Soft Gamma-ray Repeater studies with Konus experiments

D. Frederiks, R. Aptekar, S. Golenetskii, P. Oleynik, V. Pal'shin, D. Svinkin, A.Tsvetkova, M. Ulanov, and A.Kozlova

Ioffe Institute, St.Petersburg, Russia

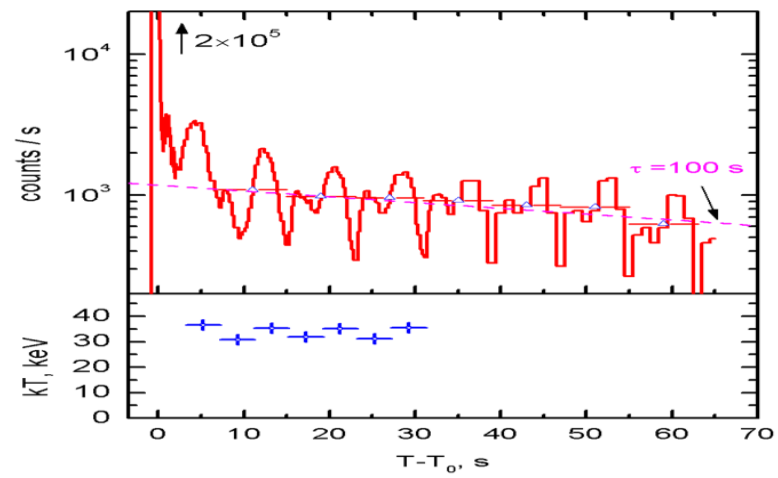
Outline

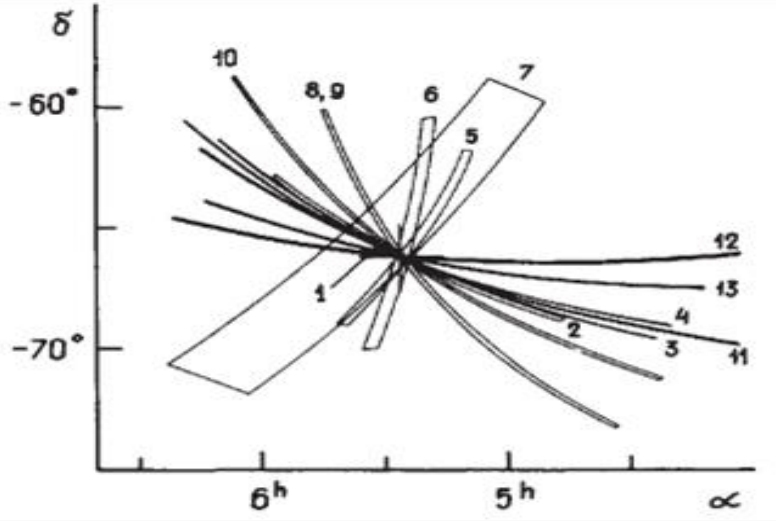
- Historical remarks: SGR discovery in early Konus experiments

- Key results from Konus experiments in 1994-2009
  - Short bursts
  - Burst “series” (clusters)
  - Giant Flares from SGR 1900+14 and SGR 1806-20
  - “Intermediate” (u-long) bursts
  - “New” SGRs

- Second Konus SGR Catalog (in preparation)

Venera Missions (1978-1983)





- **Konus experiments (Venera 11-12, Venera 13-14)**
  6 NaI detectors onboard a pair of distant s/c on the way to Venus (separation up to 60×10^6 km)

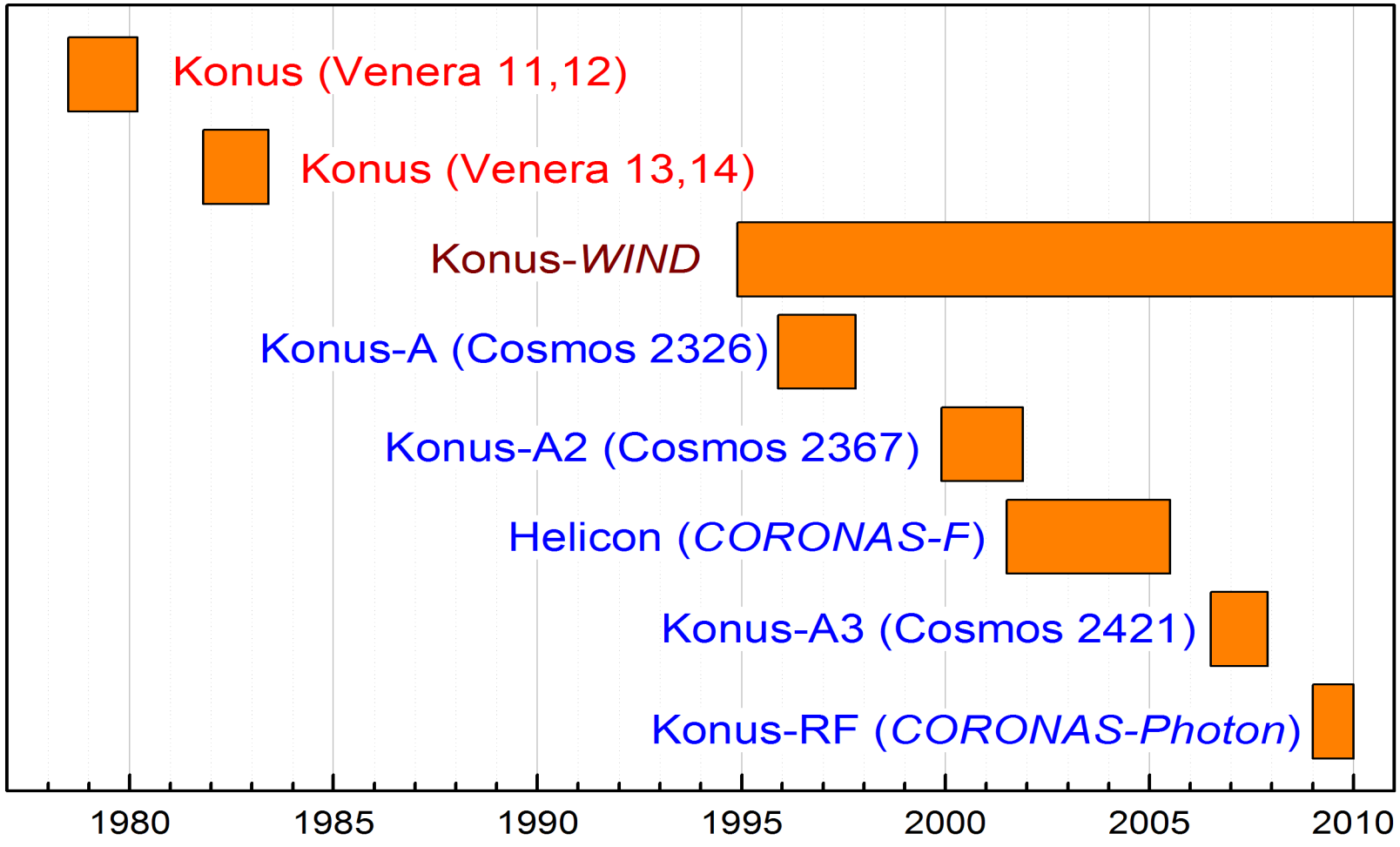
- **Giant Periodic Flare** on March 5, 1979
  (Mazets et al. 1979) followed by 16 short bursts from the same source in the next few years
  (Golenetskii, Il'inskii & Mazets 1984)
  FXP 0526-66 = SGR 0526-66
  (N49, LMC, 55 kpc; Cline et al., 1982)

- **B1900+14 = SGR 1900+14** (3 bursts in March 1979)

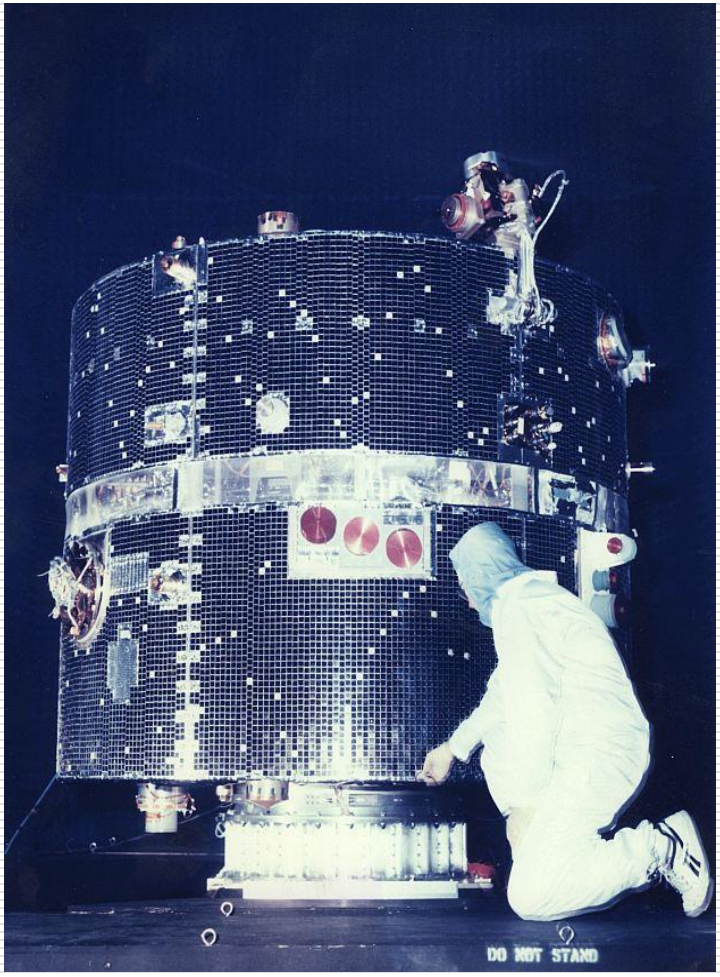
- First two sources of **short recurrent bursts with soft spectra** were discovered and localized, a distinct class of sources different from other GRBs suggested (Golenetskii, Il'inskii & Mazets 1984)

- **SGR 1806-20** (Prognoz 9, ICE, SMM) Atteia et al. 1987, Laros et al. 1987, Kouveliotou et al. 1987)
  1st Konus burst on Jan 7, 1979!

