Ioffe Workshop on GRBs
and other Transient Sources:
25 years of Konus-Wind

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Ioffe Institute

Konus-*Wind* observations of gamma-ray bursts with known redshifts

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Motivation

- ~500 GRBs with known *z* (~172 observed by KW in triggered mode);
- Redshift => distance, age, rest-frame energetics & Ep;
- The unbiased comparison between GRBs;
- Possibility to test GRB models;
- GRB population properties (Luminosity function, GRBFR, …)
- GRBs could probe the properties of high-redshift universe:
  - Cosmic expansion
  - Star formation history at high redshifts
  - Reionization history
  - Metal evolution
  - History of cosmic acceleration
  - Evolution of dark energy

Joint Russian-US Konus-*Wind* experiment

Records the light curves (LCs) in three energy windows:

- G1 (~20–80 keV, at present),
- G2 (~80–300 keV),
- G3 (~300–1200 keV).

Two modes

Triggered mode:
LC res. is 2 ms –256 ms,
LC is recorded from T_0-0.512 s to T_0+230 s;
128-ch spectra (20 keV – 20 MeV).

Waiting mode:
G1, G2, G3 with 2.944 s resolution

GRBs with known redshifts

KW triggered mode:
multichannel spectra
20 keV-20 MeV,
LC with 2 ms –256 ms resolution

- 172 events;
- $0.1 \leq z \leq 5$;
- 14 Type I GRBs: short/hard, merger-origin;
- 158 Type II GRBs: long, collapsar-origin.

Tsvetkova et al., ApJ 850:161 (2017)

KW waiting mode:
20-1500 keV, 3-channel spectra,
LC with 3 s resolution

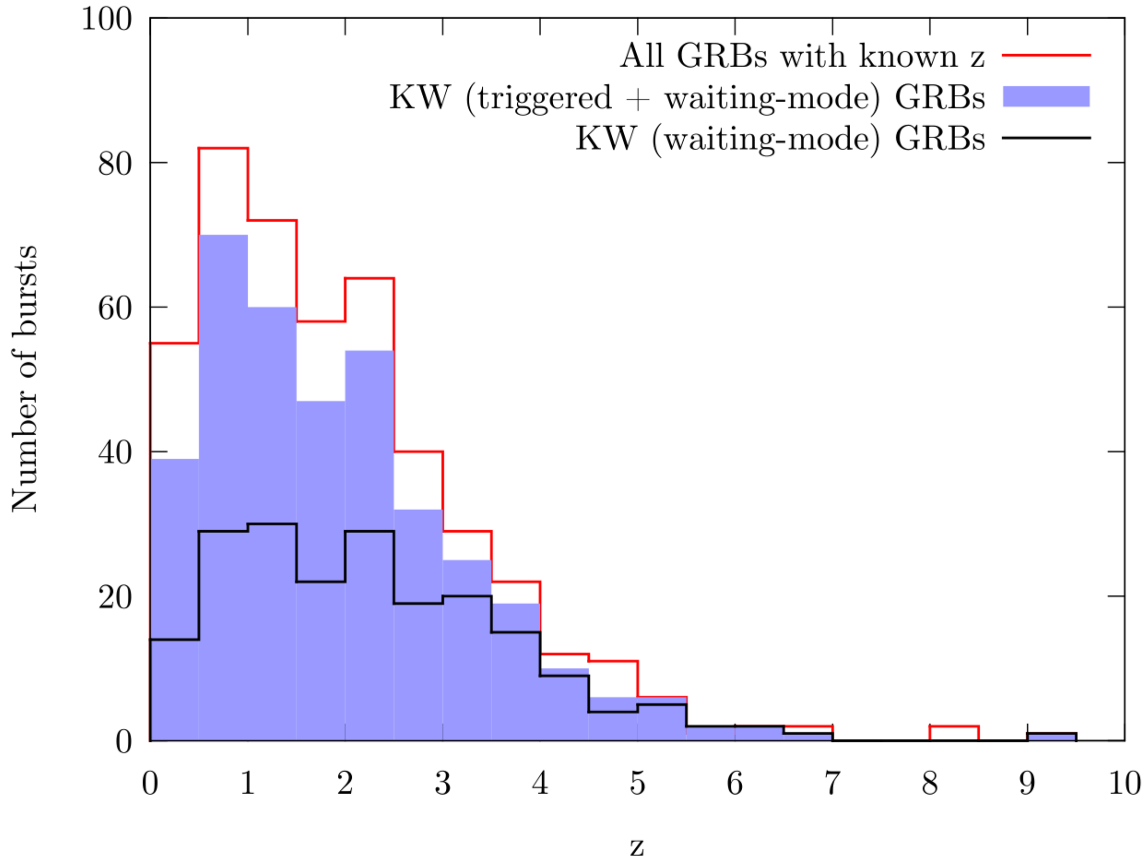
- ~200 weak/soft GRBs detected by *Swift*/BAT (15-150 keV) and by KW in the waiting mode ;
- $0.04 \leq z \leq 9.4$;
- 5 short GRBs & 6 XRFs.

KW+BAT

joint analysis

Tsvetkova et al., in preparation

The burst sample



- ~500 GRBs with known z;
- 172 triggered KW GRBs;
- ~ 200 Swift/BAT & waiting-mode KW GRBs with z.

KW waiting-mode + *Swift*/BAT joint data analysis

Targeted search of BAT GRBs with z in the KW waiting-mode LCs:
Selection of the TI & peak spectrum accumulation times based on the Bayesian block decomposition of KW LCs and S/N

+ Swift/BAT spectra ↓

Joint spectral analysis of KW+BAT data with CPL and Band functions in the wide 15 keV – 1.5 MeV energy range

↓

Selection of models for the energy estimation

+ LC Swift/BAT ↓

Total energy fluence (S) & peak energy flux (F_p)

