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

September 9–13, 2019, St.Petersburg, Russia

Ioffe Institute

Konus-*Wind* experiment: 25 years in space

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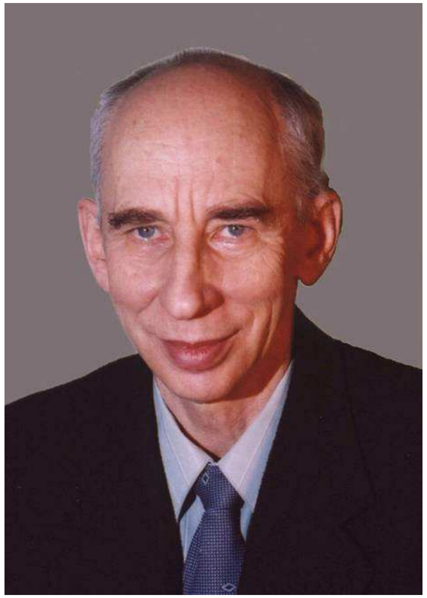
Joint Russian-US Konus-*Wind* experiment

- Started with the launch of the Russian gamma-spectrometer Konus onboard the NASA GGS-WIND spacecraft (s/c) on November 1, 1994:

  almost 25 years of continuous operation!
- Aimed at GRB, SGR, and Solar flare studies



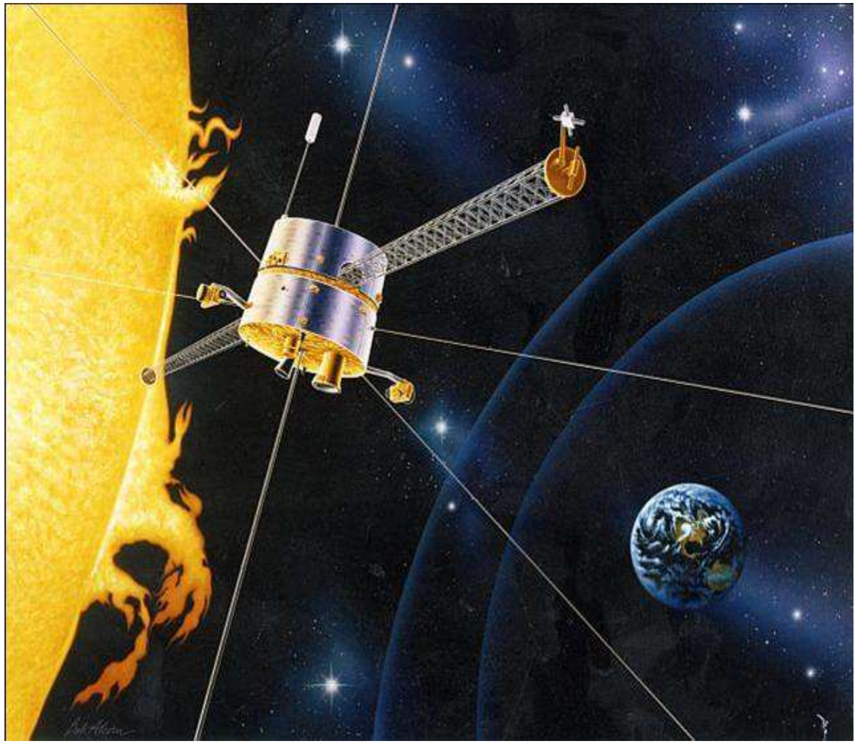
- **PI**: Prof. Eugeny Mazets (1994-2013);

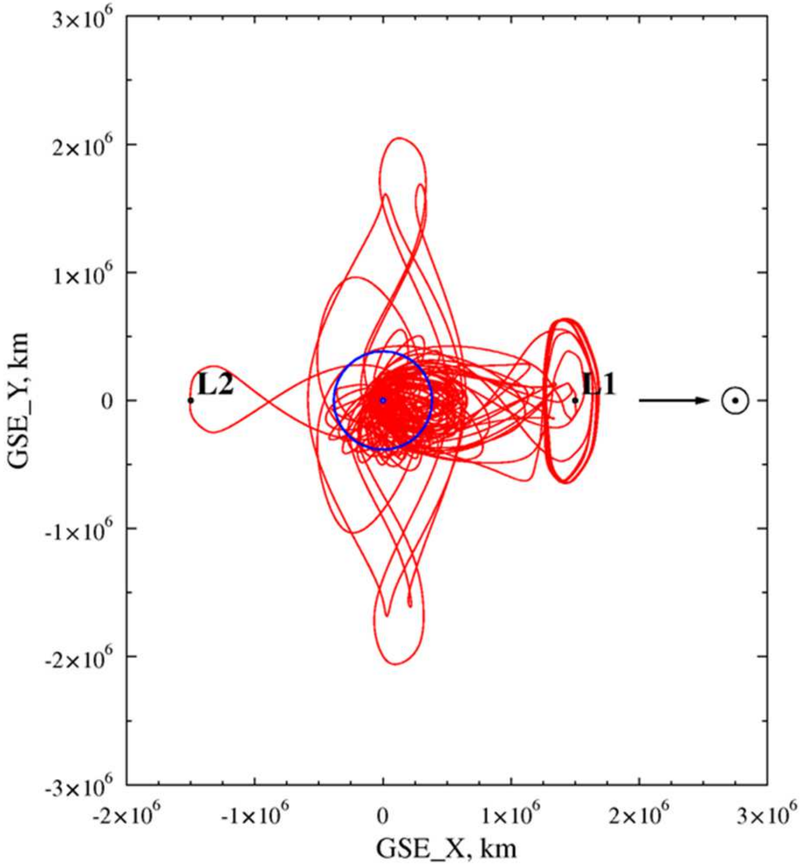
  Dr. Rafail Aptekar (2013-now)
- **Co-PI**: Dr. Thomas L. Cline (NASA GSFC)

More on the history of Konus and other GRB experiments:
R. Aptekar, T. Cline, and F. Frontera talks on Wednesday

The WIND Spacecraft

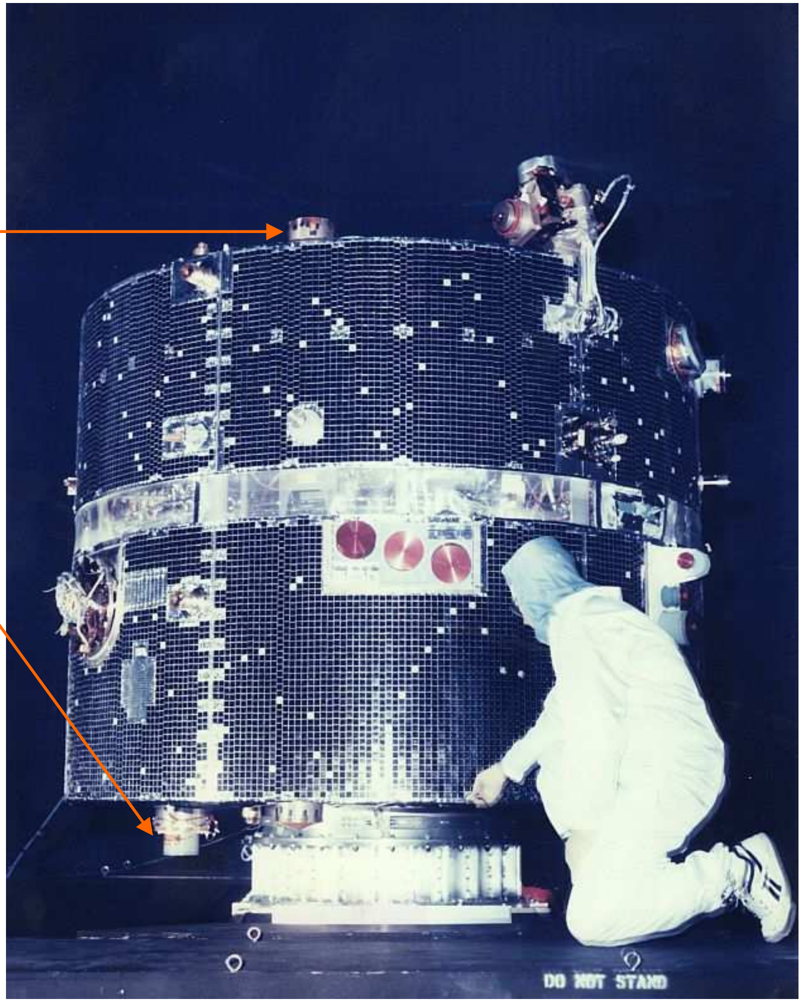
- Part of the NASA Global Geospace Science (GGS) initiative, “a solar wind workhorse”
- Since 2004, WIND is in orbit near L1, up to 2.1 million km (~7 lt s) from Earth
- Stable particle background + no Earth occultation
- The Wind mission provides an excellent opportunity for both Solar and GRB science





The Konus-*WIND* Instrument

- Scintillation gamma-ray spectrometer aimed at transient studies
- Designed and manufactured at Ioffe Institute
- Weight ~20 kg, power consumption ~10 W
- Two **NaI** detectors (75x130 mm), each 2π FOV
- **Be** entrance window, lead glass back shielding
- Fully duplicated electronics



Advantages

- Exceptionally stable background + no Earth occultation
- Continuous all-sky covering (4π FOV) in the waiting mode
- Triggers on almost all bright events ($>10^{-6}$ erg cm^{-2} s^{-1})
- Wide energy band (TM: ~20 keV – 15 MeV)
- Hi-res light curves (TM: from 2 ms)

Limitations

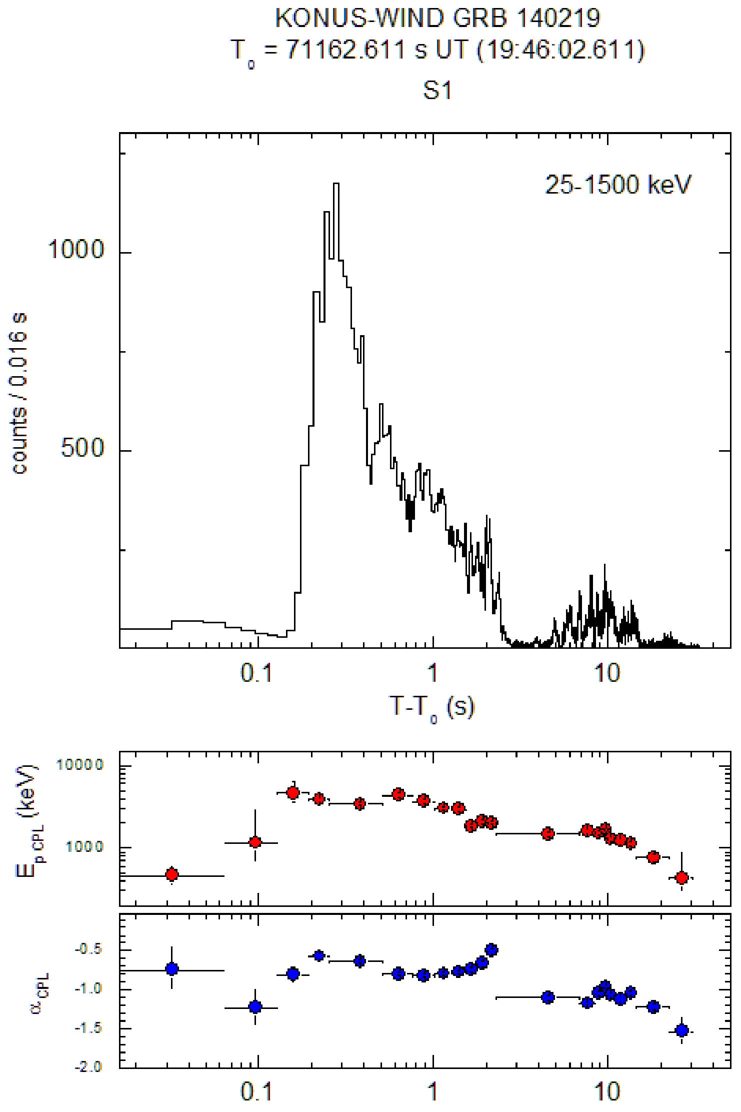
- Low data throughput (55 bits/s, <500 KB/day)
- Data availability delays (one downlink session / day)
- Fixed measurement program, no photon-by-photon data