Konus Experiments

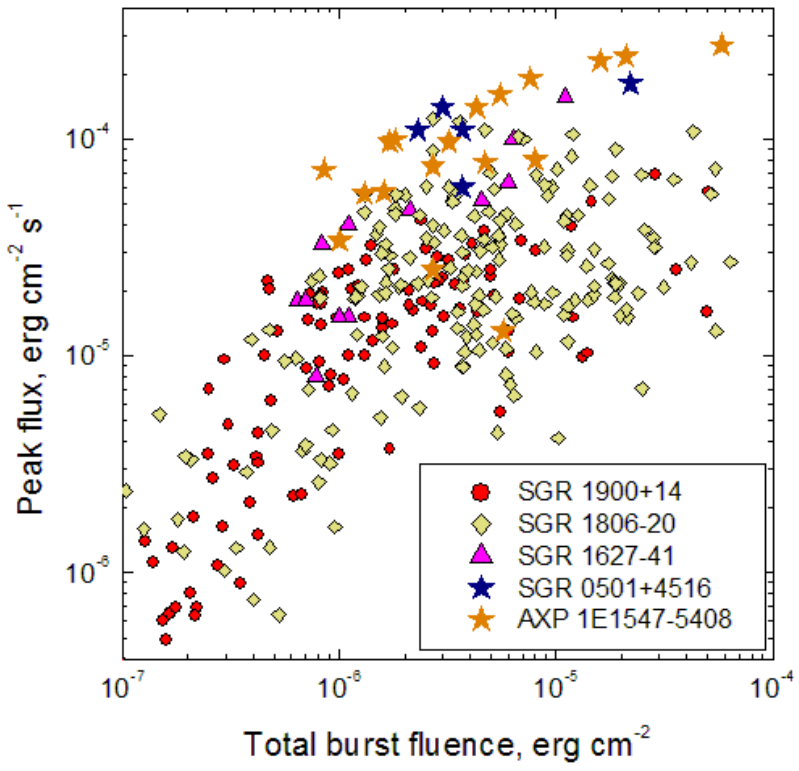


Instrumentation



- **NaI(Tl)** 130 x 75 mm (5 x 3 in.)
- **Al** housing,
  Be entrance window
  Lead glass back-shielding
- S_{eff} ~ 100-160 cm^2 (100 keV), 80-100 cm^2 (10 MeV)
- **Energy range**:
  12 keV – 10 MeV (1994)
  20 keV – 17 MeV (now)
- **Detection threshold**:
  10^{-7} – 10^{-6} erg cm^{-2}

Konus SGRs (1994-2009)

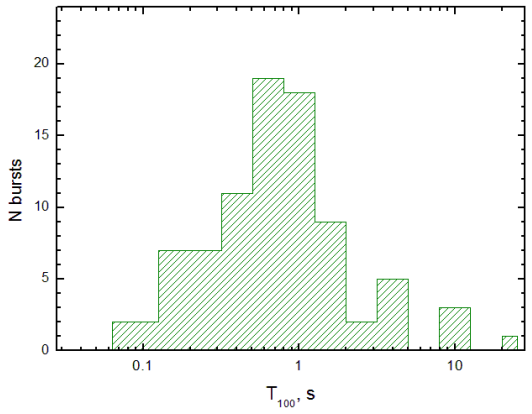


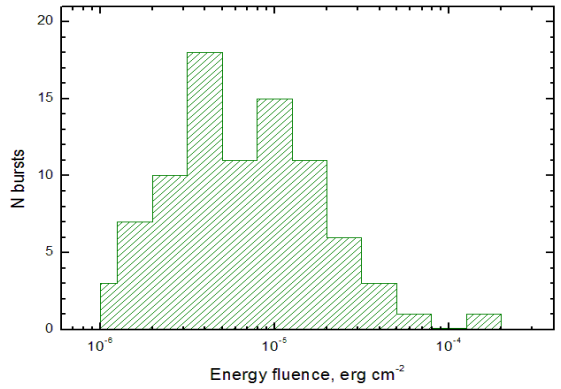
Seven SGRs have been observed

- SGR 1900+14 - 75 bursts + GF (KW, Helicon)
- SGR 1806-20 - 150 bursts + GF (KW, Helicon, KA3)
- SGR 1627-41 - 14 bursts (KW)
- SGR 0501+4516 - 5 bursts (KW)
- AXP 1E1547-5408 - 21 burst (KW+KRF)
- SGR 1801-23 - 1 burst (KW)
- SGR 0418+5729 - 1 burst (KRF)

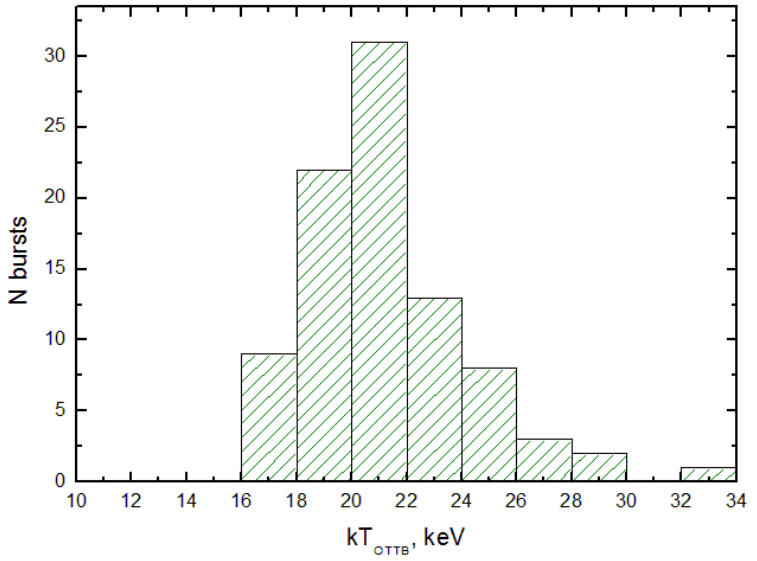
267 short and "intermediate" bursts + two GFs

Short SGR bursts





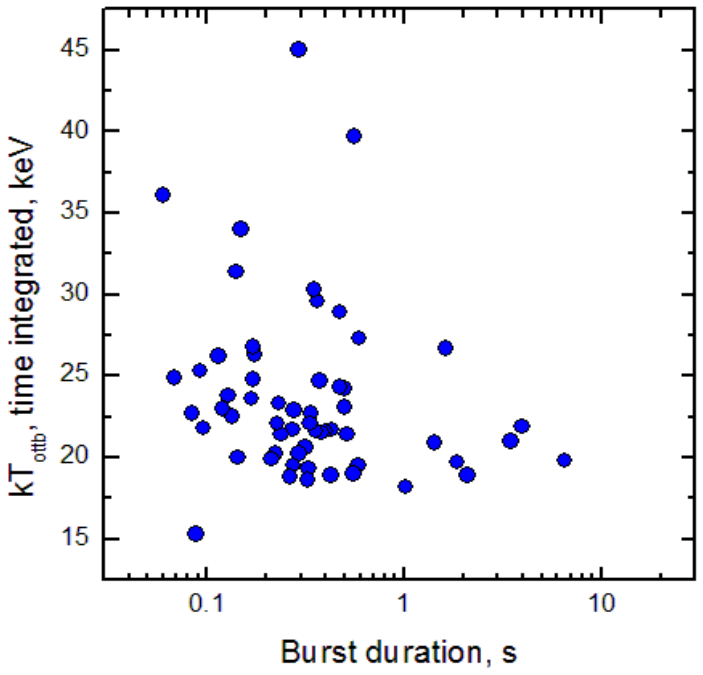
- Durations – <100 ms to few seconds
- Spectra (OTTB) – kT: 15-40 keV
- Fluences – 10^{-7} to 10^{-4} erg cm^{-2}
- Peak fluxes - 10^{-7} to 10^{-4} erg cm^{-2}

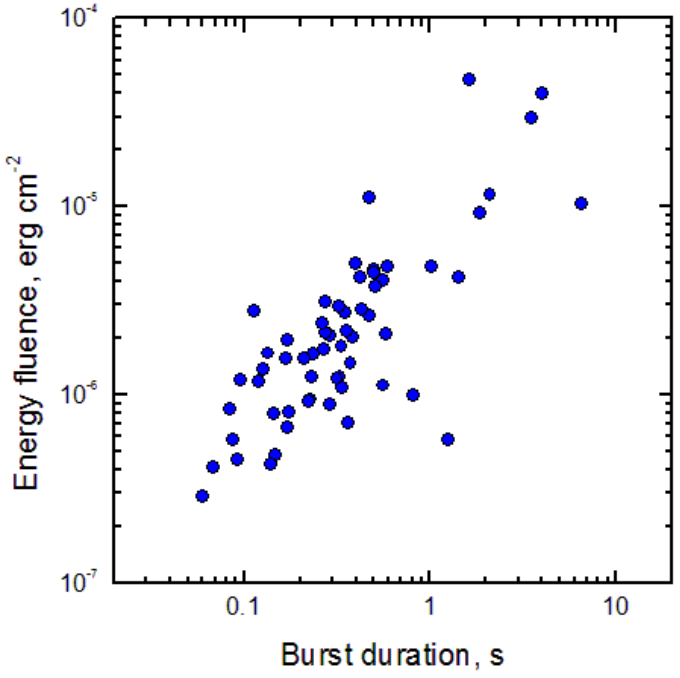


Konus catalog of SGR activity: Aptekar et al. (2001)

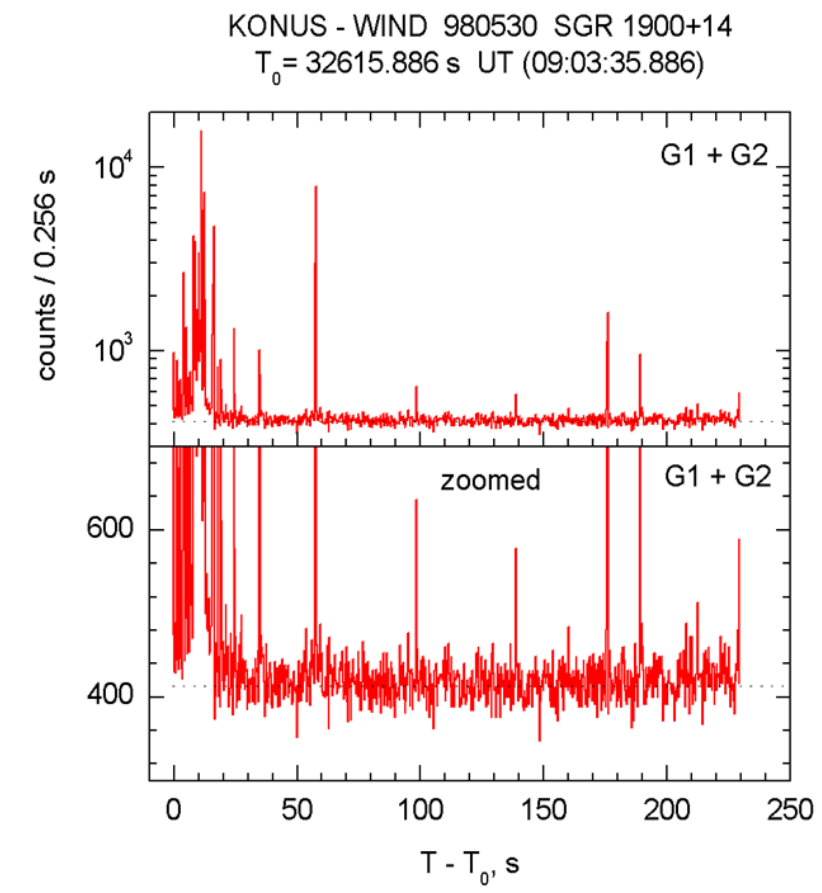
SGR 1900+14

- 75 short bursts





Konus-WIND – SGR 1900+14



- **980530 burst "series"** (cluster): multiple closely packed and partially overlapped bursts