+ redshift ↓

Rest-frame E_p & energetics

Joint spectral fits of w-m KW & BAT data

171 GRBs have at least one spectral fit with the CPL or/and BAND models

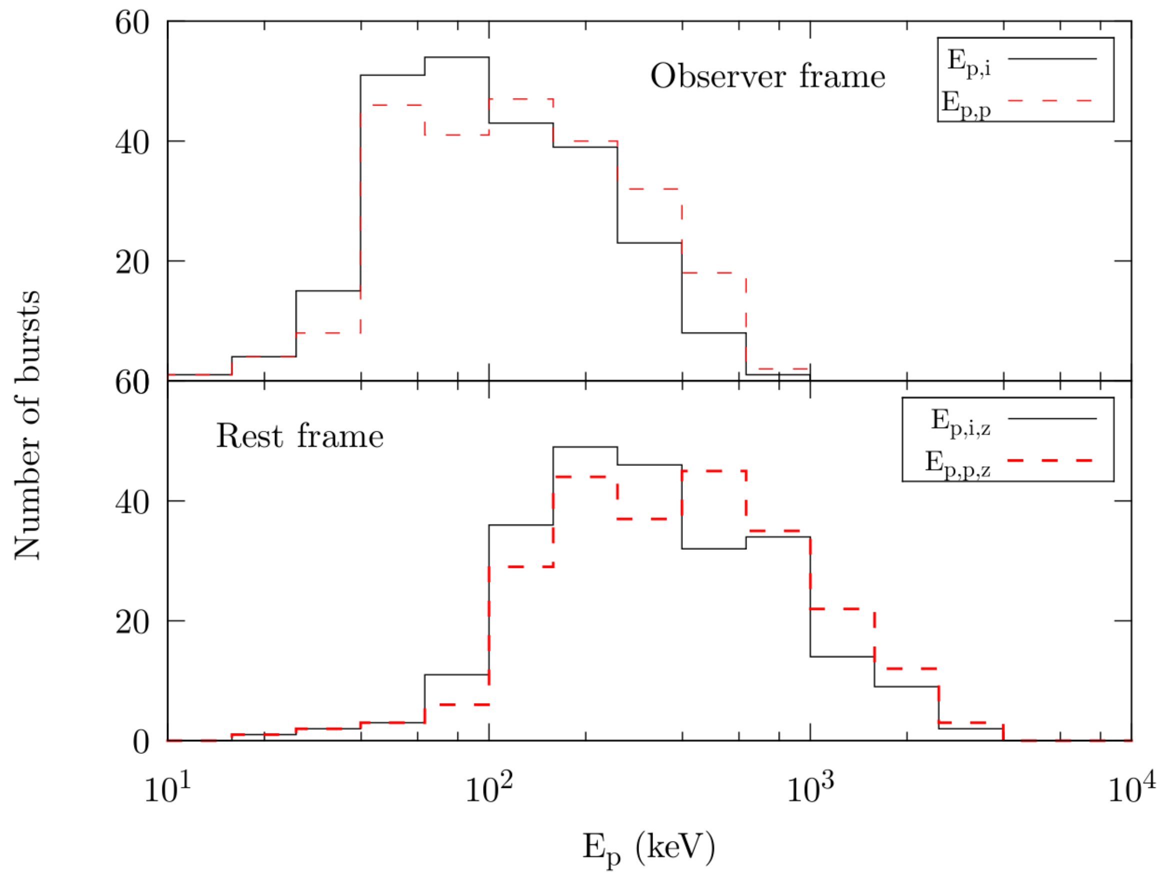
Models used for further calculations:

- BAND, if β>-3.5 and α & Ep are constrained;
- CPL.

Spectrum	CPL	BAND
Time-integrated	59%	41%
Peak	60%	40%

Peak energy distributions

- E_p = 15 keV … 700 keV, $E_{p,z} = (1+z)E_p$ = 25 keV … 3.1 MeV;
- Medians: $E_{p,i}$ = 95 keV, $E_{p,p}$ = 120 keV, $E_{p,i,z}$ = 291 keV, $E_{p,p,z}$ = 385 keV.



Rest-frame energetics

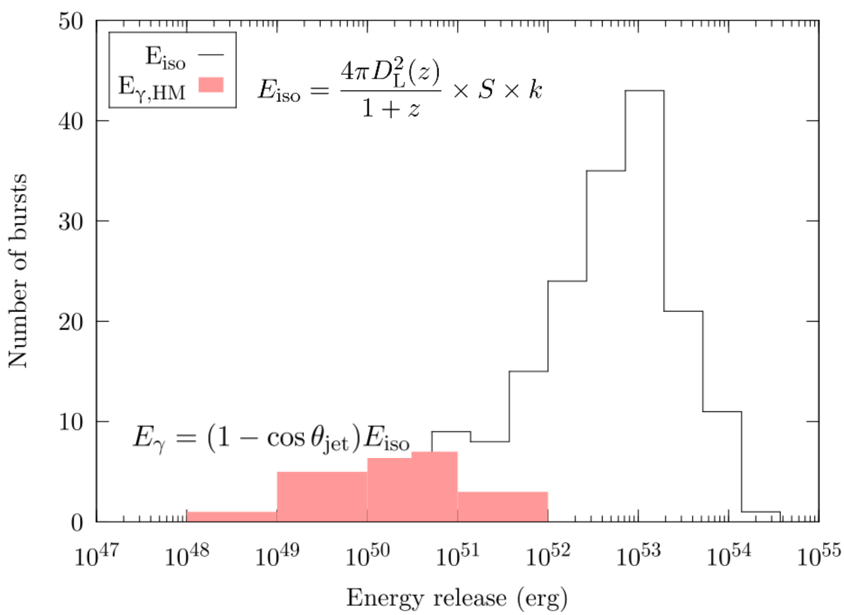
k-correction (Bloom et al. 2001, Kovacs et al. 2011):

