only 30% GRBs are precisely localizized by narrow-field instruments (Swift-BAT, Fermi-LAT, IBAS-ISGRI)
- Triangulation with distant s/c could add up to \( \sim100 \) GRBs yr\(^{-1}\)
- KW is located up to \( \sim7 \) lt-s from Earth, observes \( \sim95\% \) events \( \sim10^{-6} \) erg cm\(^{-2}\) and is a key vertex of the Interplanetary network (IPN, up to 7 s/c, a \( \sim100\% \) duty circle, all-sky GRB monitor with localization capability)
- KW and IPN provide a significant fraction of candidates for retrospective search and allow estimating upper limits on \( \gamma \)-ray emission from GW and other non-EM events (details: e.g. Hurley et al. 2016, Svinkin et al. 2017)
- Typical KW upper limits (10 keV – 10 MeV):
  
  \[ S \sim (6--10) \times 10^{-7} \text{ erg/cm}^2, \text{ sGRB spectrum} \]
  
  \[ F \sim (2--3) \times 10^{-7} \text{ erg/cm}^2/s, \text{ long GRB spectrum} \]
Konus-Wind trigger statistics (1994-2018)

- > 3000 GRBs, including ~500 short GRBs (> 100 GRBs/yr)
- > 250 bright SGR bursts, including 2 Giant Flares + 2 extragalactic GF candidates
- > 1000 Solar Flares (> 2 full 11-yr Solar cycles)
**KW Triggered GRB classification**

- **Duration distributions:**
  - short/long boundary $T_{50}=0.6 \text{ c}$ ($T_{90} \sim 2 \text{ c}$),
  - $\sim 15\%$ short GRBs.

- **2D (hardness – duration $T_{50}$) distribution:**
  - $18\%$ - Type I (short/hard),
  - $78\%$ - Type II (long/soft)
  - $4\%$ undetermined (I/II).

Of ~500 GRBs with known redshifts (1997-now):

  - 14 short/hard + 152 long/soft
  - 32 GRBs with optical/NIR jet breaks -> collimation
  - the largest sample measured over the wide energy range (20 keV – 15 MeV)

- + ~200 weaker GRBs were detected in the KW waiting mode (20-1500 keV, 3-ch)

For 171 GRBs $E_{\text{peak}}$ (CPL/Band), $E_{\text{iso}}$ and $L_{\text{iso}}$ were constrained from joint KW + Swift/BAT analysis in the wide energy band (in prep.)
KW GRBs with known redshifts: sample selection effects

Triggered GRBs (166):
- $0.1 \leq z \leq 5$;
- $S_{\text{lim,bol}} \sim 3 \times 10^{-6} \text{ erg cm}^{-2}$
- $F_{\text{lim,bol}} \sim 1 \times 10^{-6} \text{ erg cm}^{-2} \text{ s}^{-1}$

Waiting-mode GRBs (171):
- $0.04 \leq z \leq 9.4$;
- $S_{\text{lim,bol}} \sim 3 \times 10^{-7} \text{ erg cm}^{-2}$
- $F_{\text{lim,bol}} \sim 1.5 \times 10^{-7} \text{ erg cm}^{-2} \text{ s}^{-1}$ (preliminary)
KW GRBs with known redshifts: Luminosity and Energy-release functions (LF+EF)

Unbiased cumulative LF and EF were estimated using the C- method (Lynden-Bell 1971 + Efron&Petrosian 1992)

The best fits to the cumulative distributions:
- $L_{iso}$: broken PL (up to the observation limit of $\sim 5 \times 10^{54}$ erg/s)
- $E_{iso}$: exponential cutoff PL ($E_{cut} \sim 10^{54}$ erg) -> an intrinsic limit on the GRB energy!
  