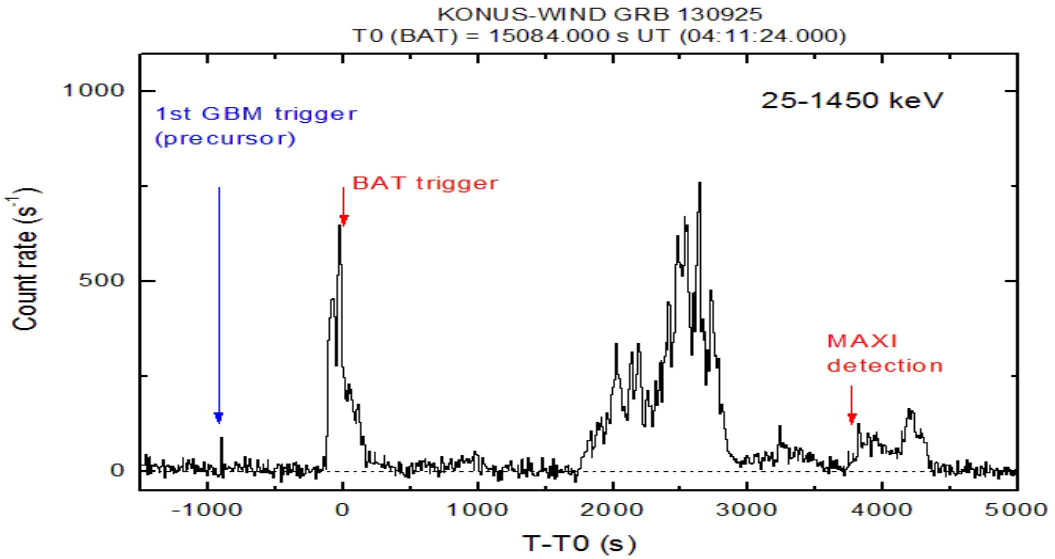
Konus-*WIND* operating modes

- Triggered mode (TM): optimized for the transient studies
  - hi-res light curves (2-256 ms, ~250 s) in 3 energy bands G1(20-80 keV), G2(80-350 keV), G3 (350-1450 keV)
  - multichannel spectra (20 keV -15 MeV, up to ~T0+470s)
  - two trigger scales (~0.1 s and 1 s) , ~9 sigma in G2

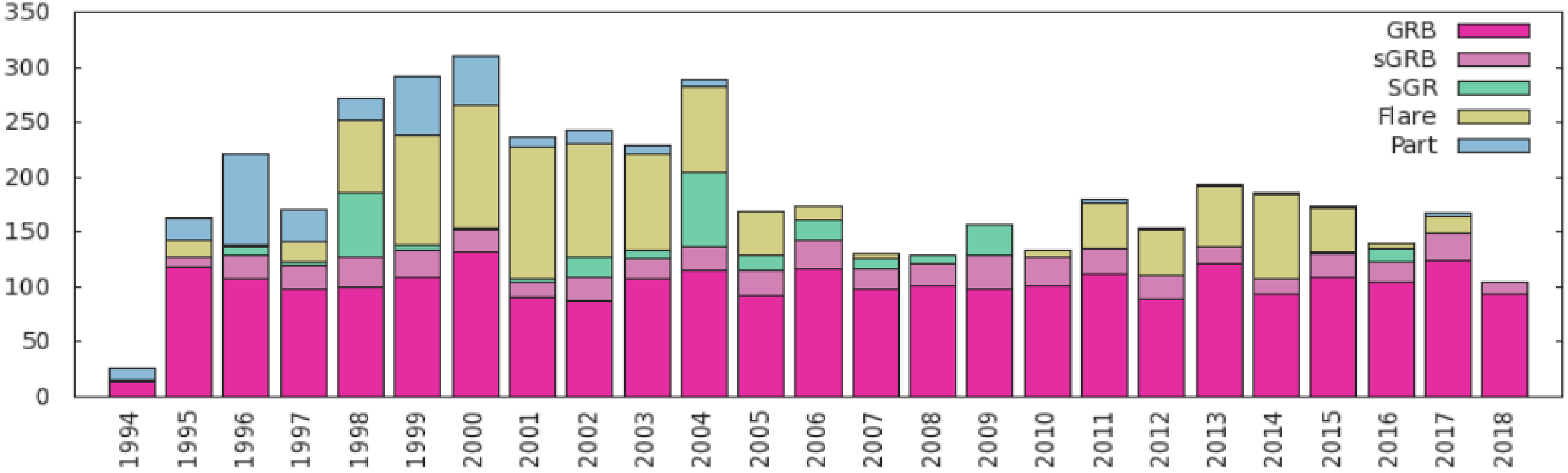
Waiting (WM) : continuous data in G1,G2,G3 (2.944 s res)

- allows to constrain simple spectral models using 3-channel spectral analysis



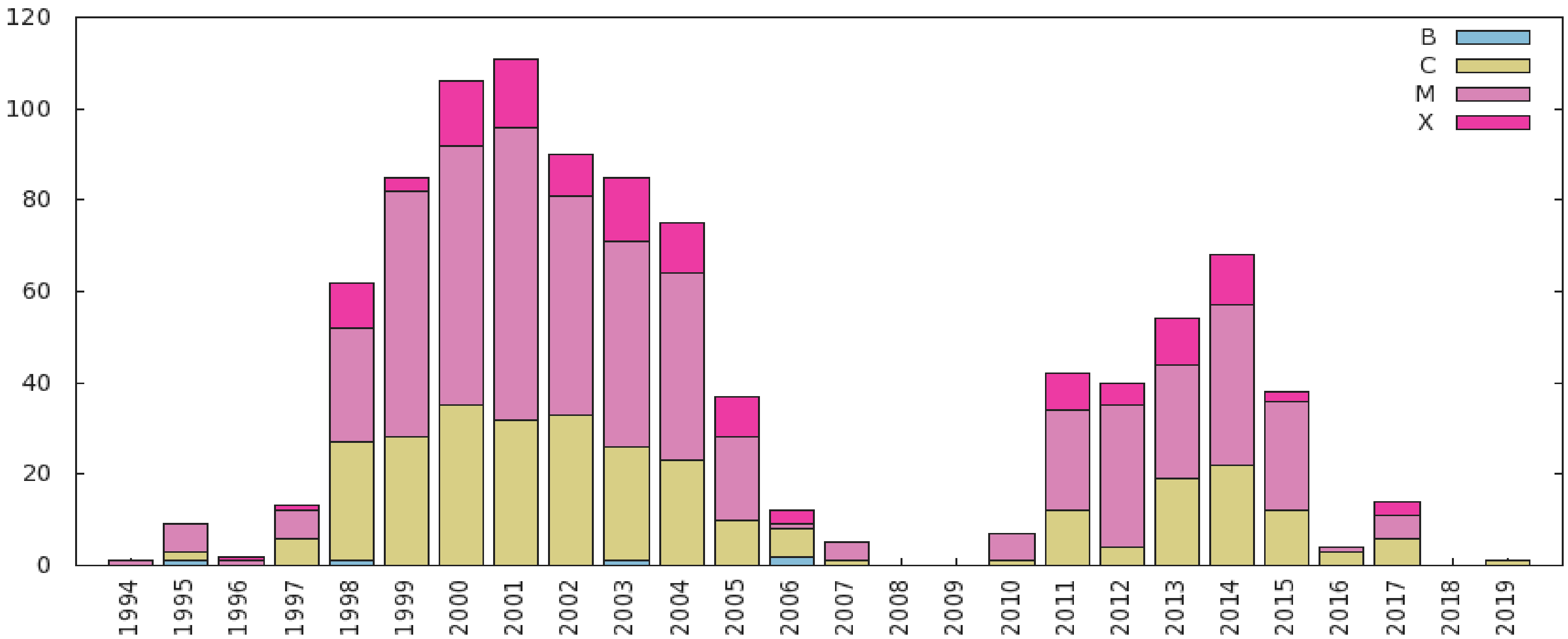


Konus-*Wind* trigger statistics since 1994



- ~ 3150 triggered GRBs (> 100 GRBs/yr), the largest GRB sample to date
- ~500 short GRBs, one of the largest samples
- > 270 bright SGR (magnetar) bursts, incl. ~40 “intermediate” and 2 Giant Flares

KW observations of Solar Flares



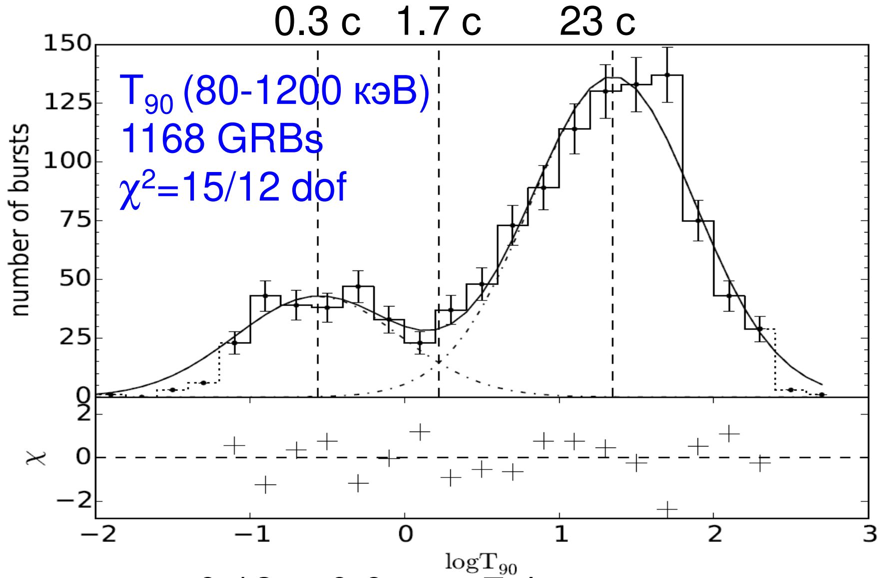
Konus-Wind advantages in solar flare studies:

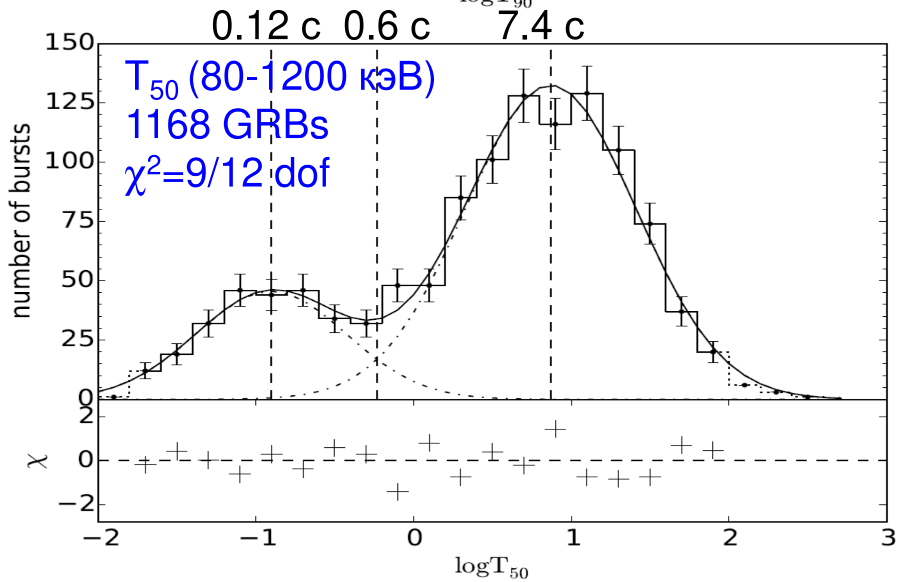
- Continuous observations of the Sun in hard X-rays, duty ciycle ~95%,
- Capability to observe long (~1–2 hour) flares for their entire duration (in WM)
- High temporal resolution in the triggered mode allows KW to observe fine temporal structures in the wide energy band
- Two full 11-yr solar cycles have been covered by the observations, more than 1000 solar triggers, many thousand flares detected in WM

More on KW solar flare observations in A. Lysenko talk on Thursday!

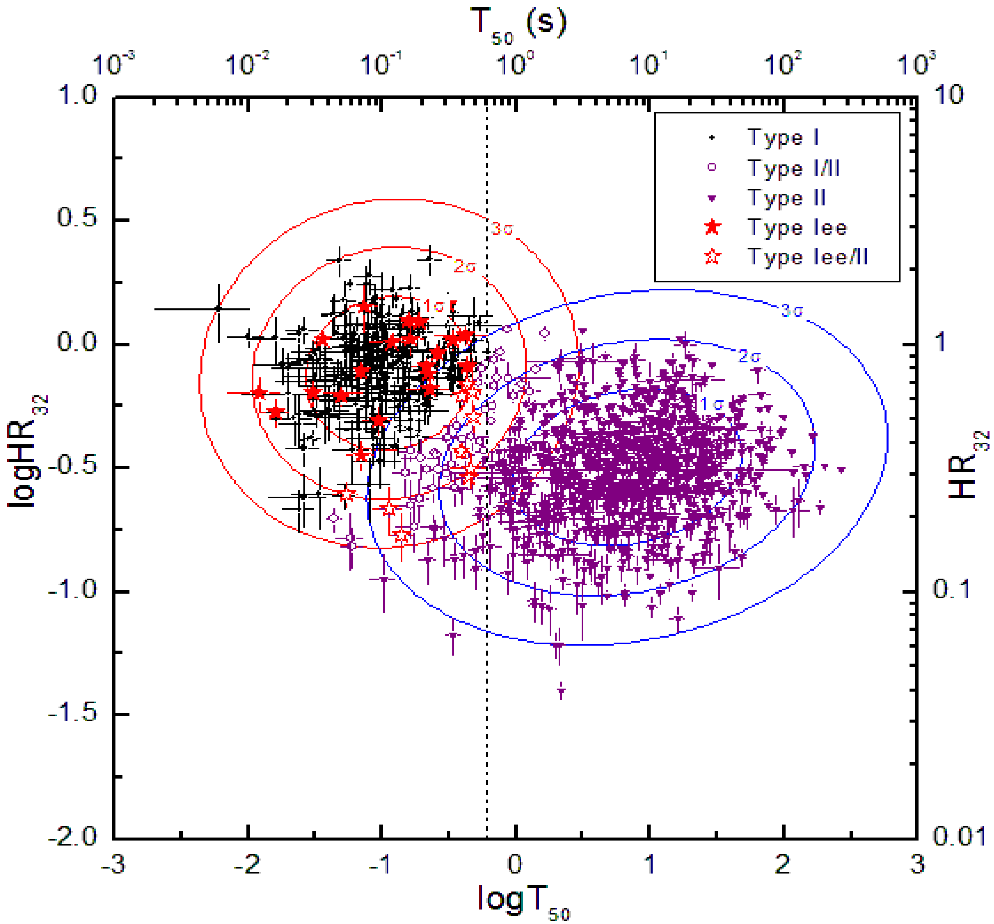
KW GRB classification

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



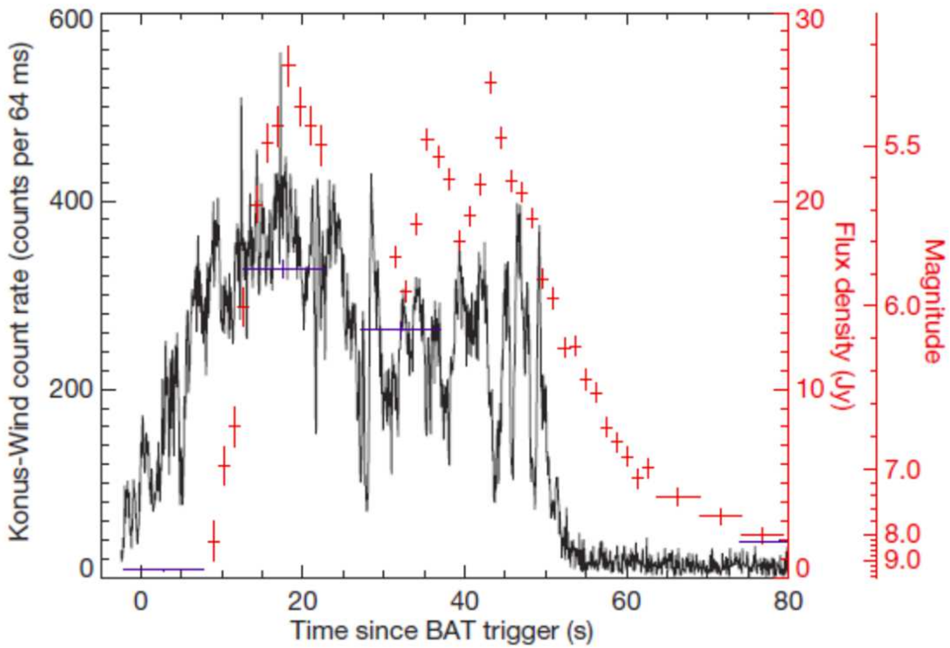


- 2D (hardness – duration T_{50}) distribution:
  18% - short/hard (Type I),
  78% - long/soft (Type II)
  4% undefinite (I/II).



Svinkin et al. 2016

Notable KW long GRBs: the Naked-eye burst



Black: Konus-Wind, Blue: ‘Pi of the Sky’, Red: TORTORA

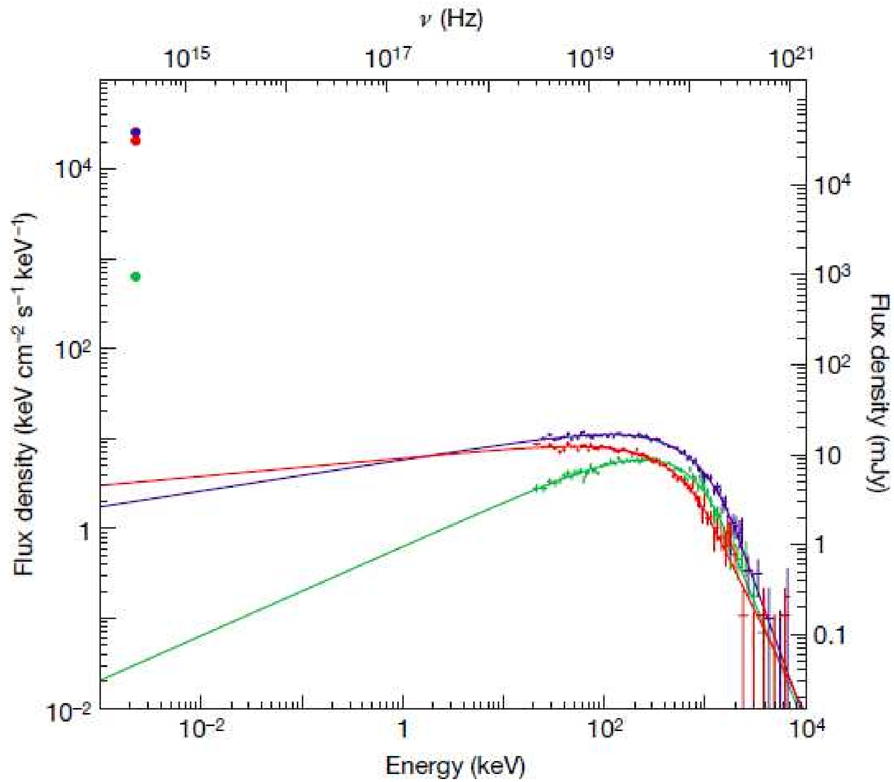
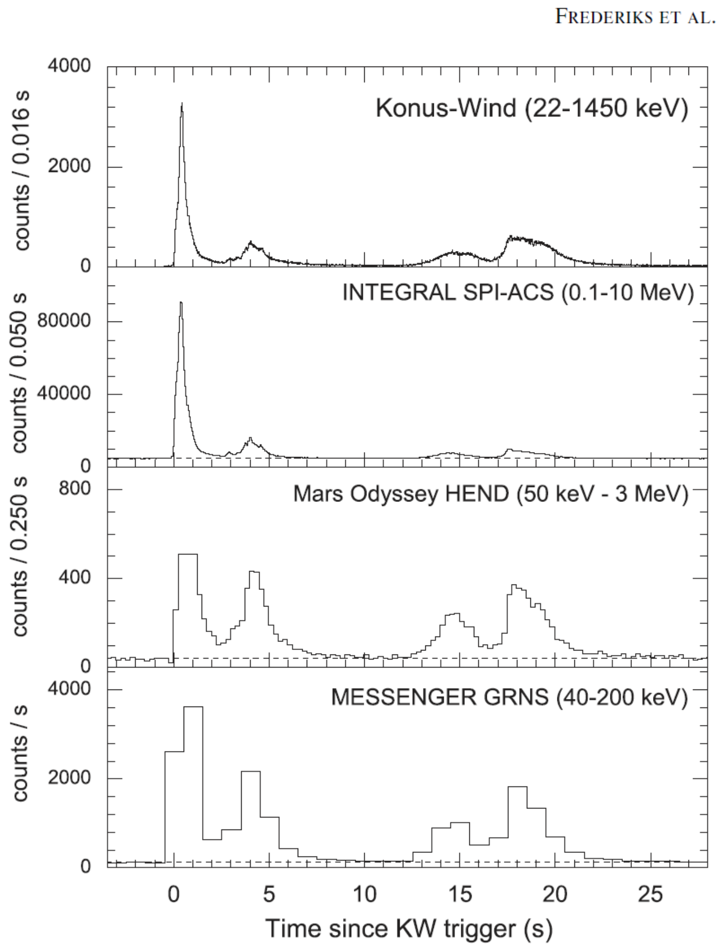