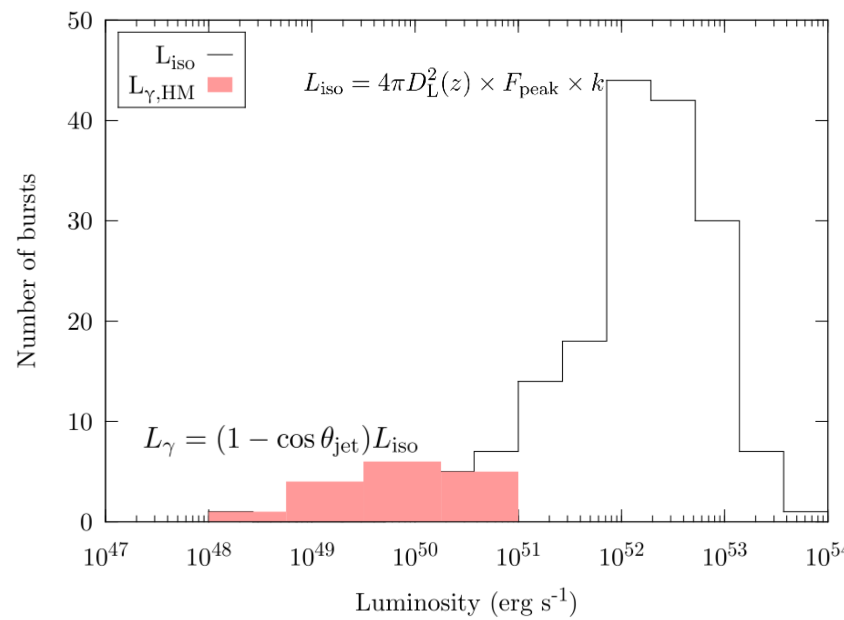
$$k = \frac{F[E_1/(1+z), E_2/(1+z)]}{F[e_1, e_2]}$$

e_1 = 10 keV, e_2 = 10 MeV;
E_1 = 1 keV, E_2 = (1+z)·10 MeV

H_0 = 67.3 km s^{-1} Mpc^{-1}, Ω_Λ = 0.685,
Ω_M = 0.315 (Ade et al., 2014)

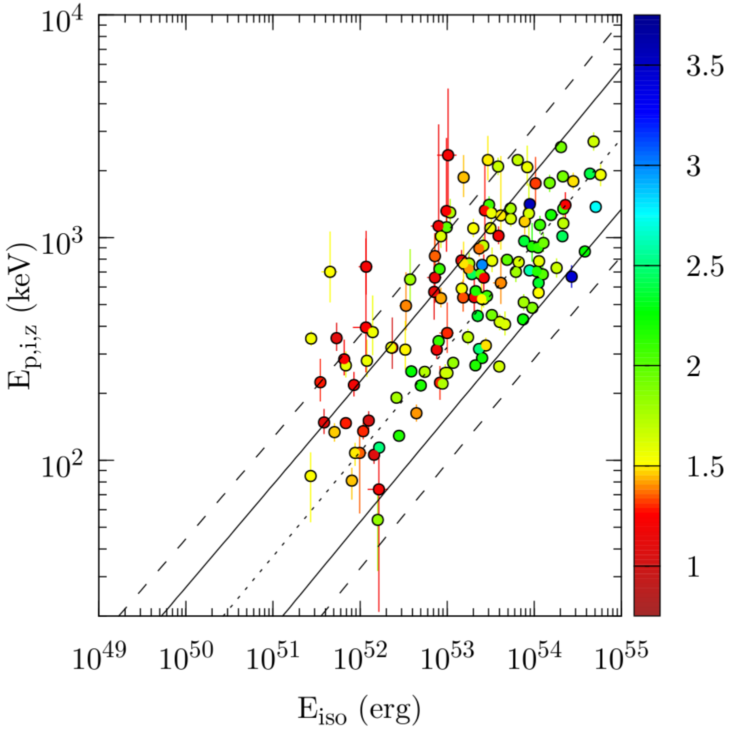
16 (1 short & 2 XRFs) GRBs have reasonably-constrained (from optical/IR afterglow or in two spectral band simultaneously) t_{jet}:
1.3°< $\theta_{jet, HM}$ < 10°
2.4×10^{-4} < 1-cos θ_{jet} < 0.015



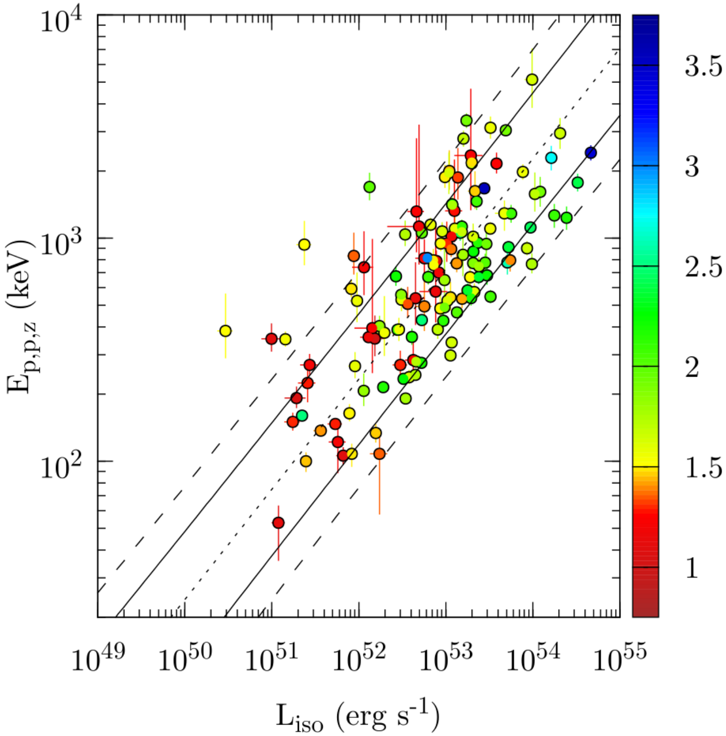


Hardness-intensity correlations for the KW long GRBs (triggered)

Amati relation (E_{iso}–$E_{p,i,z}$)
N=138, ρ_S=0.70, *P*=1.4×10^{-21}, *slope* = 0.47



Yonetoku relation (L_{iso}–$E_{p,p,z}$)
N=137, ρ_S=0.73, *P*=1.6×10^{-23}, *slope* = 0.49