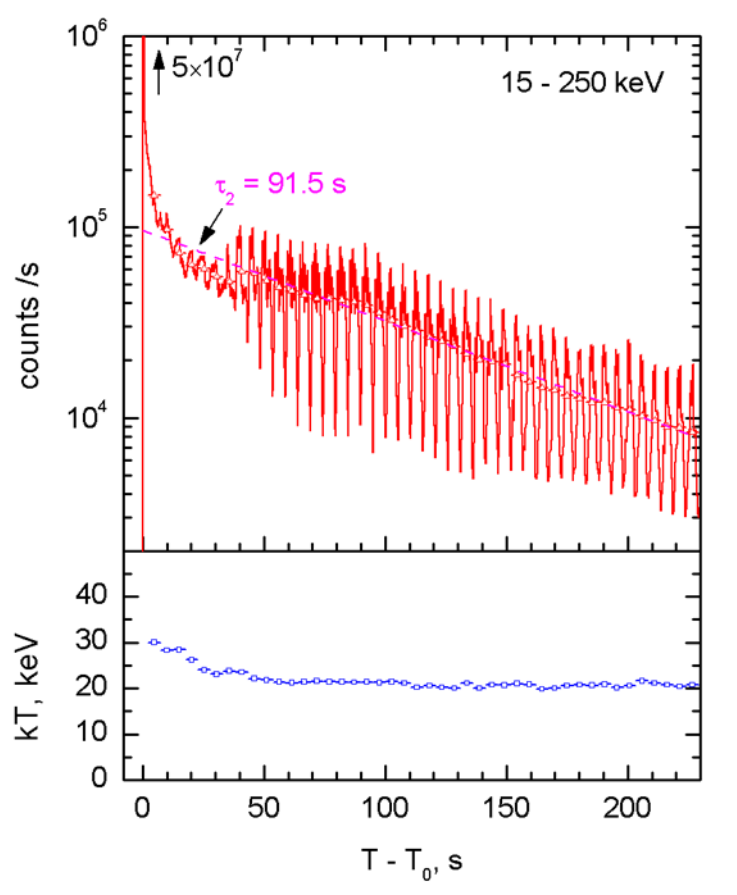
  $T > 250$ s

  $S > 5 \times 10^{-5}$ erg cm^{-2}

  $Q = 1.1 \times 10^{42}$ erg

Three months before the GF

SGR 1900+14 Giant Flare



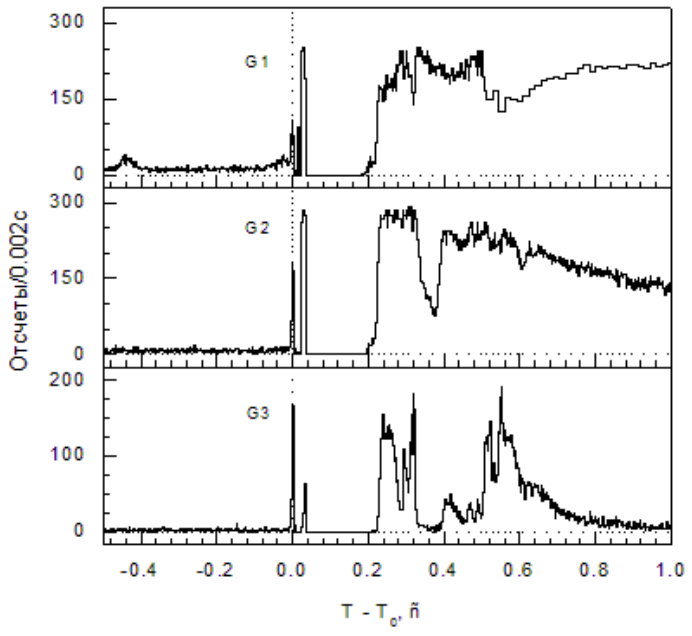
- Aug 27, 1998
  ~20 yrs after the March 5 event

Full resemblance of the SGR 0526-66 GF

- Giant, hard initial pulse
- Soft pulsating tail
  $Q \sim 1.2 \times 10^{44}\ d_{15}$erg
  (4×10^{44}) March 5

Mazets et al., 1999

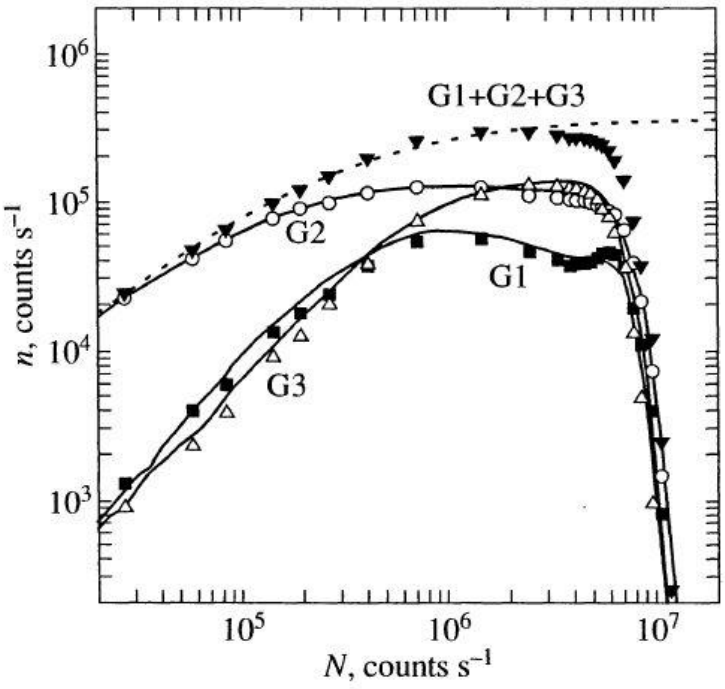
SGR 1900+14 Giant Flare – Initial pulse



- Fast rise to > 300 counts/s in <4 ms
- Full detector saturation for ~200 ms

Mazets et al., 1999

SGR 1900+14 Giant Flare – Initial pulse

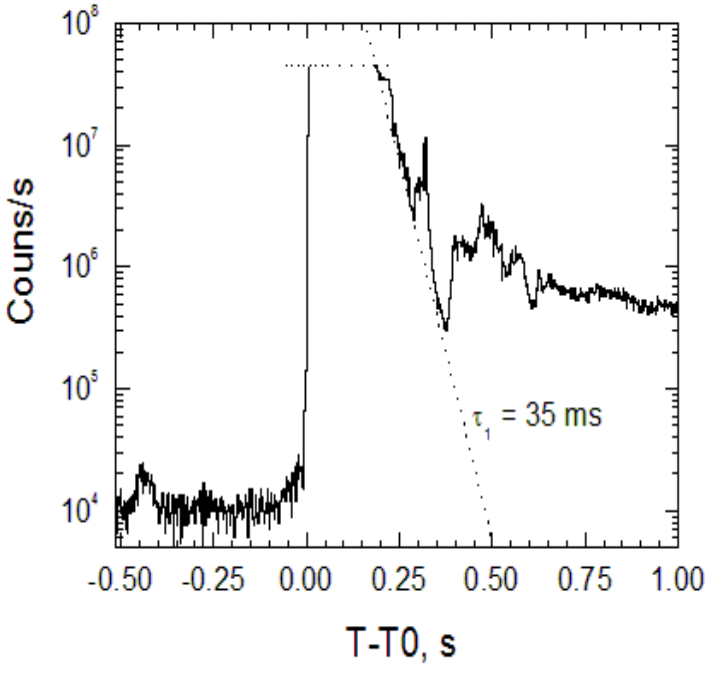


Mazets et al., 1999

- In-lab experiments with spare KW detector, testing for high loads (Am-241, Cs-137, X-ray tube)
- Software modeling and simulations of the detector analog and digital electronics behavior at high fluxes of incident photons with different energies
- Building a matrix of response of the combined (detector+electronics) system to specific photon flux and spectrum
- Reconstruction of the rising and falling slopes of the flare's initial pulse

SGR 1900+14 Giant Flare – Initial pulse

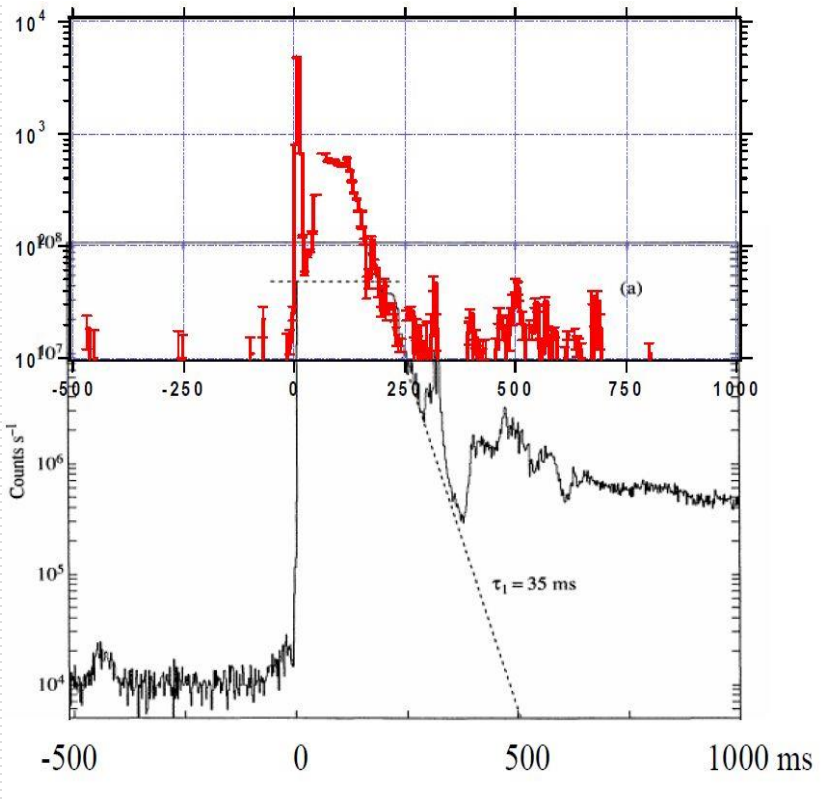
Reconstructed "base" of the initial pulse