Figure 3 | Spectral energy distribution of the prompt emission. Konus-Wind spectra and ‘Pi of the Sky’ flux density in three 10-s time intervals

GRB 080319B: the Naked-eye burst (Racusin et al. 2008), it had a peak visual apparent magnitude of 5.8 and remained visible to human eyes for approximately 30 seconds

z=0.937, $L_{iso}\approx10^{53}$ erg s^{-1}, $E_{iso}\approx10^{54}$ erg, $E\gamma\approx4\times10^{50}$ erg ($\theta\approx0.2^o$, 4^o)

Notable KW long GRBs: the Ultraluminous burst



Frederiks et al. 2013

GRB 110918A -

the most luminous GRB from the beginning of cosmological GRB era in 1997

- Localized by IPN to 2.6 sq. arcmin box, missed by *Swift* and *Fermi* due to Earth occultation.
- X-ray afterglow found by *Swift*/XRT ~1.2 day after the burst and observed for 48 days
- Burst parameters, observer frame:

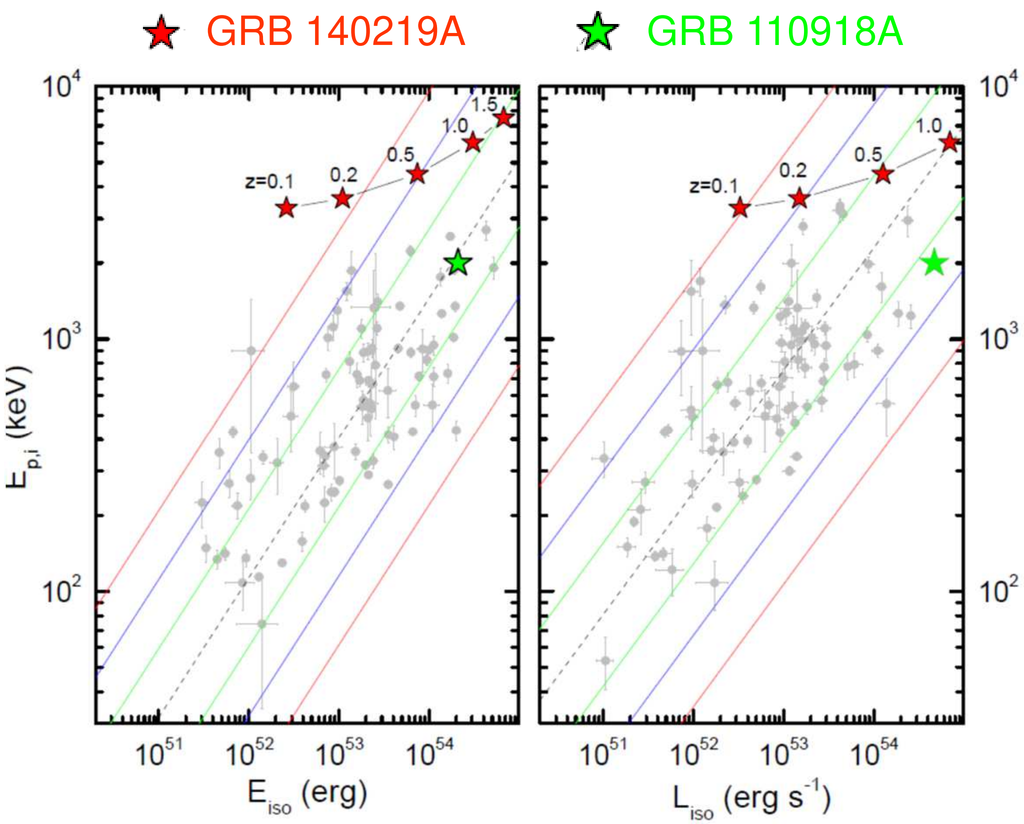
  ΔT ~30 s, $E_{p,max}$ ~4 MeV,
  S ~8×10^{-4} erg cm^{-2} and
  F_{peak} ~9×10^{-4} erg cm^{-2} s^{-1}

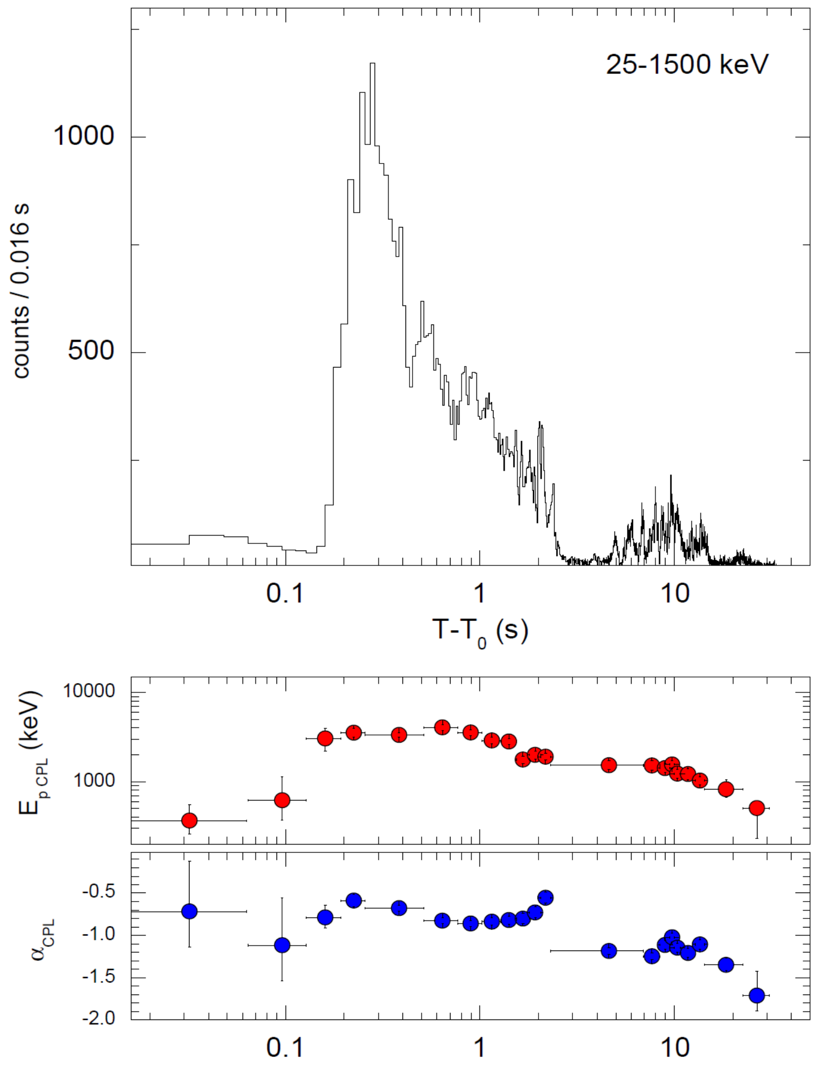
  GRB rest frame (z=0.984):
  $E_{iso}=2.1\times10^{54}$ erg,
  $L_{iso} = 4.8\times10^{54}$ erg s^{-1} (!),
  Θ_{jet}=1°.7 – 3.°4

Notable KW long GRBs: the Ultra-hard burst

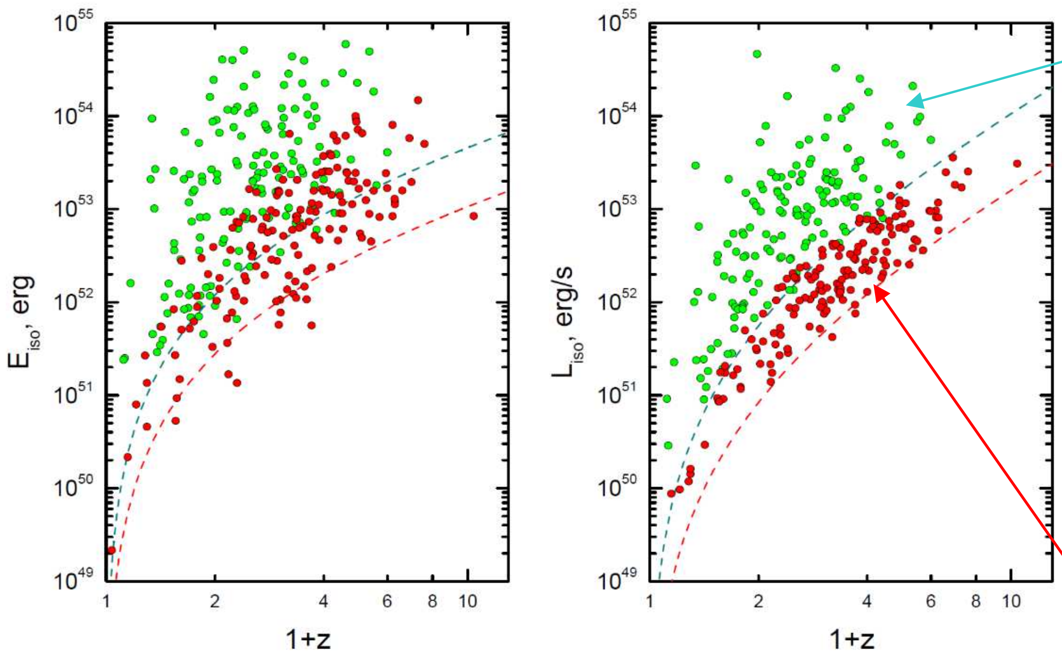
GRB 140219A

- $F_{peak} \approx 1.4\times10^{-3}$ erg cm^{-2} s^{-1} (!)
- $E_{p,max}$ ~3.4 MeV, $<E_p>$ ~2.8 MeV
- Localized by IPN; no X-ray/Opt. afterglow found
- The hardest long GRB in rest frame?