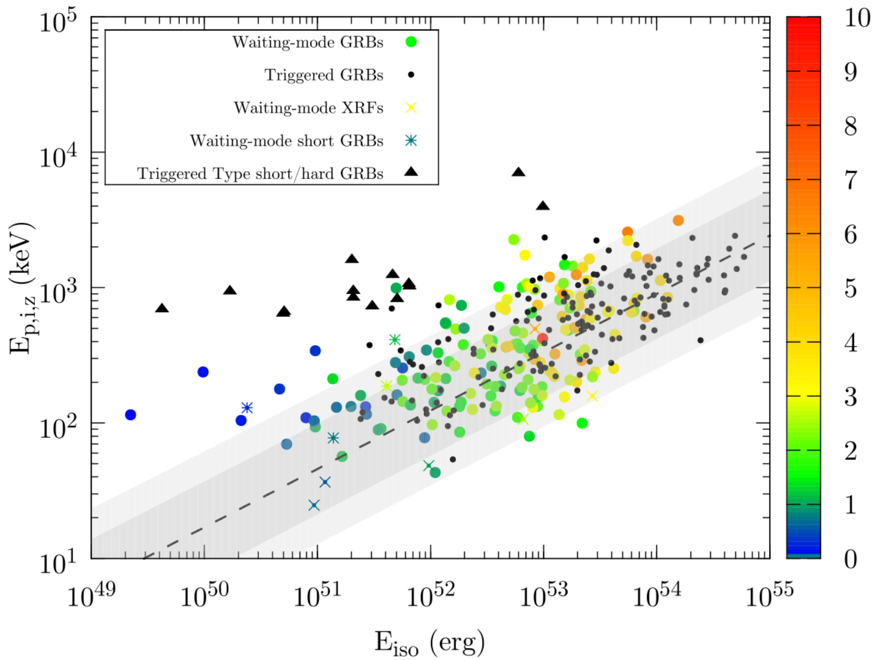


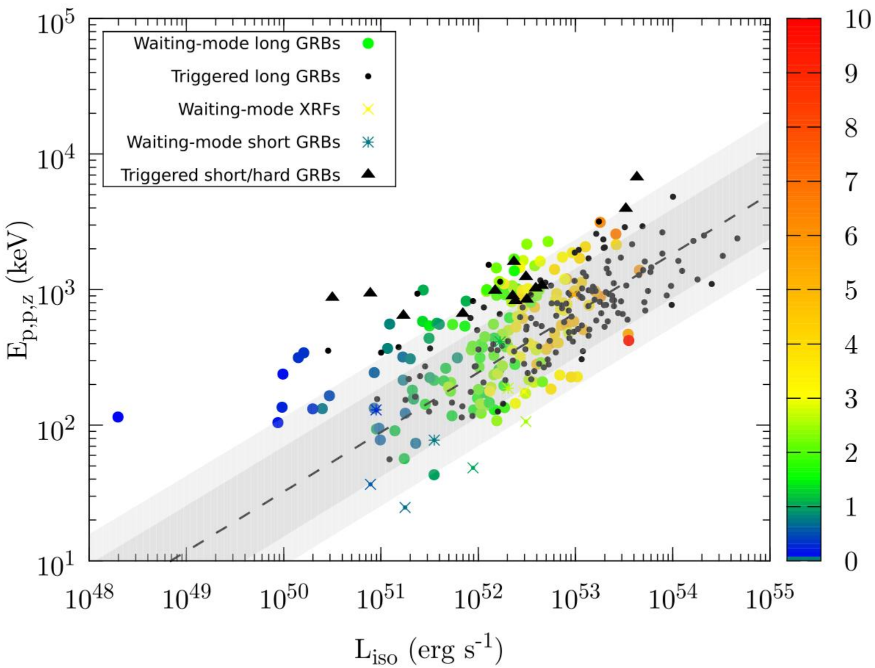
color denotes the log of the detection significance.

Hardness-intensity correlations for the long GRBs (triggered + waiting-mode)

Amati relation
N=318, ρ_S=0.69, *P*~10^{-46}, *slope* = 0.43

Yonetoku relation
N=318, ρ_S=0.69, *P*~10^{-46}, *slope* = 0.44



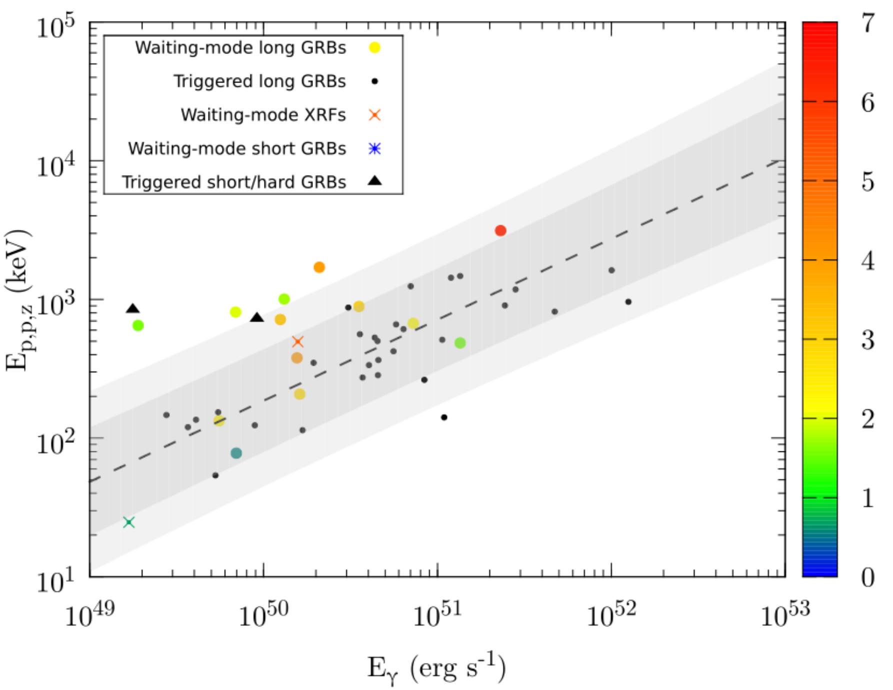


Black points – triggered GRBs,
colored dots – waiting-mode GRBs;
color denotes the redshift.