Lower limits for the pulse energetics:

- $F_{max} > 3.1 \times 10^{-2}$ erg cm^{-2}s^{-1}
  $S > 5.5 \times 10^{-3}$ erg cm^{-2}
- $L_{max} > 2 \times 10^{46}\ d_{15}$ erg s^{-1}
  $Q > 1.5 \times 10^{44}\ d_{15}$ erg s^{-1}

SGR 1900+14 Giant Flare



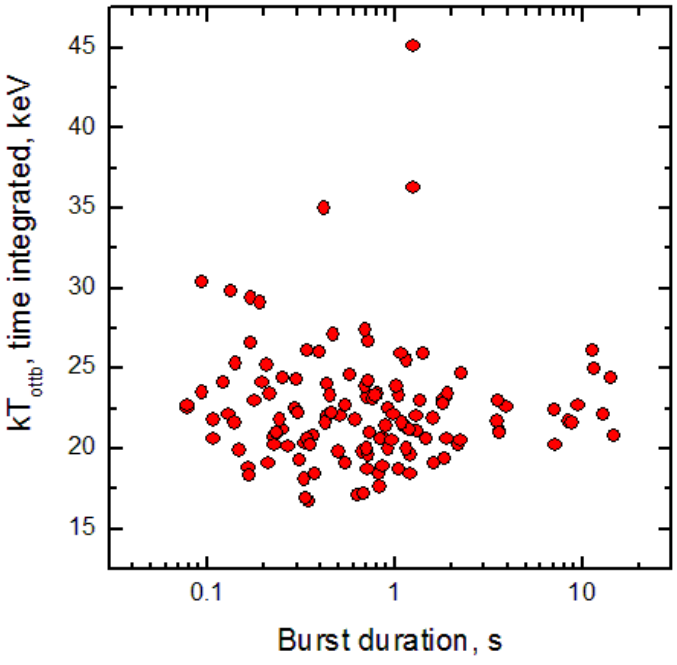
Konus-W (Mazets et al., 1999)

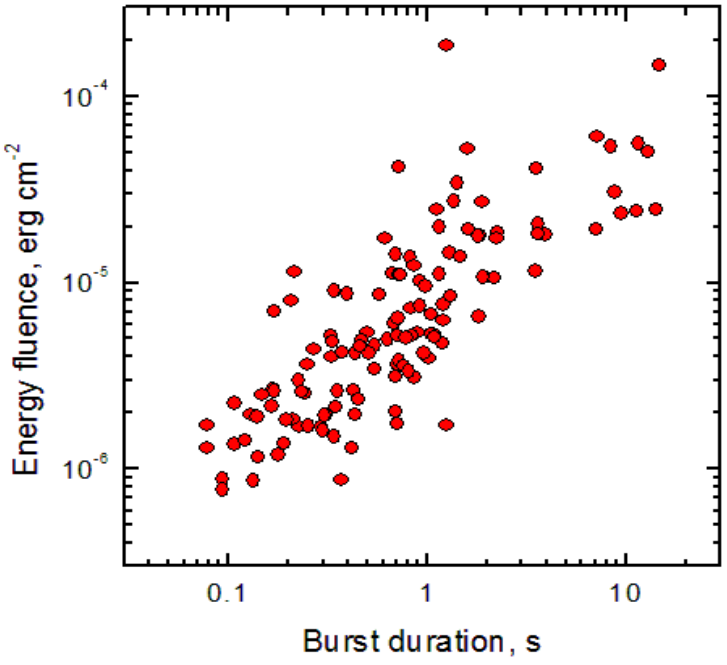
GEOTAIL-LEP (Tanaka et al., 2006, 2007)

- $L_{max} = 2.3(+2.7, -0.8)\times10^{46}\ d_{15}$ erg s^{-1}
- $Q = 4.3(+5.3,-1.5)\times10^{44}\ d_{15}$ erg s^{-1}

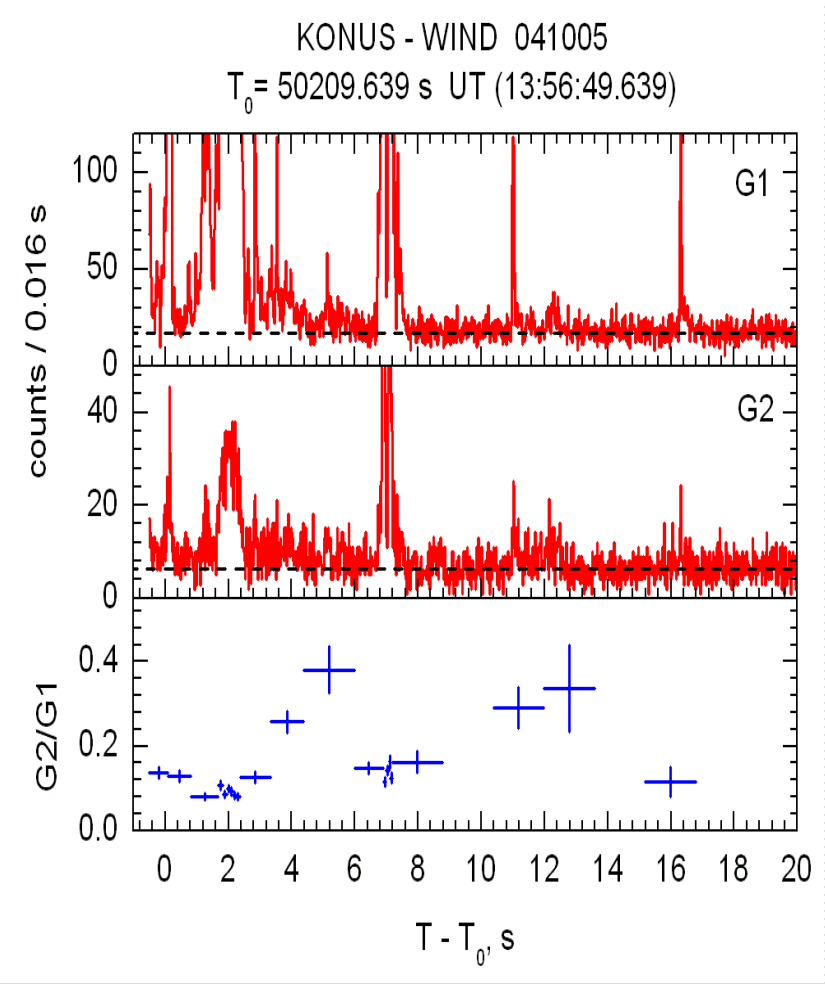
SGR 1806-20

- **1996 – 2008** (>120 short bursts)





Konus-WIND – SGR 1806-20



- Several burst clusters have been observed in 2004 (October 5, December 21 and 25)

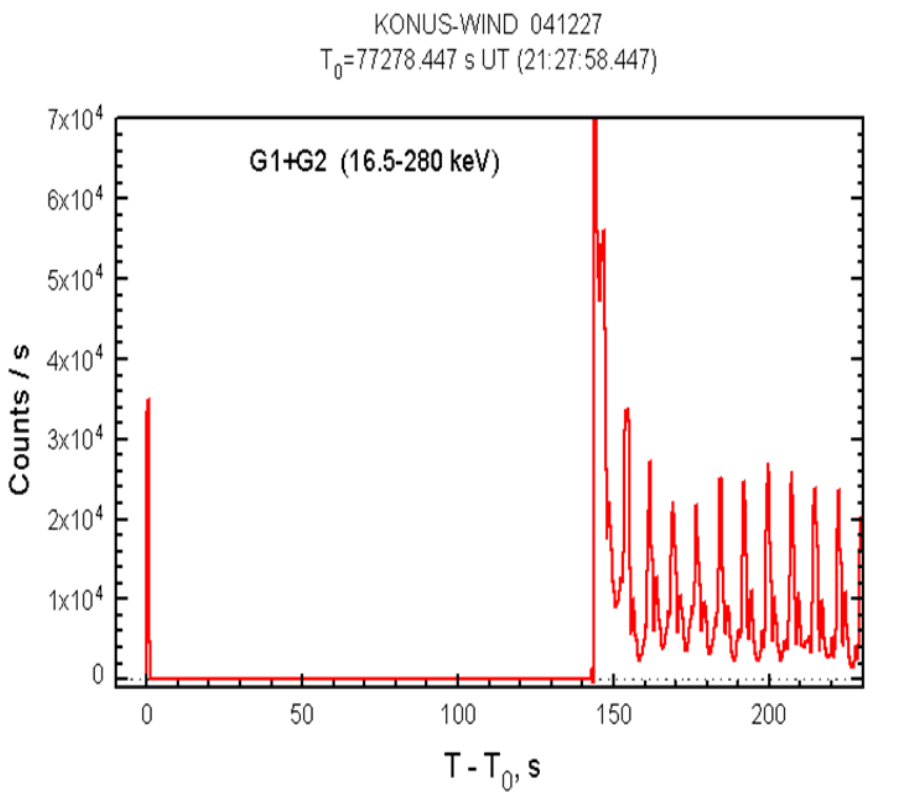
"Series" of **041005:**

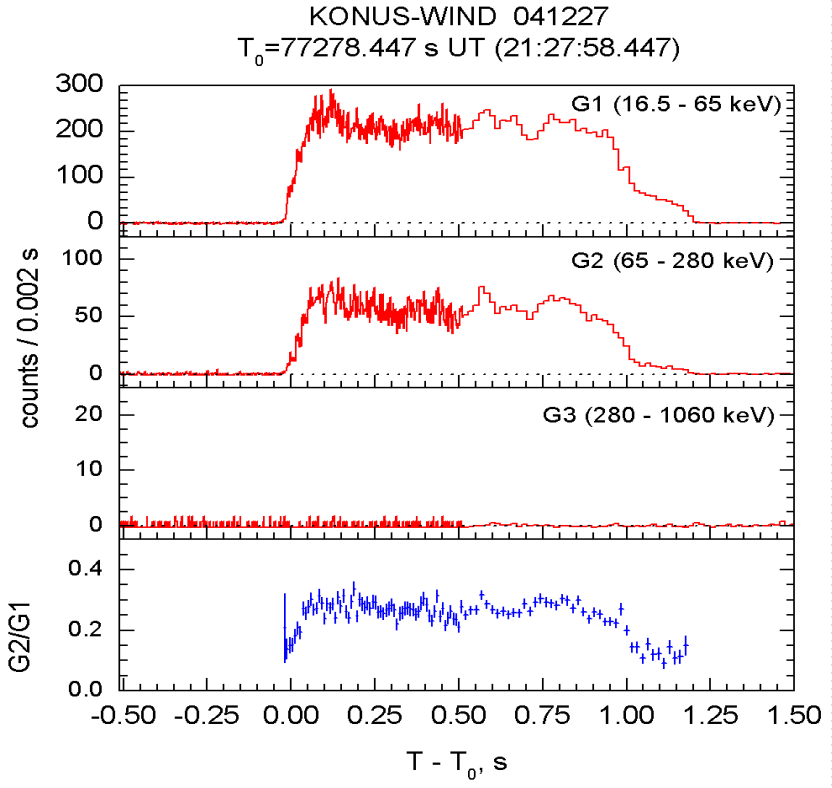
Total Fluence (>20keV)
S=7.6×10-5 erg cm^{-2}
Energy release $Q=2\times10^{42}$ erg