GRBs with known redshifts



Of ~500 GRBs with known redshifts since 1997:

- 166 bright GRBs triggered KW ($0.1 \le z \le 5$)

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

  - 14 short/hard + 152 long/soft

  - 32 GRBs with reliable jet breaks (collimation!)

  - knowing z, rest-frame GRB energy and spectrum may be constrained directly from the KW data (20 keV-15 MeV)

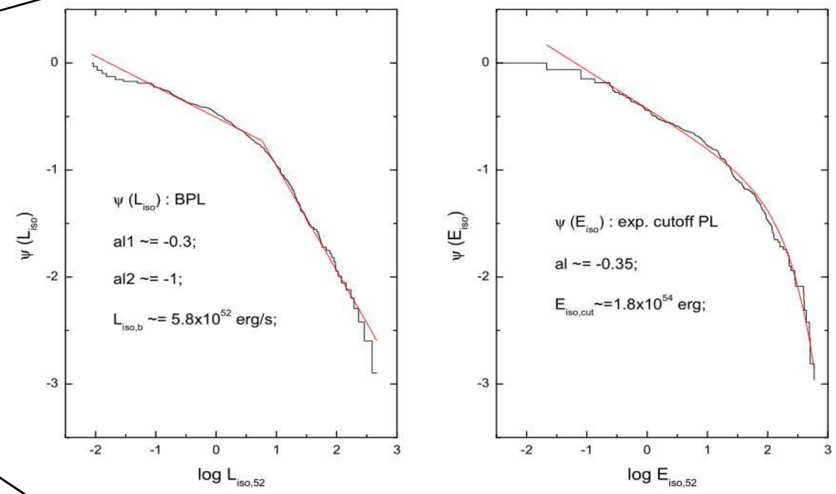
- + ~200 weaker GRBs were detected by KW in the waiting mode (20-1500 keV, 3-ch)

  For 172 Swift GRBs ($0.04 \le z \le 9.4$) we were able to constrain broadband spectra, fluences, and peak fluxes and from joint KW + *Swift*/BAT analysis (catalog: in prep.)

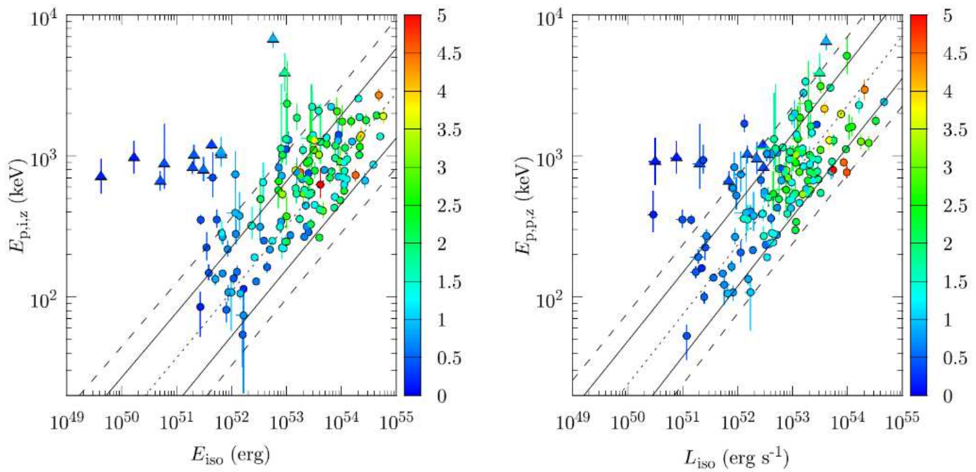
KW GRBs with known redshifts: analysis

The largest GRB sample
measured over the wide energy range
(~330 bursts, $0.04 \le z \le 9.4$)
provides an excellent opportunity to study:

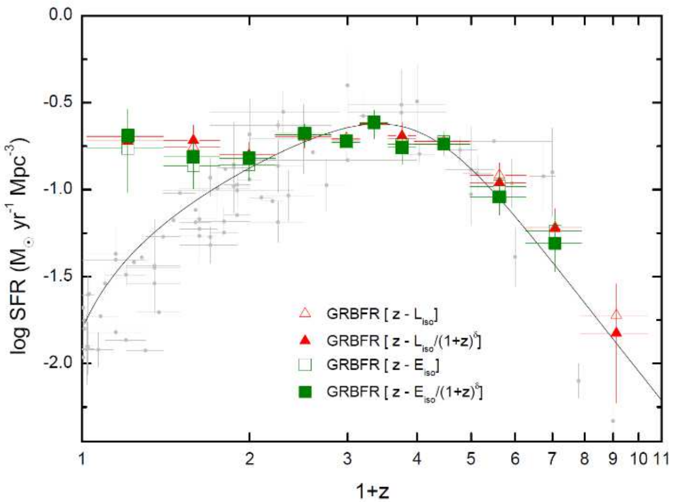
GRB luminosity and E_{iso} functions



GRB rest-frame correlations (standard candle?)



GRB formation rate
(progenitors?)



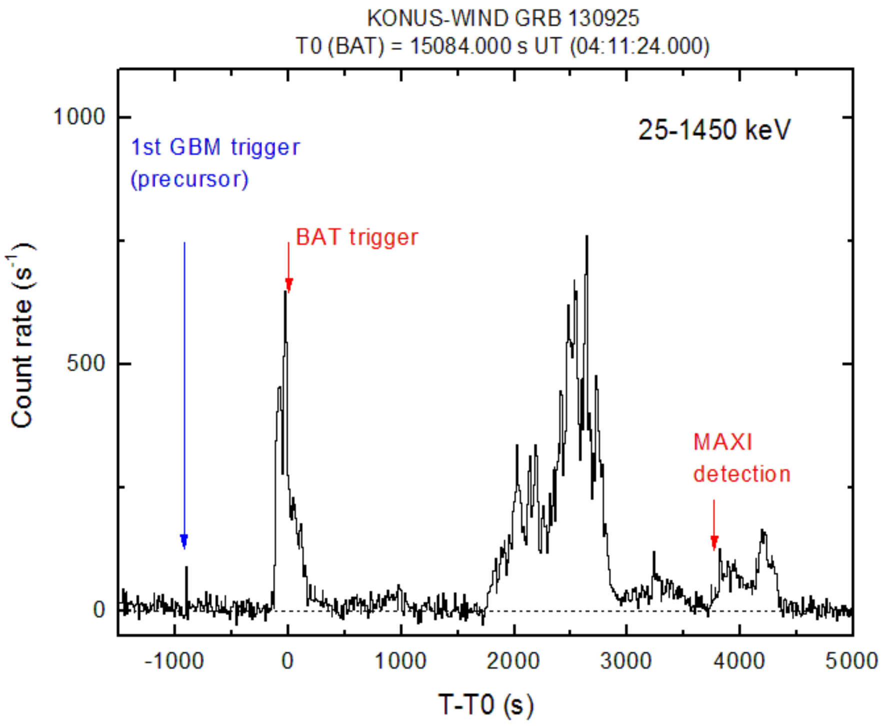
Details: A.Tsvetkova talk on Wednesday

KW observations of ultra-long GRBs

Extremely rare class of GRBs with durations > 1 ks, less than a dozen reported so far.

Do they come from a distinct population?

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

8 KW ultra-long GRBs reported so far (5 with known z):

GRB 971208 (Pal'shin+2008) T~2.5 ks;

GRB 020410A (Nicastro+2004) T~1.6 ks, z~0.5;

GRB 060814B (Pal'shin+2008) T~2.7 ks;

GRB 080407 (Golenetskii+2011) T~2.1 ks;

GRB 091024A (Virgili+2013) T~1.2 ks, z=1.1;

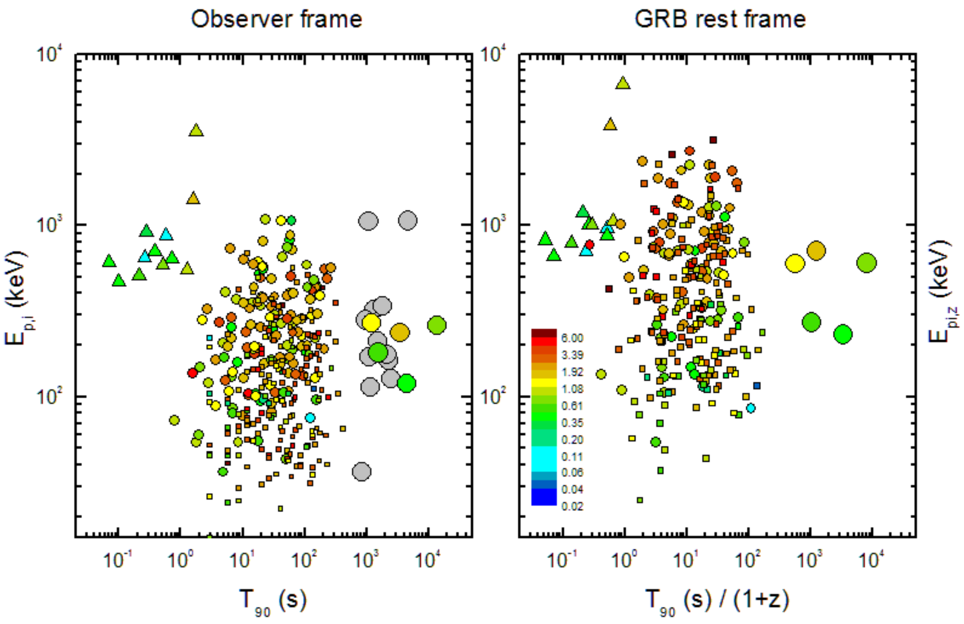
GRB 111209A (Golenetskii+2011) T~14 ks, z=0.7;