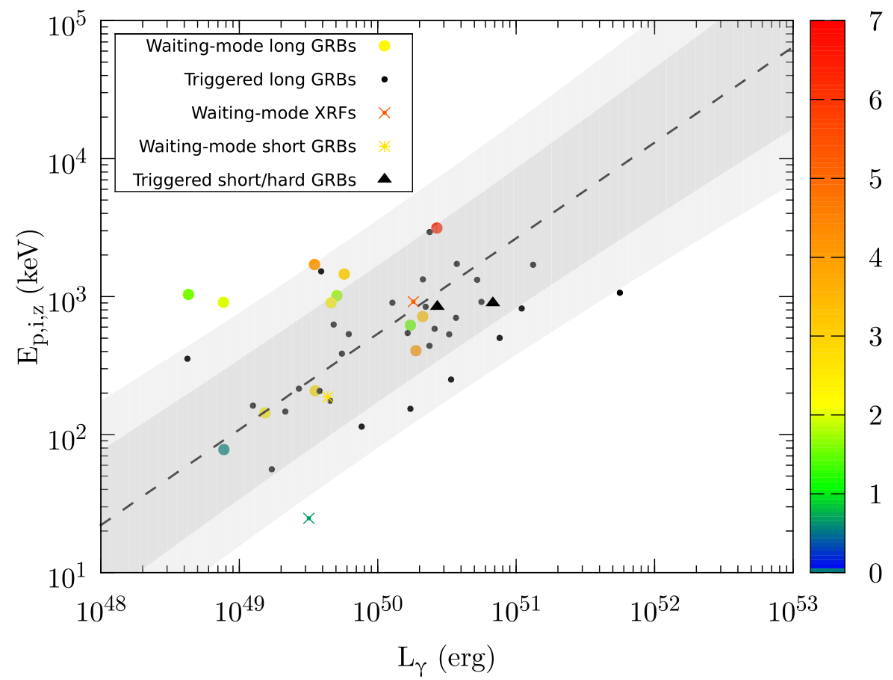
Hardness-intensity correlations for the long GRBs (triggered + waiting-mode)

Collimation-corrected

Ghirlanda relation for the time-int. spectra
N=43, ρ_S=0.58, *P*~10^{-5}, *slope* = 0.58
Amati relation: ρ_S=0.75, *P*~10^{-9}, *slope* = 0.53



Ghirlanda relation for the peak spectra
N=43, ρ_S=0.43, *P*~10^{-3}, *slope* = 0.69
Yonetoku relation: ρ_S=0.65, *P*~10^{-6}, *slope* = 0.50



Black points – triggered GRBs, colored dots – waiting-mode GRBs, color denotes the redshift.

Selection effects

KW-specific effects:
- Prompt emission properties (LC, spectral shape, energy fluxes);
- Redshift;
- Observational conditions.

«External biases»:
- GRB localization;
- GRB redshift estimation;
- Swift/BAT-specific selection effects

Luminosity function

Without loss of generality, the total luminosity function (LF; number of bursts per unit luminosity) $\Phi(L_{iso}, z)$ can be rewritten as

$$\Phi(L_{\rm iso}, z) \quad = \quad \rho(z)\phi(L_{\rm iso}/g(z), \alpha_s)/g(z)$$ Lloyd-Ronning (2002)

$\rho(z)$ – GRB formation rate (GRBFR)

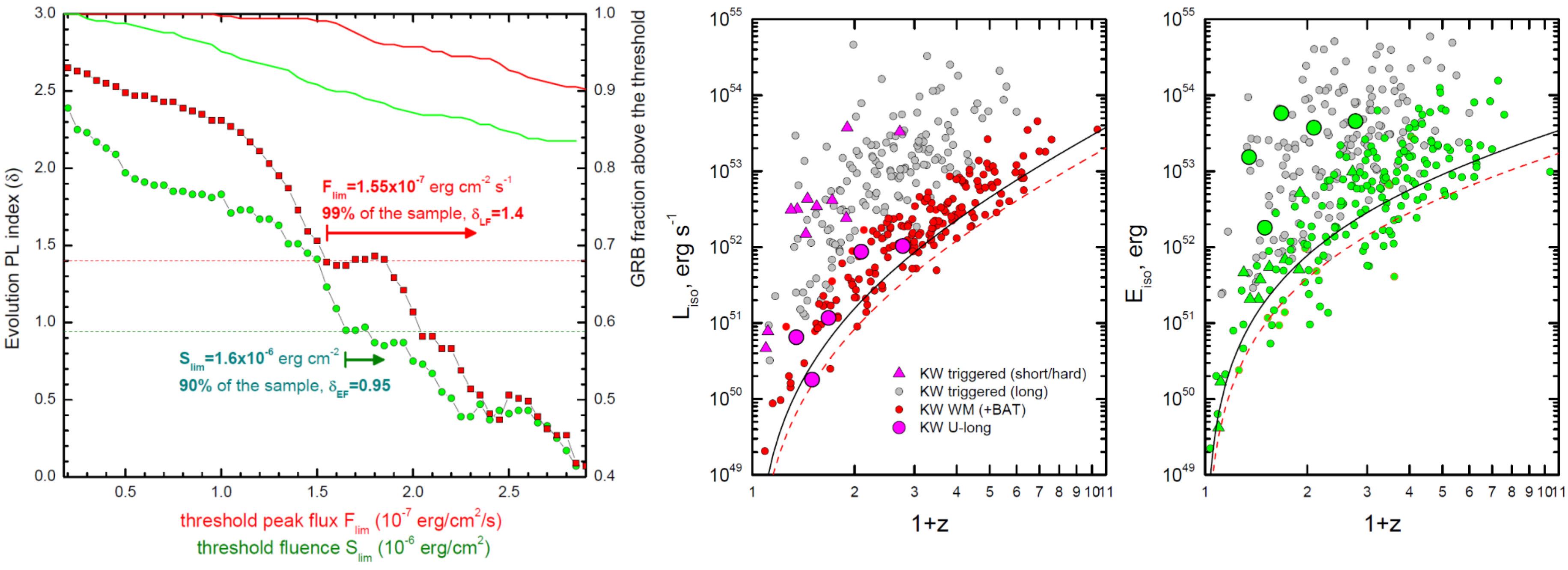
$\phi(L_{\rm iso}/g(z))$ – local LF

$g(z) = (1+z)^\delta$ – luminosity evolution

α_s – shape of the LF

Non-parametric statistical technique: *Lynden-Bell (1971)* *Efron & Petrosian (1992)*

Selection of threshold fluxes and fluences



Luminosity and energy release evolution

Triggered KW GRBs:
(Tsvetkova et al. 2017)