Peak Flux (>20keV) $F_{max}=5.6\times10^{-5}$ erg $cm^{-2}s^{-1}$
$L_{max}=1.5\times10^{42}$ erg s^{-1}

Remembering the SGR 1900+14 "series" of 980530, a giant flare of December 27 was predicted in October (!)
(Golenetskii et al., GCN #2769)

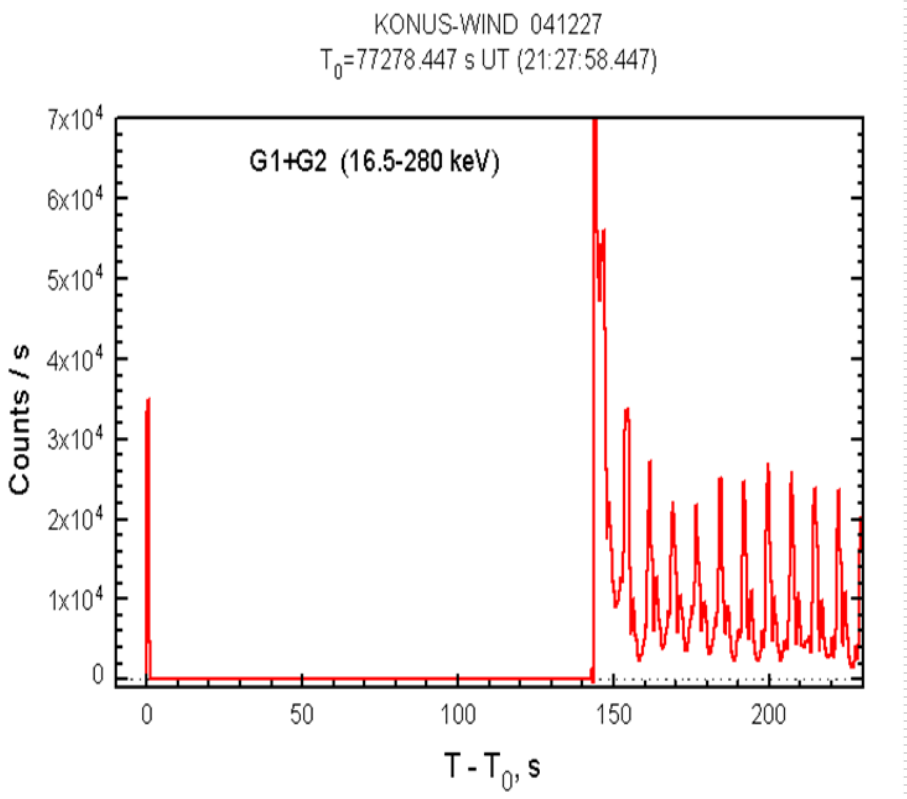
SGR 1806-20 Giant Flare (Dec 27,2004)

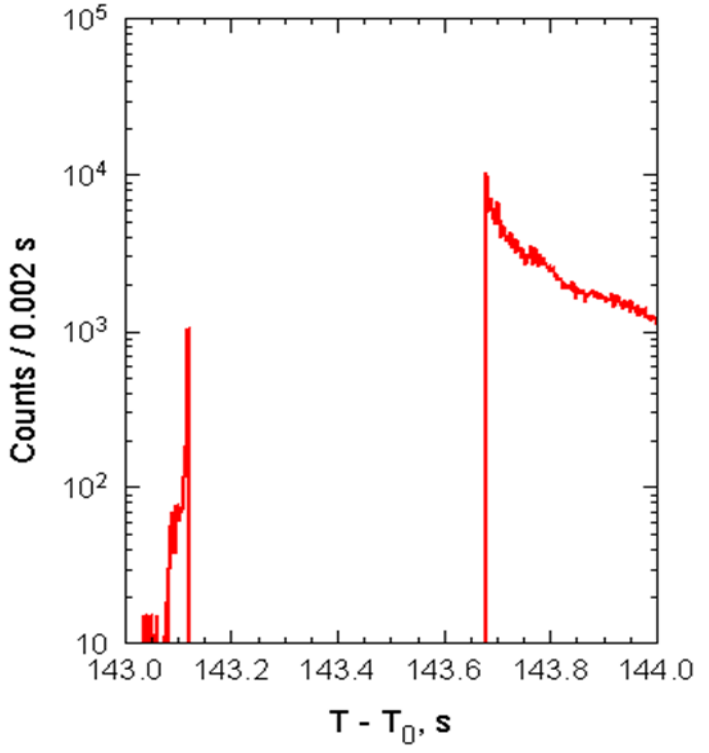




- Dec 27, 2004 Giant Flare (3rd in history and most powerful GF yet)
- Detected by 6 spacecraft
- KW triggered on bright precursor (probably the most intense short burst from the source, ($Q = 3.4 \times 10^{42}$ erg)

SGR 1806-20 Giant Flare (Dec 27,2004)

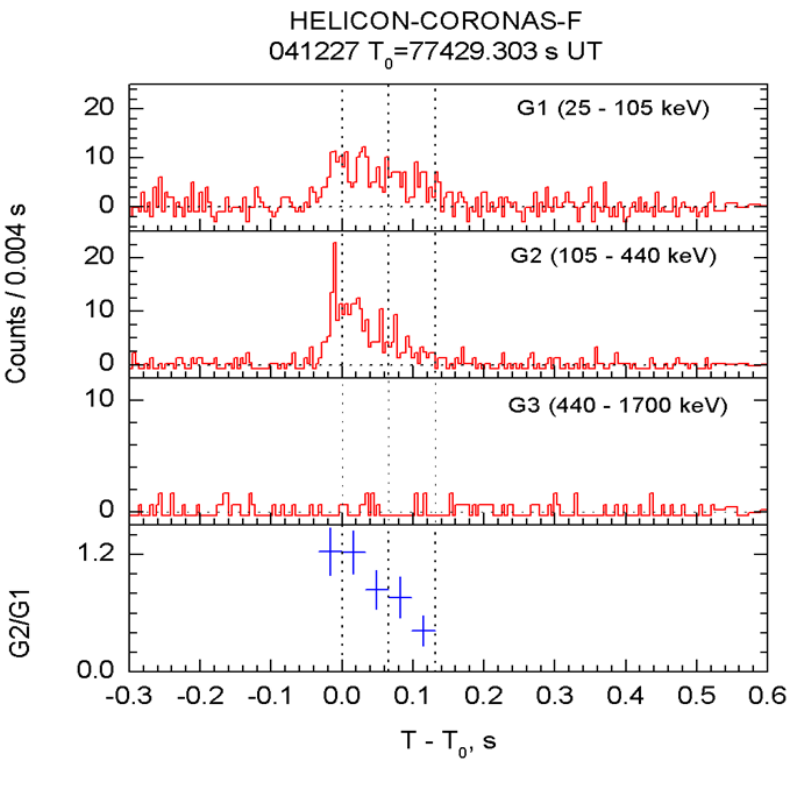


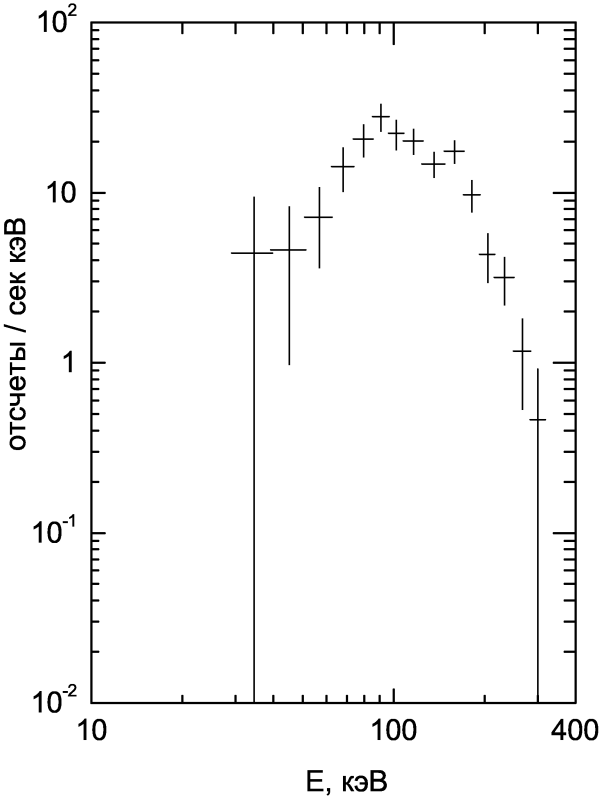


- Initial GF pulse at T0+143 s:

  full detector saturation for ~500 ms

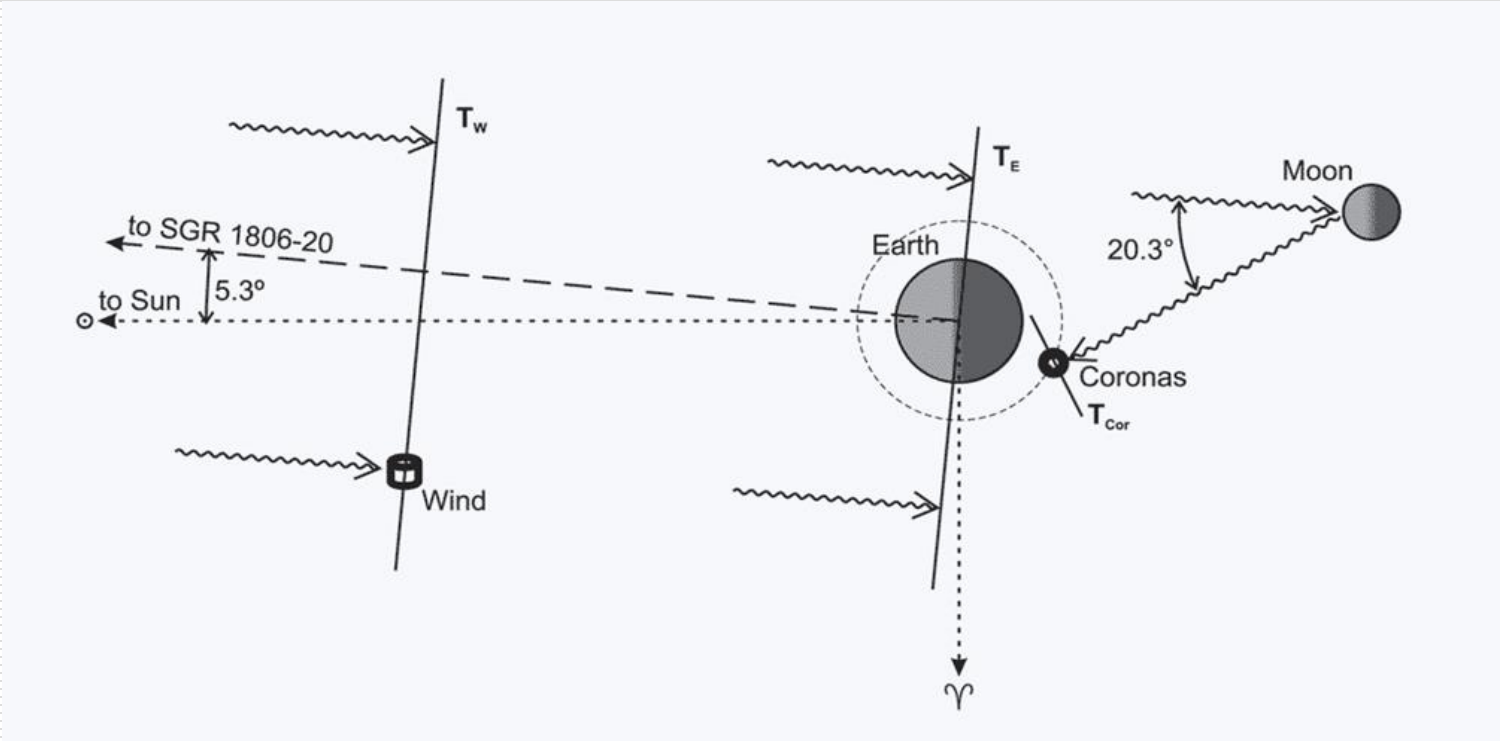
SGR 1806-20 GF reflection from the Moon and detection by Helicon (CORONAS-F)





A few seconds later an unusual short GRB triggered the Helicon instrument onboard CORONAS-F solar observatory

SGR 1806-20 GF reflection from the Moon and detection by Helicon (CORONAS-F)



The burst front propagation timing analysis confirmed this idea!

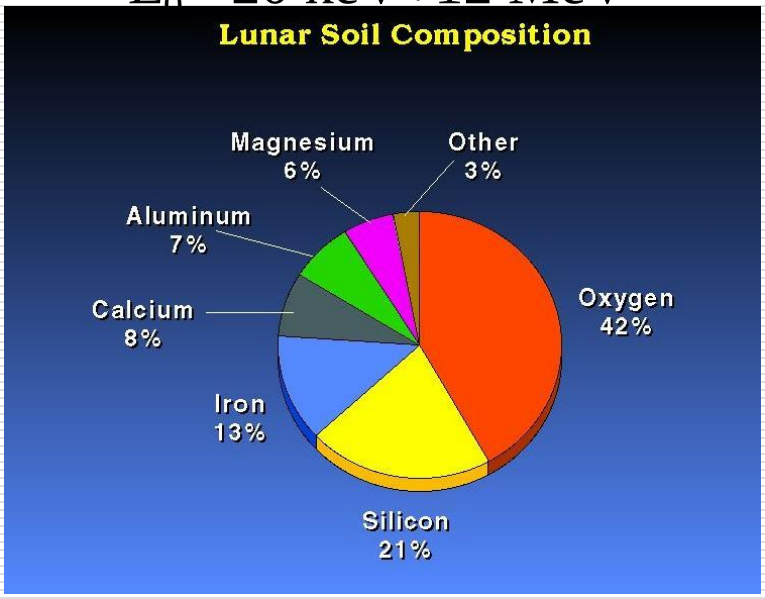
Reconstruction of the GF initial pulse

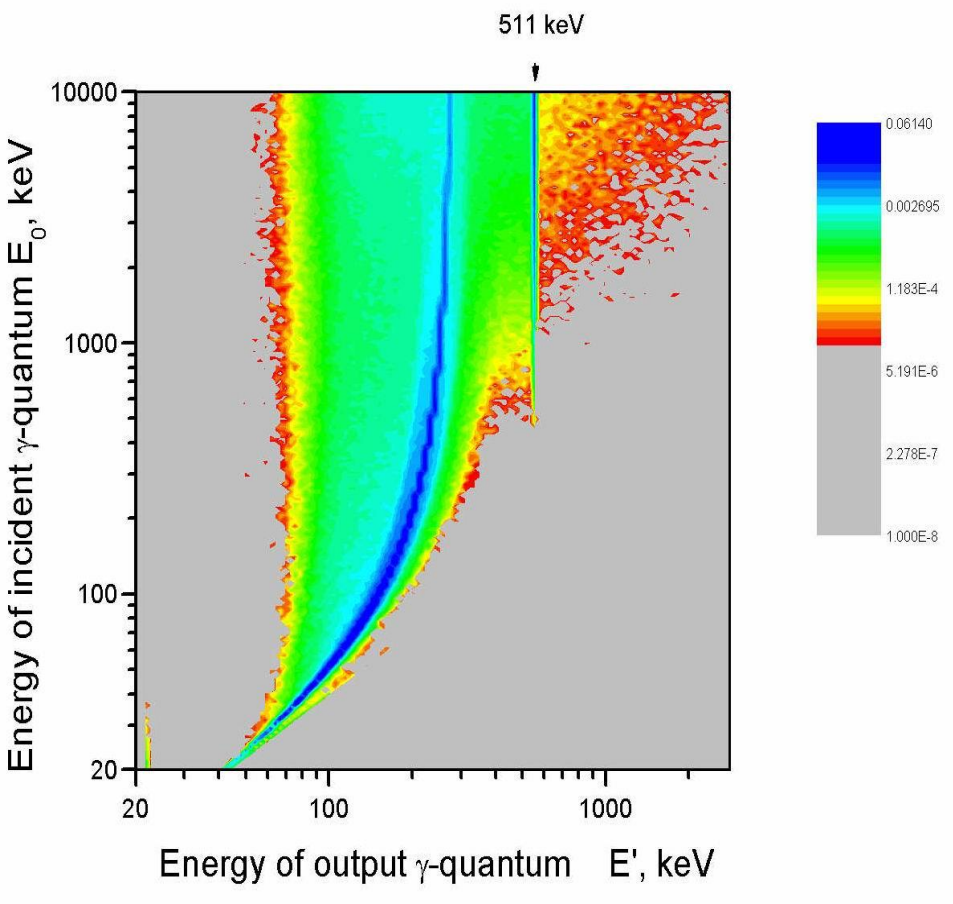
- Calculation of the lunar soil response to gamma-rays
- Folding the lunar response with Helicon DRM
- Fitting the Helicon spectrum with XSPEC
- Light curve reconstruction

Moon response matrix

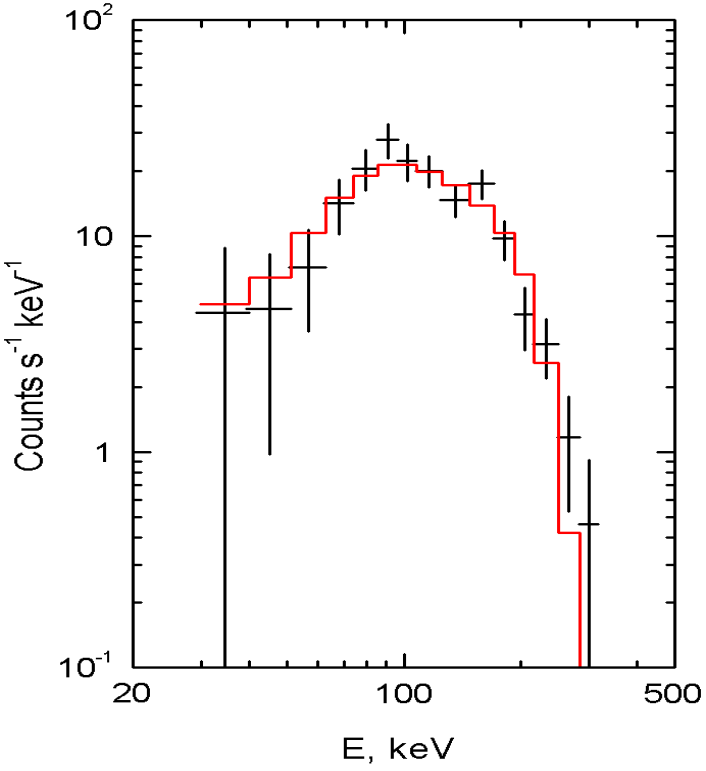
- Thick spherical target
- Escape angle θ=159°±2°
- Energy of incident γ-quanta