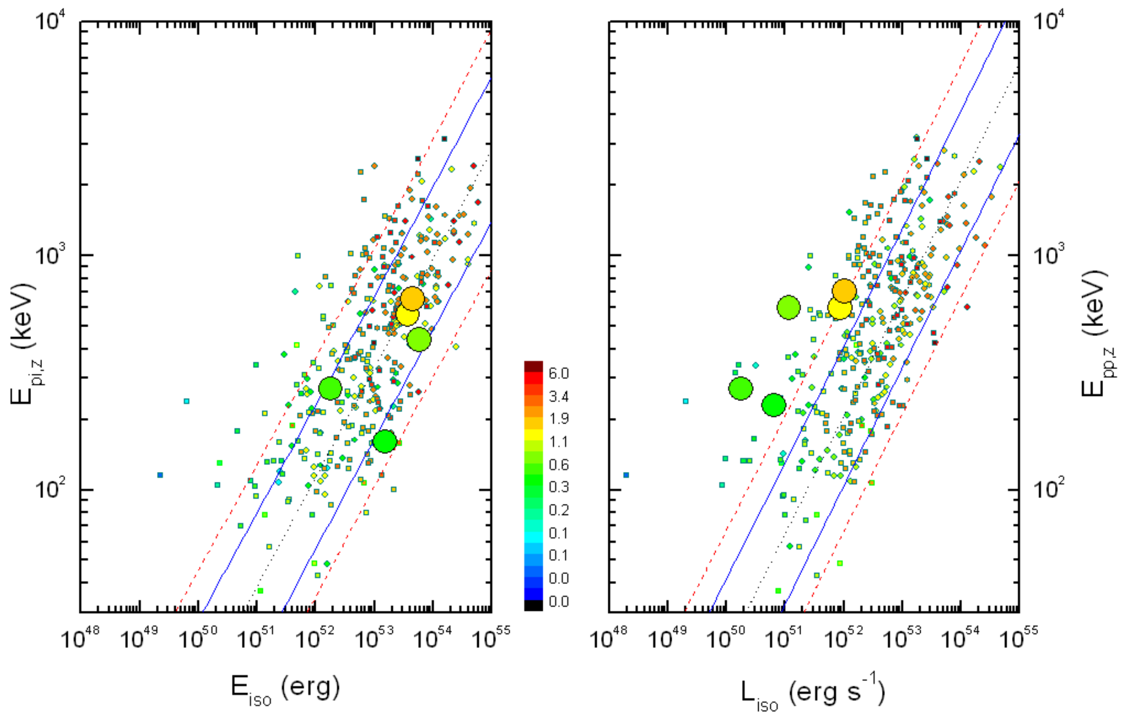
GRB 121027A (Golenetskii+2012) T~1.4 ks, z=1.8;

GRB 130925A (Evans+2014, Greiner+2014) T~5 ks, z=0.35

Ultra-long GRBs with known redshifts

Five u-long GRBs with measured z (so far), all detected by KW:





The known u-long GRBs with measured z:

- are still u-long in the rest frame;
- nicely follow the $E_{p,z}$-E_{iso} relation for "classic" long KW GRBs (the same energy reservoir?);
- reside on the low-luminosity side of the $E_{p,z}$-L_{iso} relation (a slightly different emission mechanism?)

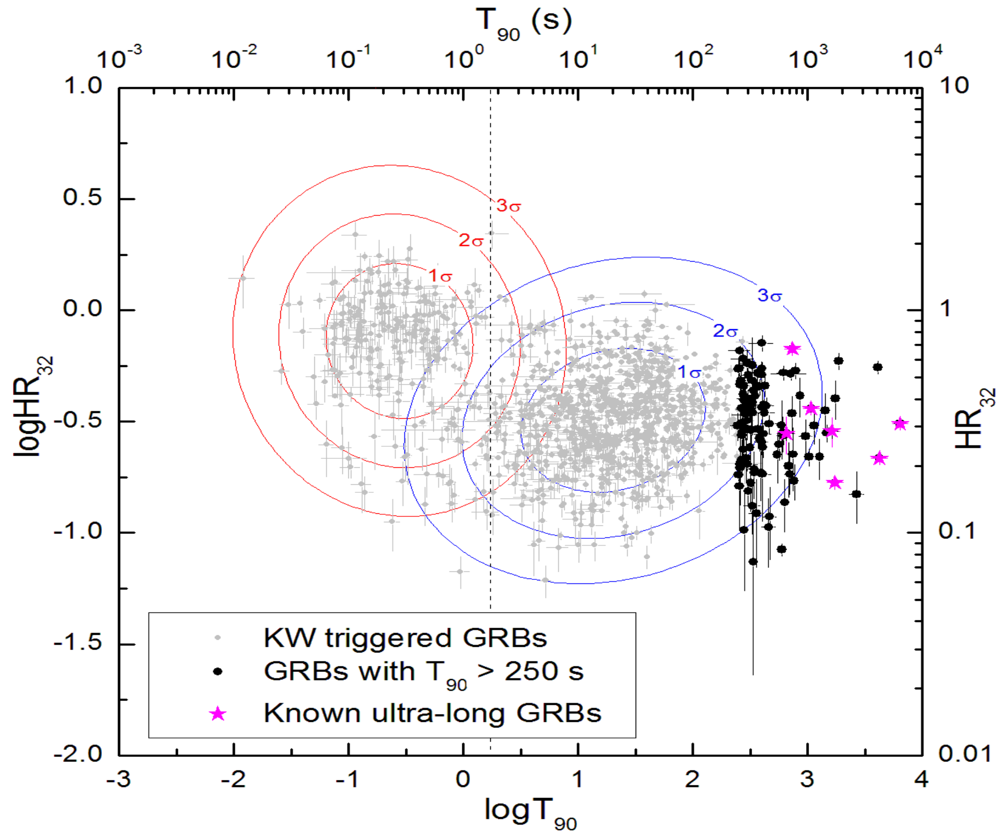
Search for ultra-long GRBs in the KW WM data

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

  http://www.ioffe.ru/LEA/kw/wm/index.html

- Search for very- and ultra-long GRBs:
  - criteria: T_{100} >250 s, S/N >10, hard spectrum
  - ~100 very-long GRB candidates
  - 17 GRBs with T_{100} >1 ks (8 known + 9 new!)

  http://www.ioffe.ru/LEA/kw/wm/ulong/index.html

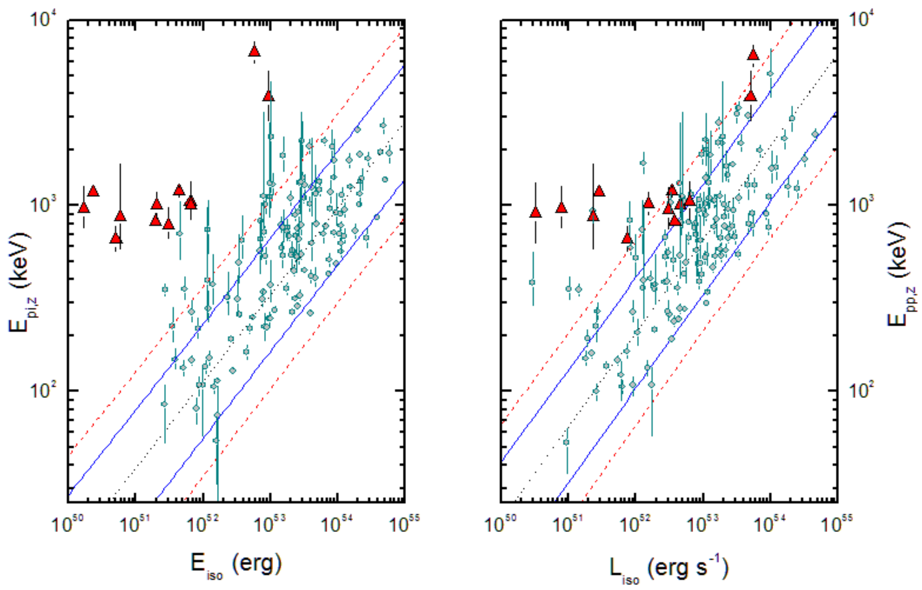


More on the KW u-long GRBs:
D. Svinkin talk on Tuesday

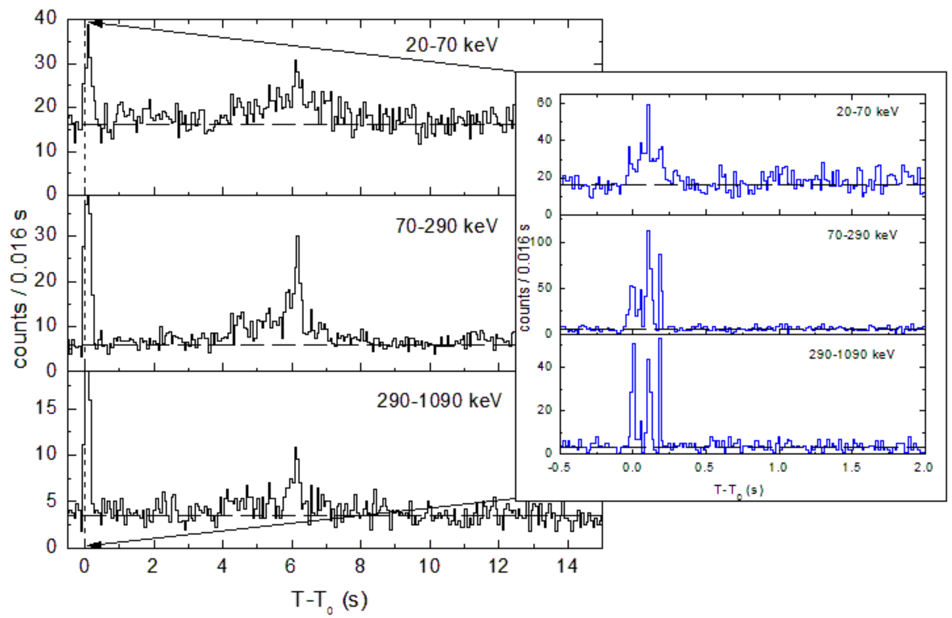
KW short GRBs

~500 short KW GRBs to date (~15%): KW sGRB catalog: Svinkin et al. 2016

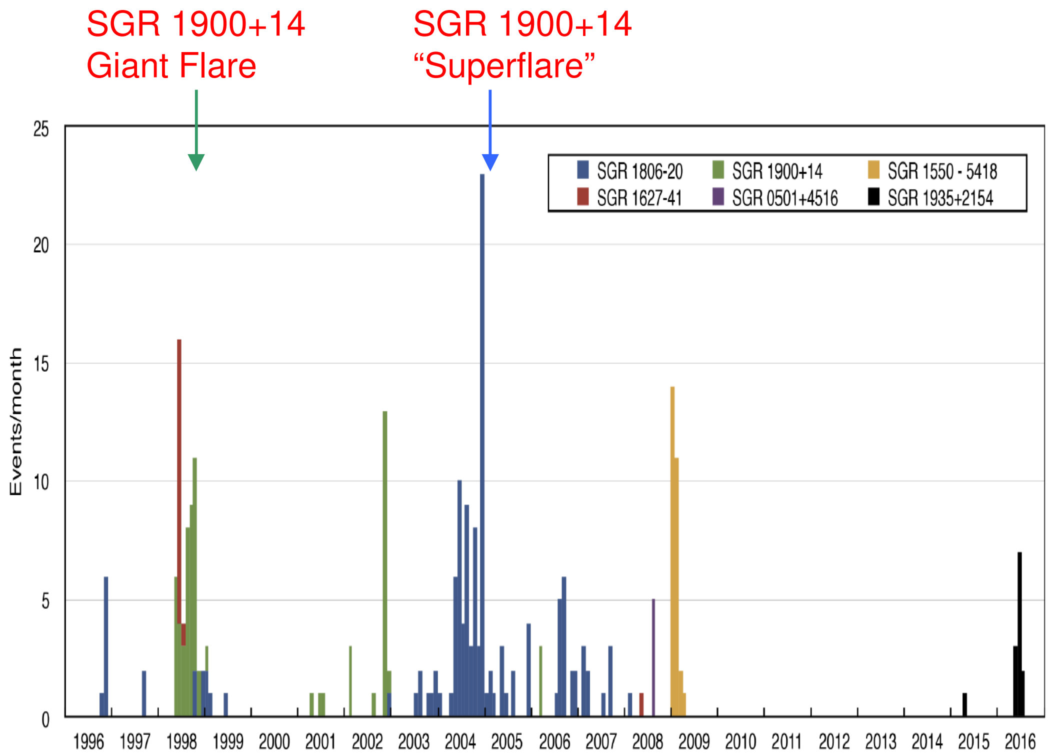
- One of the largest samples of short GRBs detected over the wide energy band (20 keV – 15 MeV)
- 14 short/hard GRBs with known redshifts (catalog: Tsvetkova et al. 2017)
- ~30 short GRBs with extended emission (EE), 6 bursts show rather hard EE (E_p ~ 160 keV – 2.2 MeV!)
- Three short GRBs with an additional hard power-law spectral component
- Two extragalactic SGR Giant Flare candidates: GRB 051103 (M81/82?) and GRB 070201 in Andromeda galaxy(?)