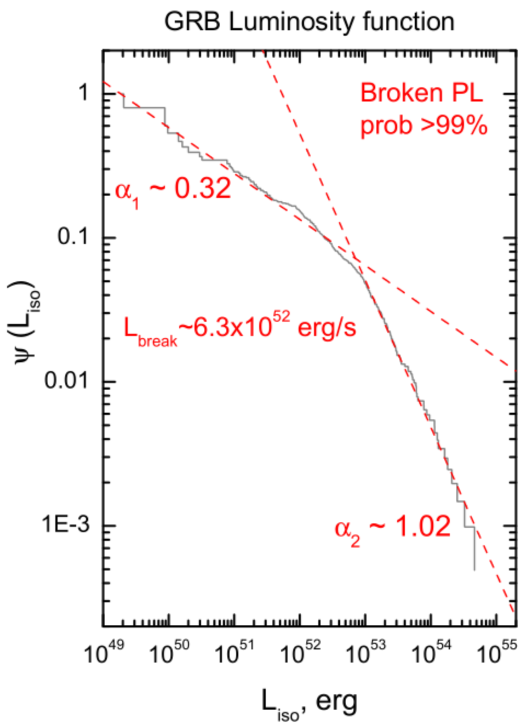
L_{iso}: $\tau_0 = 1.7\sigma$ $\delta_L = 1.7^{+0.9}_{-0.9}$ $(1\sigma\ \mathrm{CL})$

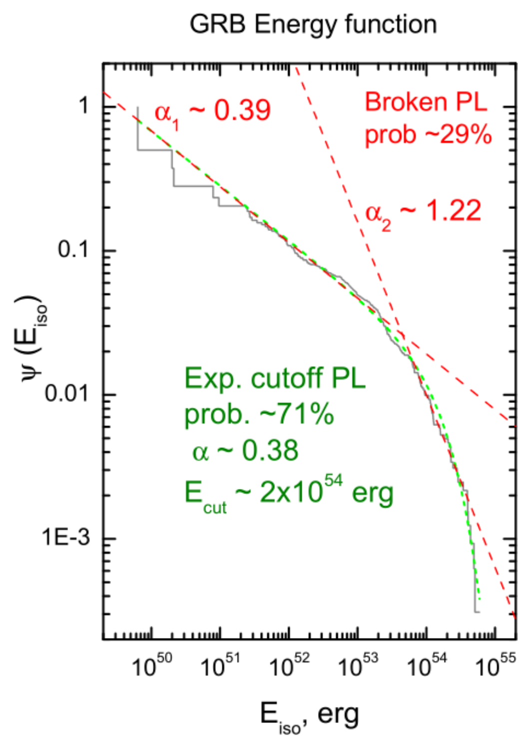
E_{iso}: $\tau_0 = 1.6\sigma$ $\delta_E = 1.1^{+1.5}_{-0.7}$

All KW GRBs: L_{iso}: $\tau_0 = 2.2\ \sigma$; $\delta_L \sim 1.4\ (-0.6,+0.6)$
E_{iso}: $\tau_0 = 1.6\ \sigma$; $\delta_E \sim 0.95\ (-0.6,+1.0)$;

Luminosity and energy release functions for the sample of triggered + waiting-mode GRBs

Cumulative luminosity function $$\ln \psi(L'_i) = \sum_{j=2}^{i} \ln\left(1 + \frac{1}{N'_j}\right)$$





BPL:

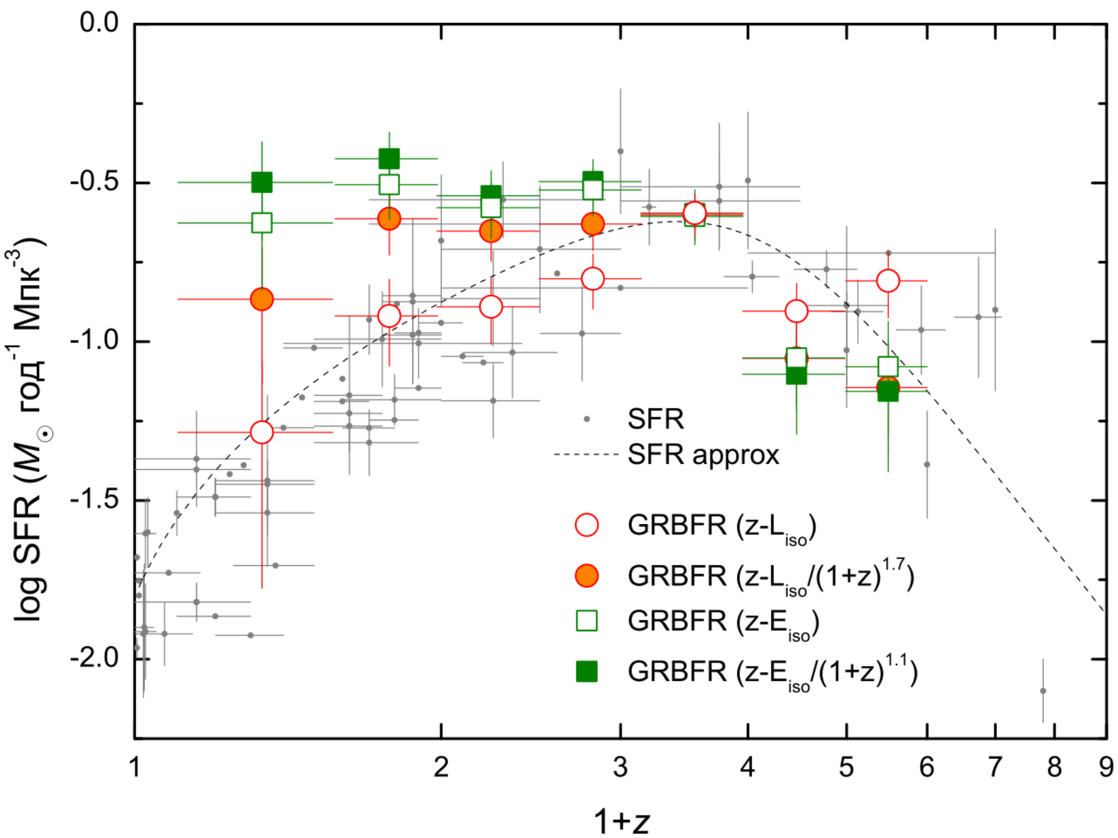
$$\psi(x) \propto \begin{cases} x^{\alpha_1}, & x \le x_b \\ x_b^{(\alpha_1-\alpha_2)} x^{\alpha_2}, & x > x_b \end{cases}$$

CutoffPL:

$$\psi(x) \propto x^{\alpha} \exp(-x/x_{\rm cut})$$

The existence of a sharp cutoff of the isotropic energy agrees with the results of Atteia et al. (2017), the next talk

GRBFR (triggered GRBs)



SFR: Hopkins (2004), Bouwens et al. (2011), Hanish et al. (2006), Thompson et al. (2006), Li (2008).