  E_0= 20 keV÷12 MeV





Spectral fits with (Moon x DR) Matrix



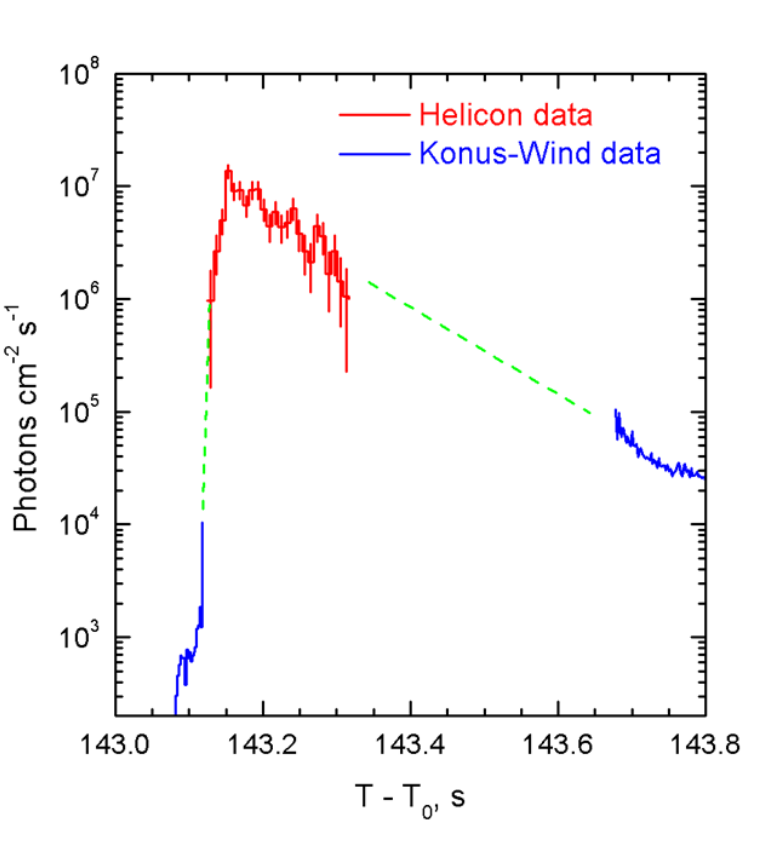
- **CPL**: χ^2 = 10.3/12 dof,
  α = -0.73(-0.47,+0.64),
  Ep = 850(-30,+1260) keV

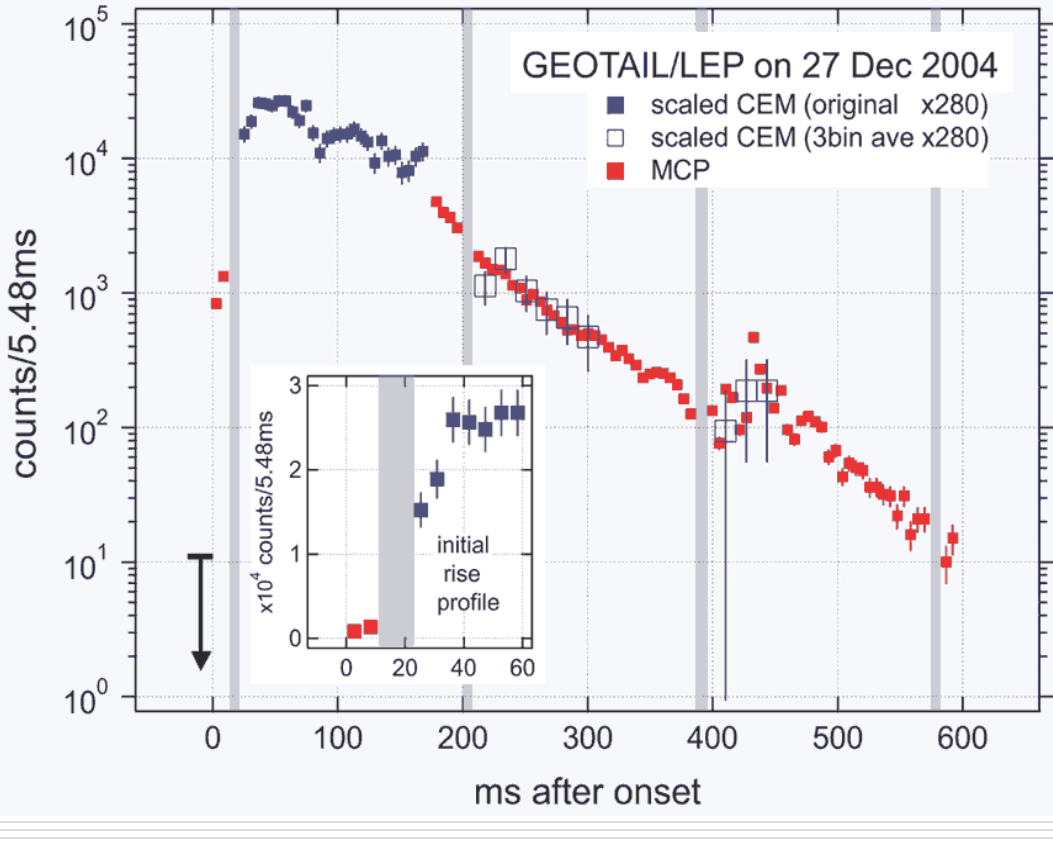
  Band: χ^2 = 10.3/11 dof
  the same α and Ep, $\beta \leq$ -1.6

- **PL**: γ = 1.4±0.1, χ^2 = 18.4/13

- **BB**: kT=116 keV, χ^2 = 27.4/13

Reconstructed light curve of the initial pulse



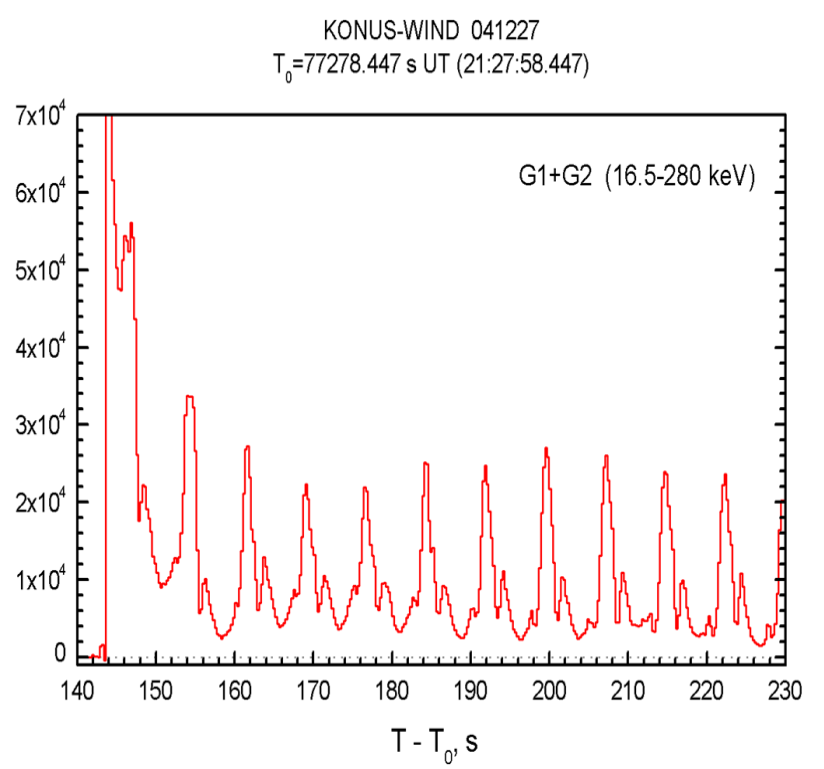


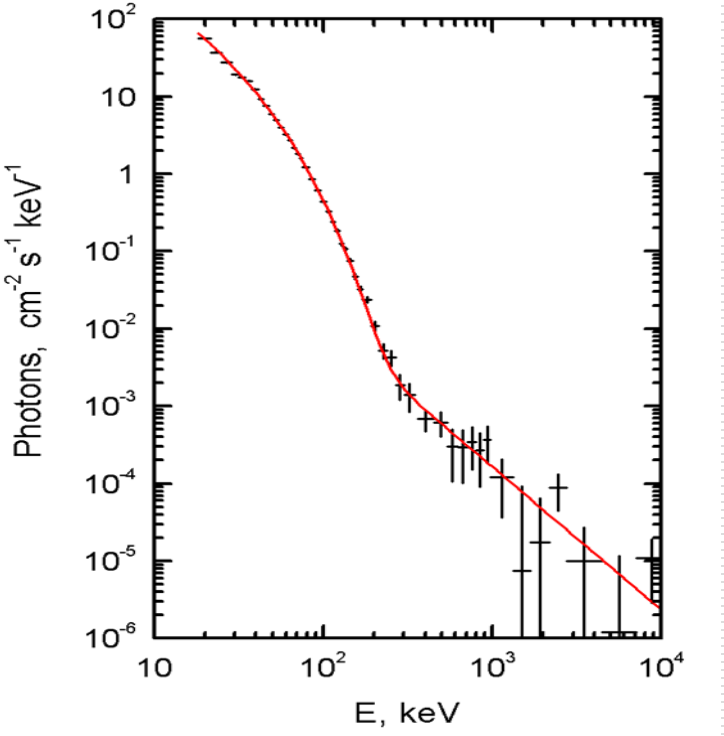
S=0.6 erg cm^{-2}, F_{max} = 9 erg cm^{-2} s^{-1}

Q = 2.3x10^{46} erg; L_{max} = 4x10^{47} erg s^{-1}

~100x SGR 1900+14 GF!