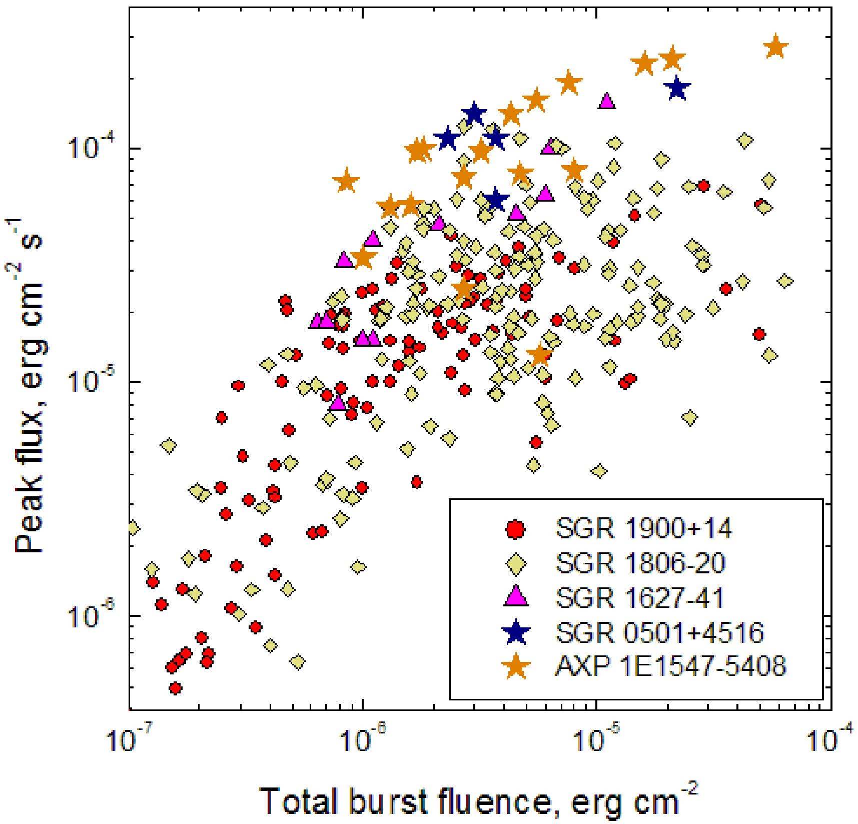


Tsvetkova et al. 2017



KW observations of SGR (magnetar) flares

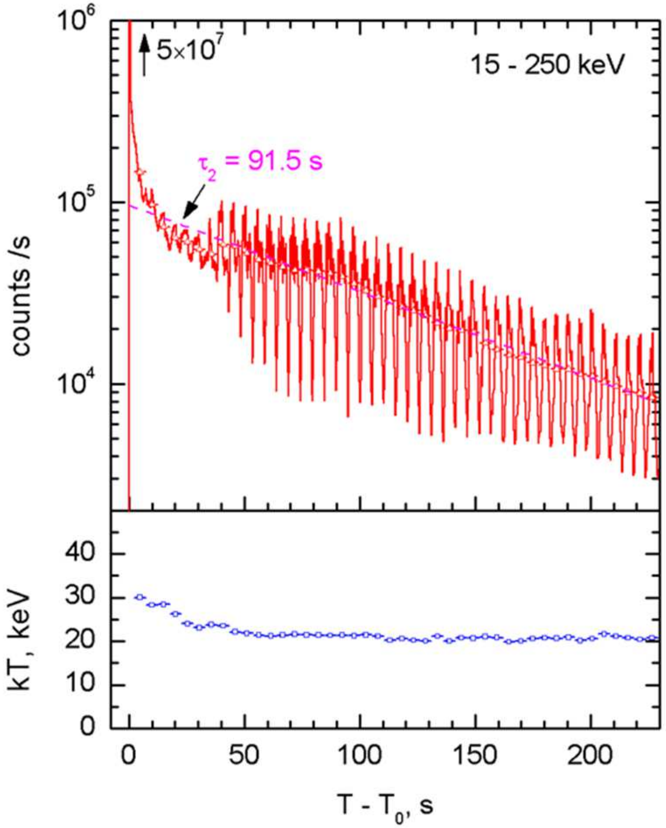


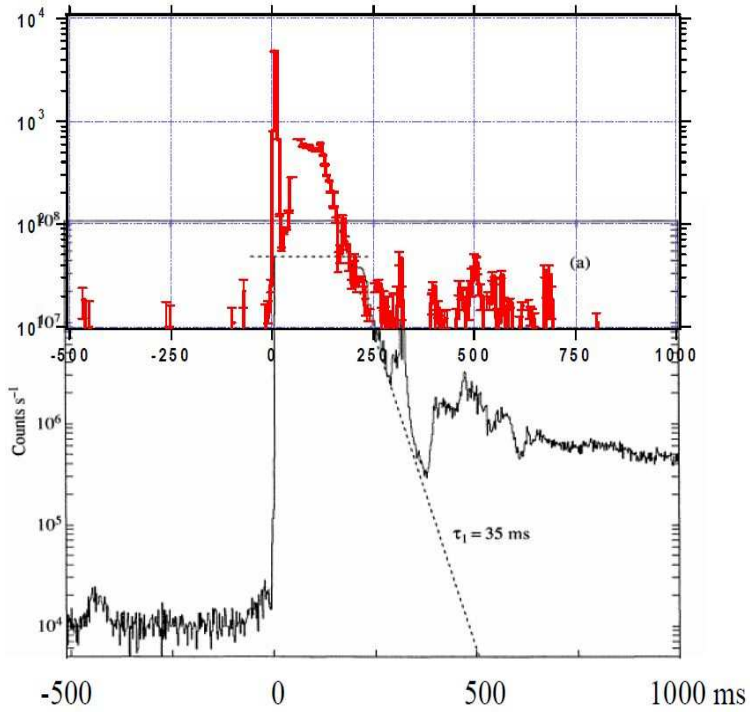


- >200 rather bright 'short' SGR bursts from 8 sources (T<1 s, E_{tot} ~ 10^{38}-10^{40} erg)
- > 40 'intermediate' flares (T~1-30 s, E_{tot} ~ 10^{40}-10^{43} erg)
- 2 Giant Flares (T>100 s, E_{tot} ~ 10^{44}-10^{46} erg, L_{peak} ~ 10^{46}-10^{47} erg/s)

Details: A.Kozlova talk on Friday

SGR 1900+14 GF (August 27, 1998)



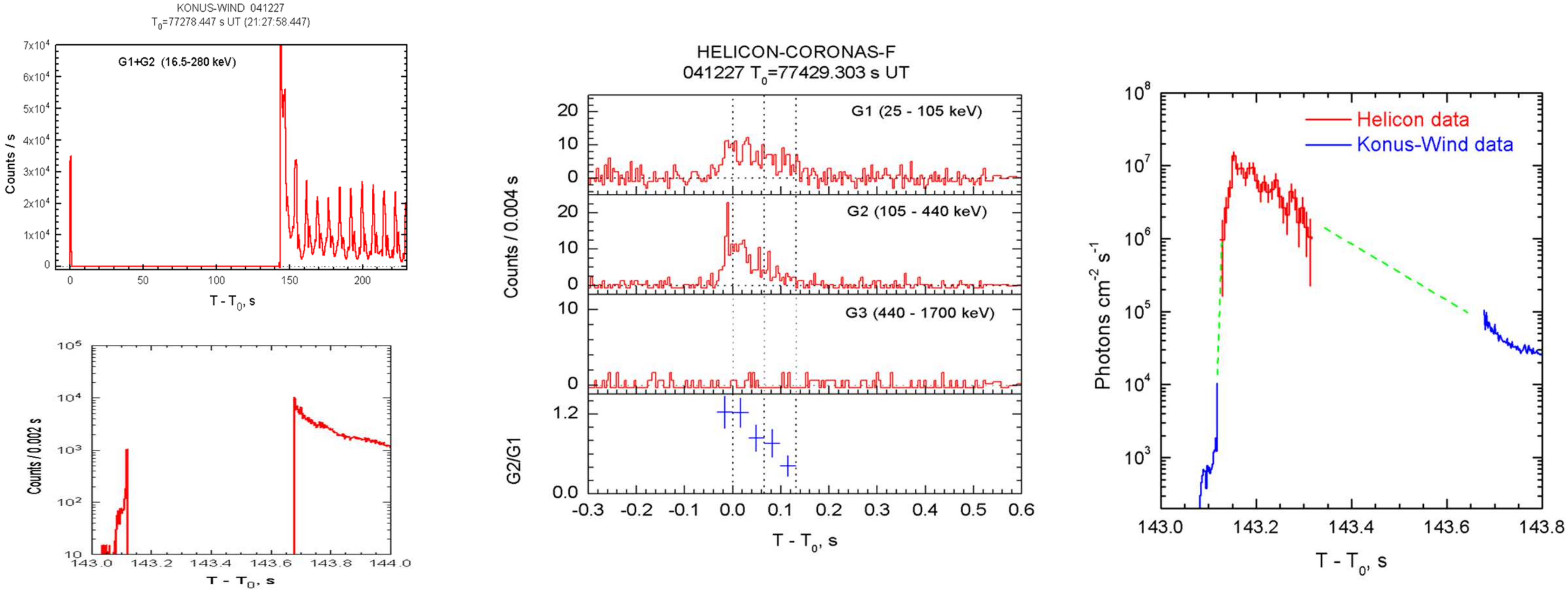


GEOTAIL-LEP
(Tanaka+2006,07)

Konus-WIND
(Mazets+1999)