Cumulative rate evolution:

$$\ln \psi(z_i) = \sum_{j=2}^{i} \ln\left(1 + \frac{1}{M_j}\right)$$

Comoving density rate:

$$\rho(z) = \frac{d\psi}{dz}(1+z)\left(\frac{dV(z)}{dz}\right)^{-1}$$

Differential comoving volume:

$$\frac{dV(z)}{dz} = \frac{4\pi D_{\rm H} D_{\rm M}^2}{E(z)}$$

D_M — is the transverse comoving distance

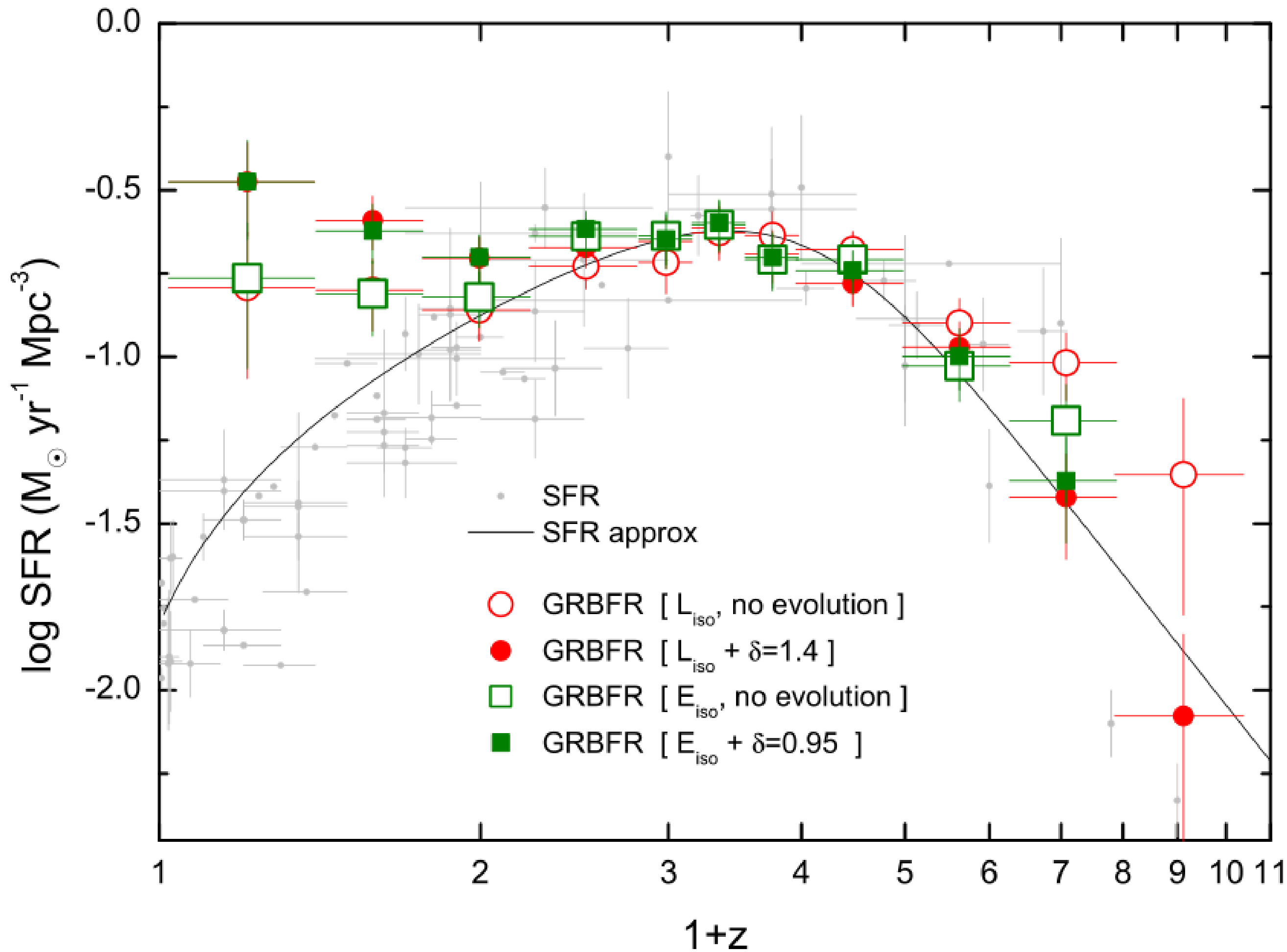
Hubble distance:

Normalized Hubble parameter:

$$E(z) = \sqrt{\Omega_{\rm M}(1+z)^3 + \Omega_\Lambda}$$

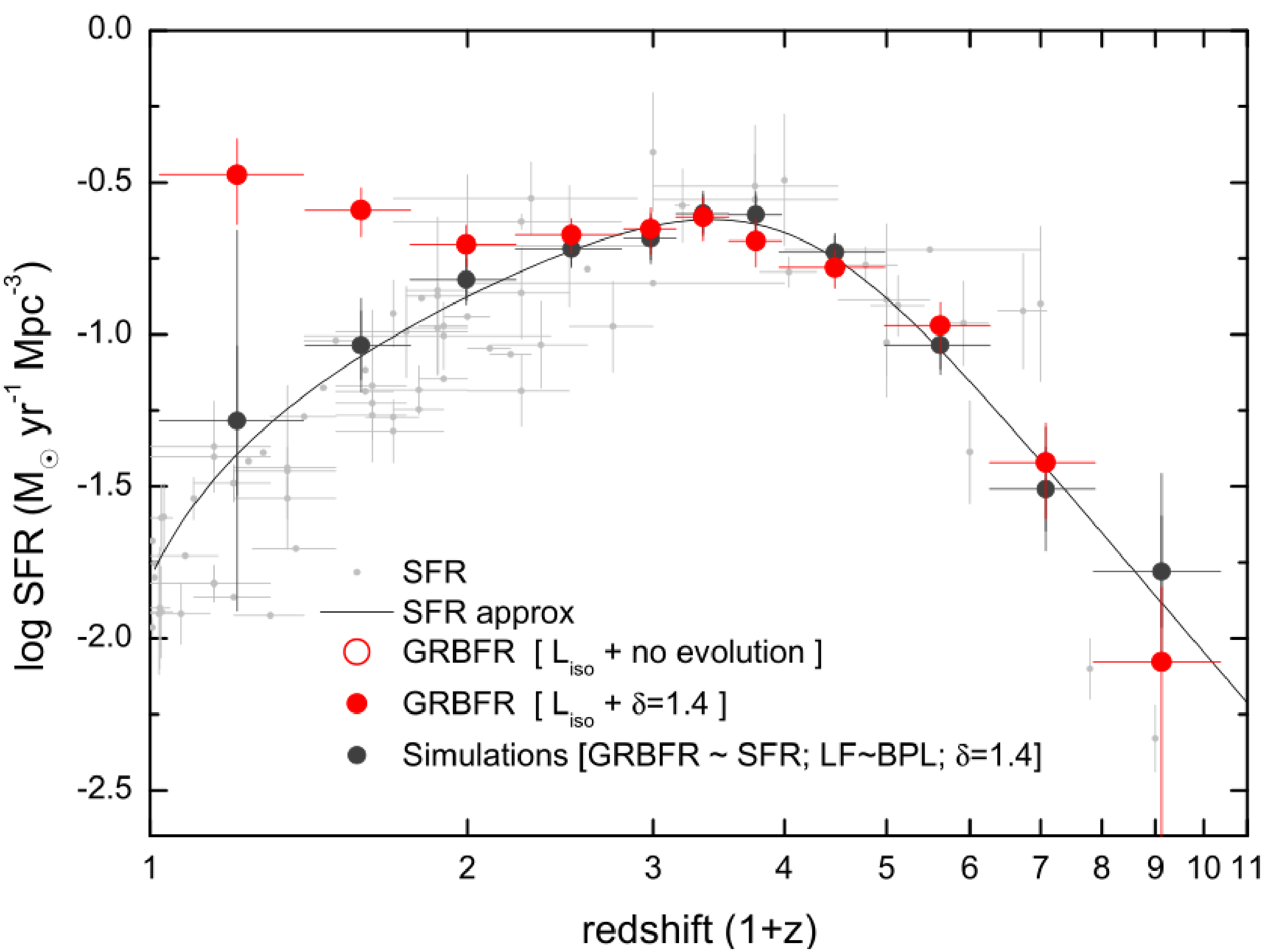
The relative excess of GRBFR over SFR at low z agrees with Yu et al. (2015) and Petrosian et al. (2015).

GRBFR (triggered + waiting-mode KW GRBs)



SFR: Hopkins (2004), Bouwens et al. (2011), Hanish et al. (2006), Thompson et al. (2006), Li (2008).

GRBFR (triggered + waiting-mode KW GRBs)



SFR: Hopkins (2004), Bouwens et al. (2011), Hanish et al. (2006), Thompson et al. (2006), Li (2008).

Summary

- Joint KW+BAT spectral analysis (15–1500 keV) was performed for $\sim$200 waiting mode GRBs, for 171 events spectra are well fitted by CPL or/and Band function;
- The sample of KW GRBs with *z*, and Ep + broadband energetics extended to 343 GRBs (0.04 <= *z* <= 9.4);
- The "Amati" and "Yonetoku" correlations were confirmed for the KW sample;
- The correction for the jet collimation does not improve the "Amati" and "Yonetoku" correlations for the KW sample;
- LF and EF evolution is limited at $\delta <\sim 1.4$, $\tau_0 <\sim 2\sigma$;
- The exponential cutoff of GRB EF at $E_{iso} >\sim 2\times10^{54}$ erg (first reported by Atteia et al. 2017) and its absence for the GRB LF (Tsvetkova et al. 2017) were confirmed;
- The GRBFR follows the SFR at $1 < z < 9.4$, and the relative excess of GRBFR at $z<1$ was confirmed.

On-line catalog of the KW triggered GRBs with z

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- Konus-RF
- SFAR project
- GRB 2014 workshop

The Konus-*Wind* Catalog of Gamma-Ray Bursts with Known Redshifts. I. Bursts Detected in the Triggered Mode

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ABSTRACT

In this catalog, we present the results of a systematic study of gamma-ray bursts (GRBs) with reliable redshift estimates detected in the triggered mode of the Konus-*Wind* (KW) experiment during the period from 1997 February to 2016 June. The sample consists of 150 GRBs (including 12 short/hard bursts) and represents the largest set of cosmological GRBs studied to date over a broad energy band. From the temporal and spectral analyses of the sample, we provide the burst durations, the spectral lags, the results of spectral fits with two model functions, the total energy fluences, and the peak energy fluxes. Based on the GRB redshifts, which span the range $0.1 \leq z \leq 5$, we estimate the rest-frame, isotropic-equivalent energy, and peak luminosity. For 32 GRBs with reasonably constrained jet breaks, we provide the collimation-corrected values of the energetics. We consider the behavior of the rest-frame GRB parameters in the hardness–duration and hardness–intensity planes, and confirm the "Amati" and "Yonetoku" relations for Type II GRBs. The correction for the jet collimation does not improve these correlations for the KW sample. We discuss the influence of instrumental selection effects on the GRB parameter distributions and estimate the KW GRB detection horizon, which extends to $z \sim 16.6$, stressing the importance of GRBs as probes of the early universe. Accounting for the instrumental bias, we estimate the KW GRB luminosity evolution, luminosity and isotropic-energy functions, and the evolution of the GRB formation rate, which are in general agreement with those obtained in previous studies.

ADS Link: 2017ApJ...850..161T

- Figures:
  - Light curves
  - Spectral fits
- ASCII tables

Thank you!

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