KW GRBs with known redshifts: GRB formation rate (GRBFR)

- Shape of GRBFR follows that of SFR at $z \geq 1$

- Prominent low-$z$ GRBFR excess over SFR (e.g. Yu et al. 2015; Petrosian et al. 2015, Tsvetkova et al. 2017)


GRBFRs were estimated from $(z-L_{iso})$ and $(z-E_{iso})$ distributions using the C-method and normalized to SFR at $z=2.5$
KW GRBs with known redshifts: rest-frame hardness-intensity correlations
(150 triggered GRBs)

\[ E_{p,z} - E_{iso} \ (Amati\ relation) \]
\[ \rho_s = 0.70, \ slope \sim 0.47 \]

\[ P_s < 10^{-20} \]

\[ E_{p,z} - L_{iso} \ (Yonetoku\ relation) \]
\[ \rho_s = 0.73, \ slope \sim 0.49 \]

Tsvetkova et al. 2017
KW GRBs with known redshifts: rest-frame hardness-intensity correlations (320+ long GRBs)

\[ E_{p,z} - E_{iso} \ (Amati \ relation) \]
\[ \rho_S = 0.71, \ \rho_{S \sim 10^{-49}}, \ \text{slope} \sim 0.43 \]

\[ E_{p,z} - L_{iso} \ (Yonetoku \ relation) \]
\[ \rho_S = 0.70, \ \rho_{S \sim 10^{-48}}, \ \text{slope} \sim 0.45 \]

Black symbols – KW triggered GRBs (T17+)
Colored symbols – KW waiting-mode GRBs (preliminary)
KW GRBs with known redshifts: rest-frame hardness-intensity correlations (collimation-corrected, 32 GRBs)

\[ E_{p,z} - E_\gamma \]
\[ \rho_z = 0.76 \ (0.82), \ \text{slope} \sim 0.60 \ (0.53) \]

\[ E_{p,z} - L_\gamma \]
\[ \rho_z = 0.61 \ (0.75), \ \text{slope} \sim 0.73 \ (0.53) \]

Tsvetkova et al. 2017
Ultra-long GRBs

Duration > 1000 s, low luminosity, less than a dozen reported so far

Levan et al. 2016
Ultra-long GRBs

- KW triggered-mode observations are limited to SNR>9 and T<250 s
- KW waiting mode (WM): continuous observations in 3 channels (20-1500 keV) with 2.944 s res.
- In the waiting mode, KW provides an excellent opportunity to observe prompt emission of u-long GRBs for the whole duration and to constrain their spectra and fluences in the wide energy band

Frederiks et al. 2013
Search for very- and ultra-long GRBs in the KW data

- Search for transient events in the KW WM data using Bayesian block analysis:
  - ~ 26000 transient events found (1994-2017)
  - ~ 12000 GRBs and GRB candidates
  - ~ 6900 previously non-identified events
    

- Search for very- and ultra-long GRBs:
  - criteria: $T_{90} > 250$ s, SNR >10 (fluence), hard spectrum
  - 110 very-long GRB candidates (vlGRBs)
  - 13 GRBs with $T_{90} > 1000$ s (ulGRBS, 5 known + 8 new!)
    

GRB 991009_T59657
1-st pulse: KW, Ulyssess, 2-nd: KW, Ulysses, BATSE
KW very- and ultra-long GRBs

- $T_{90}$ (80-1200 keV)
- 1168 KW GRBs
- $\chi^2 = 15/12$ dof

- T90 distribution of very- ultra-long KW GRBs extends that of the triggered long GRBs

(preliminary)
KW very- and ultra-long GRBs

- Hardness-duration distribution of very- and u-long GRBs extends that of triggered long GRBs

(preliminary)
Ultra-long GRBs with known redshifts

Five u-long (> 1000 s) GRBs with measured $z$ (so far)

KW short/hard GRBs (Tsvetkova et al., 2017)
KW long GRBs (Tsvetkova et al., 2017)
KW u-long GRBs

(preliminary)
Summary (and useful links)

Konus-WIND: almost 25 years of continuous observations (1994 – now)

- > 4000 triggers (GRBs, sGRBs, SGRs, Solar Flares)

- ~26000 waiting-mode transients (analysis in progress...)

- GRBs with known redshifts (166 triggered, 14 short/hard, 32 with jet breaks)
  - [http://www.ioffe.ru/LEA/zGRBs/triggered/](http://www.ioffe.ru/LEA/zGRBs/triggered/)

- > 100 very- and ultra-long GRB candidates (analysis in progress...)
Thank you!