- First GF after the famous March 5, 1979 event (SGR 0526-66 @ LMC, Mazets+1979)
- Giant, hard-spectrum initial pulse + soft pulsating tail
- E_{tot} ~ 4x10^{44} erg, L_{peak} ~ 2x10^{46} erg/s

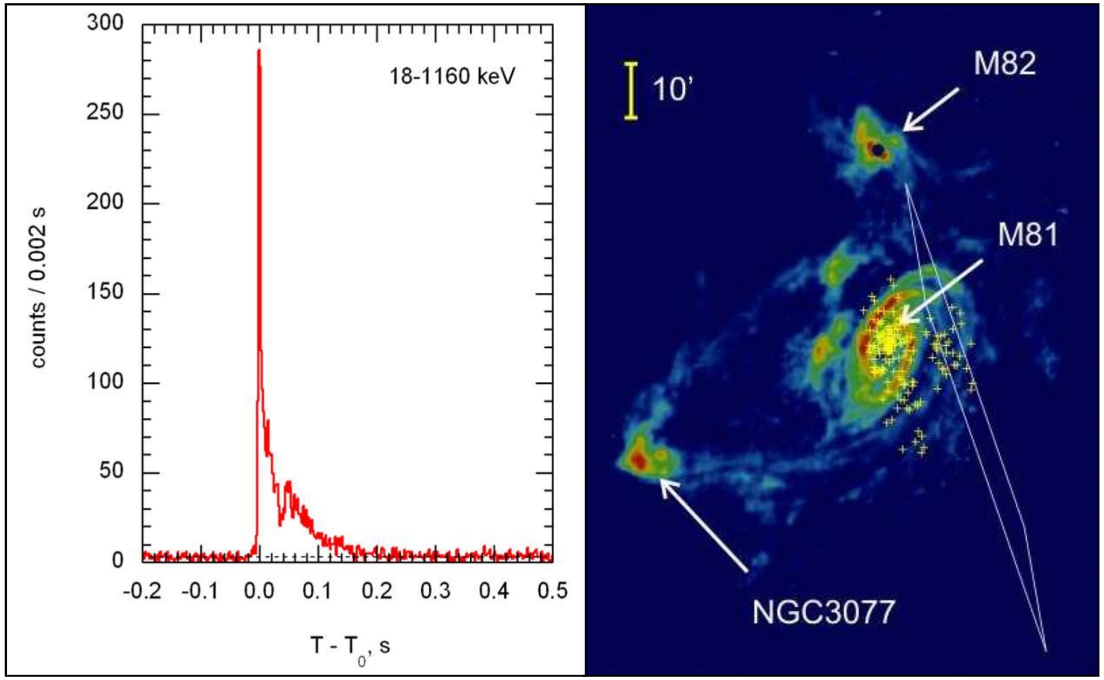
SGR 1806-20 “Superflare” (December 27, 2004)



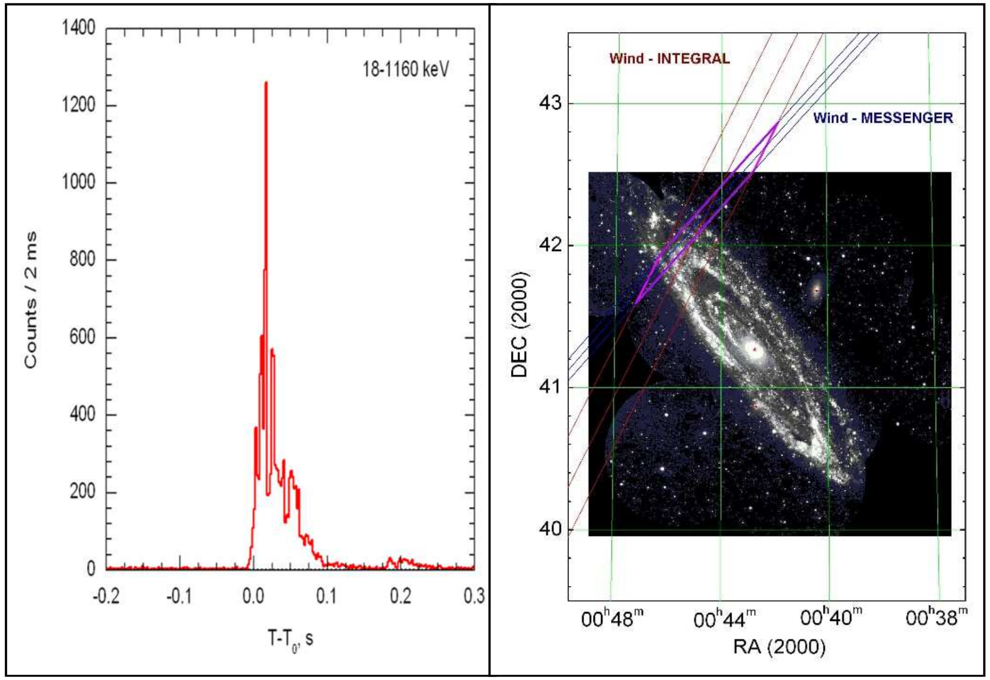
Frederiks+2007a

- 3rd in history and the most powerful GF yet
- As for the August 27, 1997 GF, KW was fully saturated for ~500 ms in the initial pulse
- Helicon/*CORONAS-F* detected the GF initial pulse reflected from the Moon
- From joint KW+Helicon analysis: E_{tot} ~ 2x10^{46} erg, L_{peak} ~ 4x10^{47} erg/s

KW short GRBs - extragalactic GF candidates



GRB 051103 (Frederiks et al. 2007)



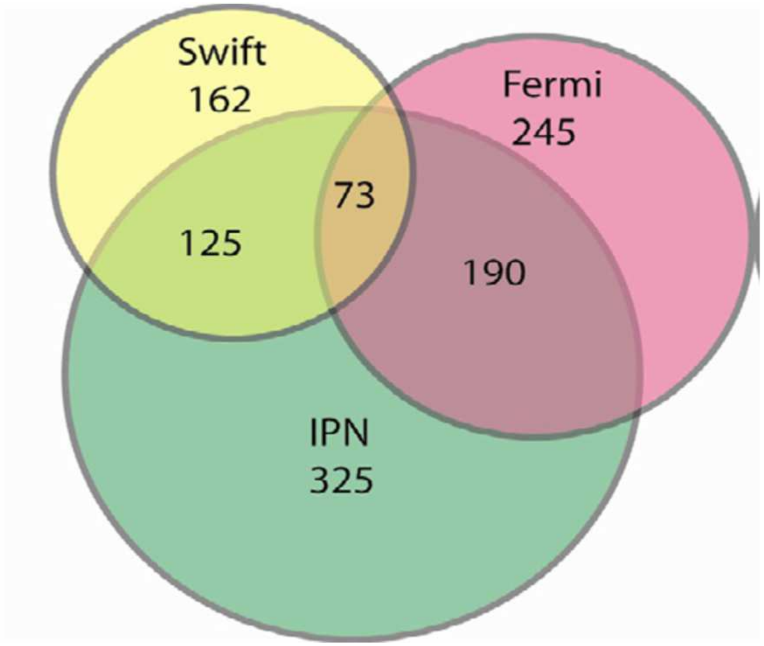
GRB 070201 (Mazets et al. 2008)

Original idea (Mazets & Golenetskii 1981) that some (if not all) short hard GRB are in fact distant Giant Flares was based on properties of the March 5, 1979 event. The superflare in SGR 1806-20 renewed the interest.

- GRB 051103 and GRB 070201 are extremely bright short events with sharp rise, dT ~150-200 ms and hard energy spectra, these characteristics of the events match the general pattern of a GF very closely
- For both bursts their IPN localization boxes overlap with starforming regions of nearby large spiral galaxies
- Assuming M81/82 and M31, respectively, the burst energies are close to that of initial pulses of known GFs
- GRB 070201: weak extended tail (~100 s) with the energy comparable that of GF pulsating tails
- More on short GRB/GF candidate search: Svinkin et al. (2015)

KW and IPN capabilities for multi-messenger astronomy

- In the era of multi-messenger astronomy only 30% GRBs are precisely localized by narrow-field instruments (*Swift*-BAT, *Fermi*-LAT, IBAS-ISGRI).
- Triangulation with distant s/c could add up to ~100 GRBs yr^{-1}
- Located up to ~7 lt-s from Earth, KW observes ~95% events $>10^{-6}$ erg cm^{-2} and is a key vertex of the IPN (comprises up to 7 s/c, a ~100% duty circle, all-sky GRB monitor with localization capability)
- IPN triangulation: >500 GCN circulars + 8 IPN catalogs of gamma-ray burst localizations
- KW and IPN provide a significant fraction of candidates for prompt and retrospective search and allow estimating upper limits on γ-ray emission from GW and other non-EM events (Hurley+2016, Abbot+2017, …), and SNe Ib/c (Whitesides+2017, Margutti+2019, …)



Hurley et al. (2013)

Summary

- For almost 25 years of operation Konus-Wind has been collecting important, often unique, data on GRBs, SGR bursts and GFs, Solar flares and other transients, providing reliable measurements of their temporal and spectral properties
- KW provides excellent results in the collaboration with many space-based missions (Swift, Fermi, INTEGRAL, etc.) and ground-based facilities
- KW is a basic vertex of the IPN, the seven-spacecraft network that provides localizations for events missed by narrow-field telscopes. In the era of multi-messenger astrophysics KW and IPN provide a unique opportunity for prompt and retrospective search for hard EM counterparts to GW, neutrinos and SNe
- The Wind s/c and the Konus instrument are both in a good health and we expect more exciting science with the joint Konus-Wind experiment!

Collaboration with other instruments

- IPN triangulation – ~450 GCN circulars + 8 IPN catalogs of gamma-ray burst localizations.
- Konus-Wind rapid results on interesting events are regularly reported in GCN Circulars (~530 circulars have been published).
- Search for GRB afterglows in collaboration with robotic telescopes:
  Fermi-GBM GRBs (iPTF+IPN, Singer et al., ApJ, 2015),
  GRB 140801A (MASTER, Lipunov et al., MNRAS, 2016).
- Offline search for e/m and non-e/m counterparts: SNs, Neutrino events, LIGO triggers
  (SN2011fe, Margutti et al., ApJ, 2012; GW150914, Hurley et al., ApJ, 2016; etc.).
- Cross-calibration with other instruments:
  - Swift-BAT and Suzaku-WAM (Sakamoto et al., PASJ, 2011);
  - Fermi-GBM and INTEGRAL-SPI-ACS is under way.

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

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

  http://www.ioffe.ru/LEA/kw/triggers/

  http://www.ioffe.ru/LEA/catalogs.html

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

  http://www.ioffe.ru/LEA/kw/wm/

- GRBs with known redshifts (166 triggered, 14 short/hard, 32 with jet breaks)

  http://www.ioffe.ru/LEA/zGRBs/triggered/

- > 100 very- and ultra-long GRB candidates (analysis in progress…)

  http://www.ioffe.ru/LEA/kw/wm/ulong/index.html

Thank you!