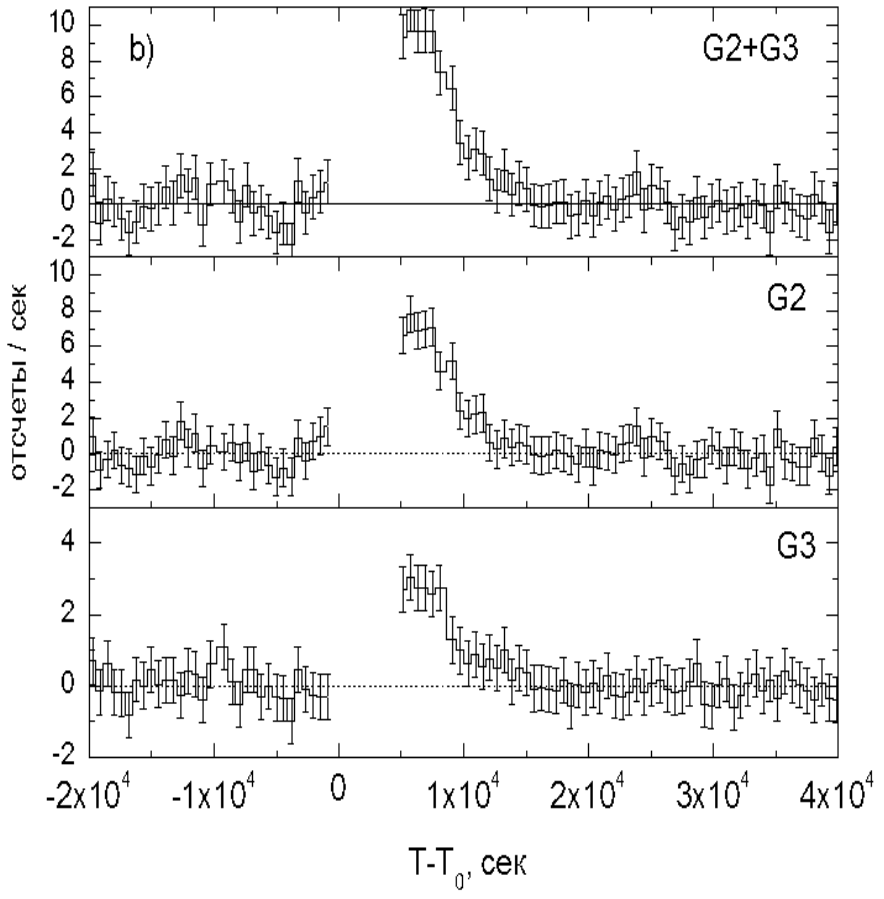
SGR 1806-20 GF tail





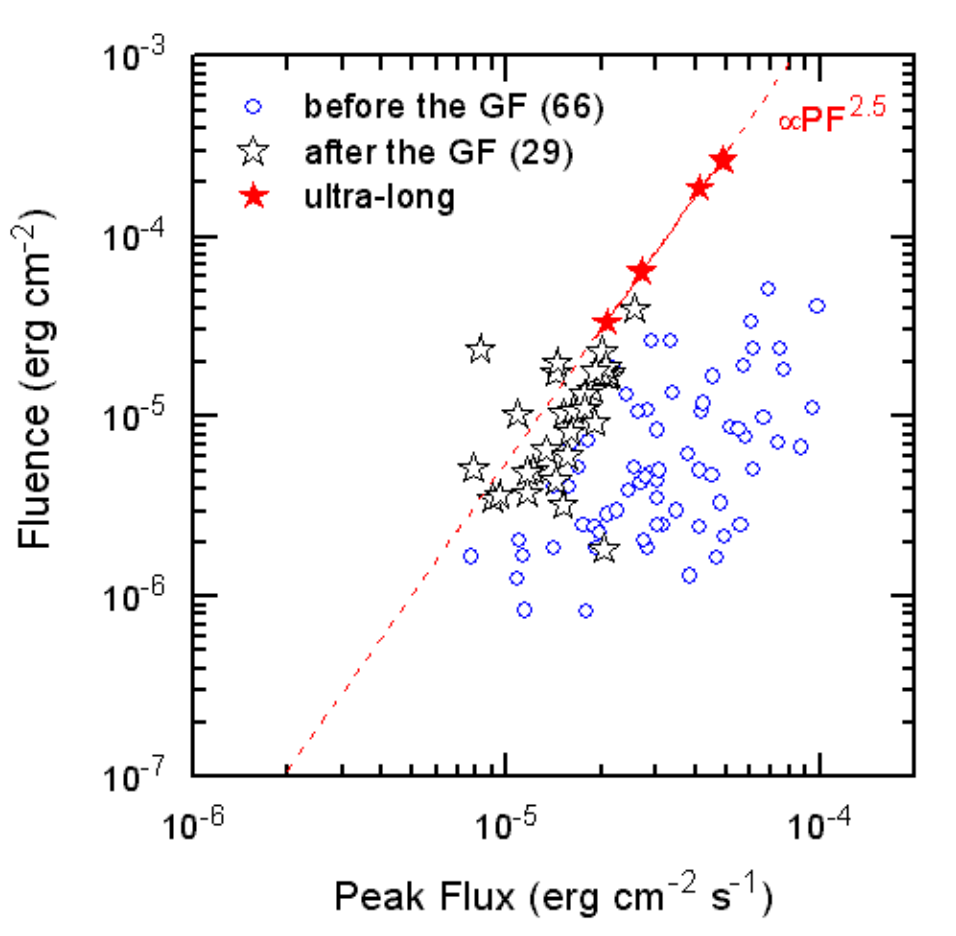
- P = 7.56 s
- OTTB (kT≈30 kev) + strong PL component (1.8 ± 0.2)
- $Q_{tail} = 2.1 \times 10^{44}$ (15 kpc)

SGR1806-20 GF afterglow (Konus-Wind)



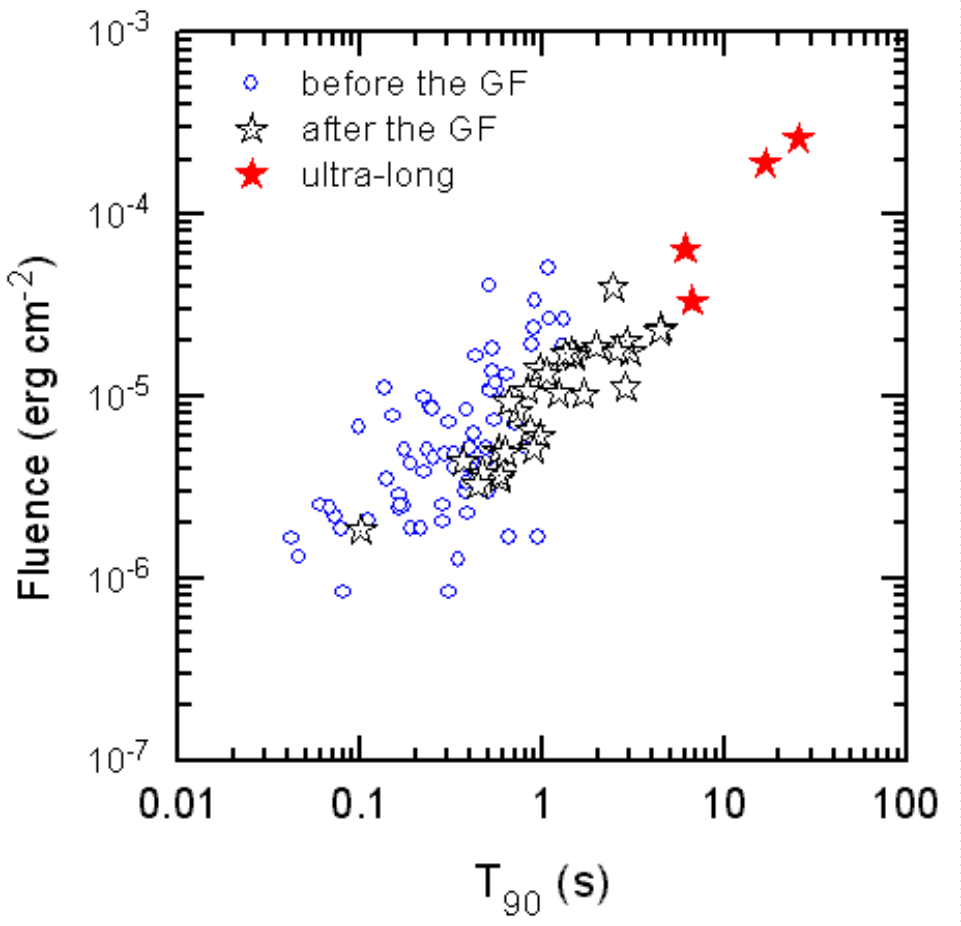
- First reported by INTEGRAL SPI-ACS (Mereghetti et al. 2005)
- Detectable until ~T0+12000 s
- PL spectrum with the photon index of ~1.6
- Fluence of the KW-observed phase ~2×10^{-4} erg cm^{-2}

SGR 1806-20 after the giant flare



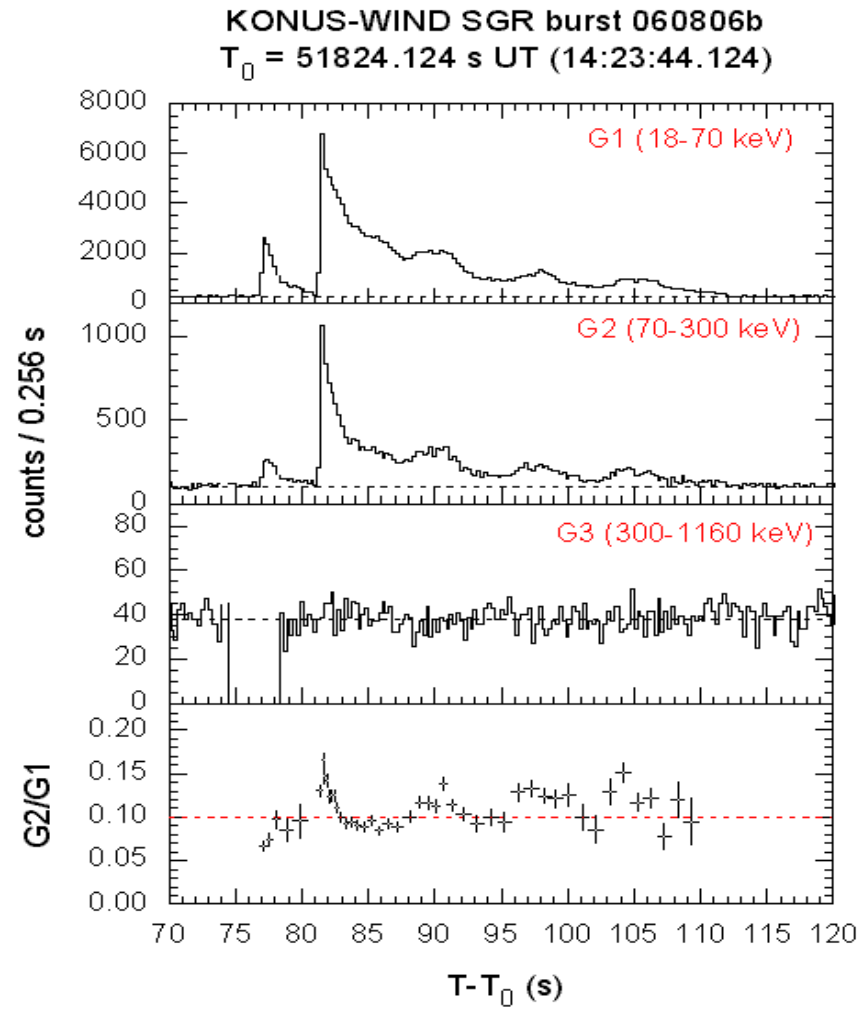
- Since Dec 27, 2004 Konus and Helicon detected ~40 bursts from SGR 1806-20
- Bursts became generally weaker (in terms of peak flux) than the bursts detected before the giant flare

SGR 1806-20 after the giant flare



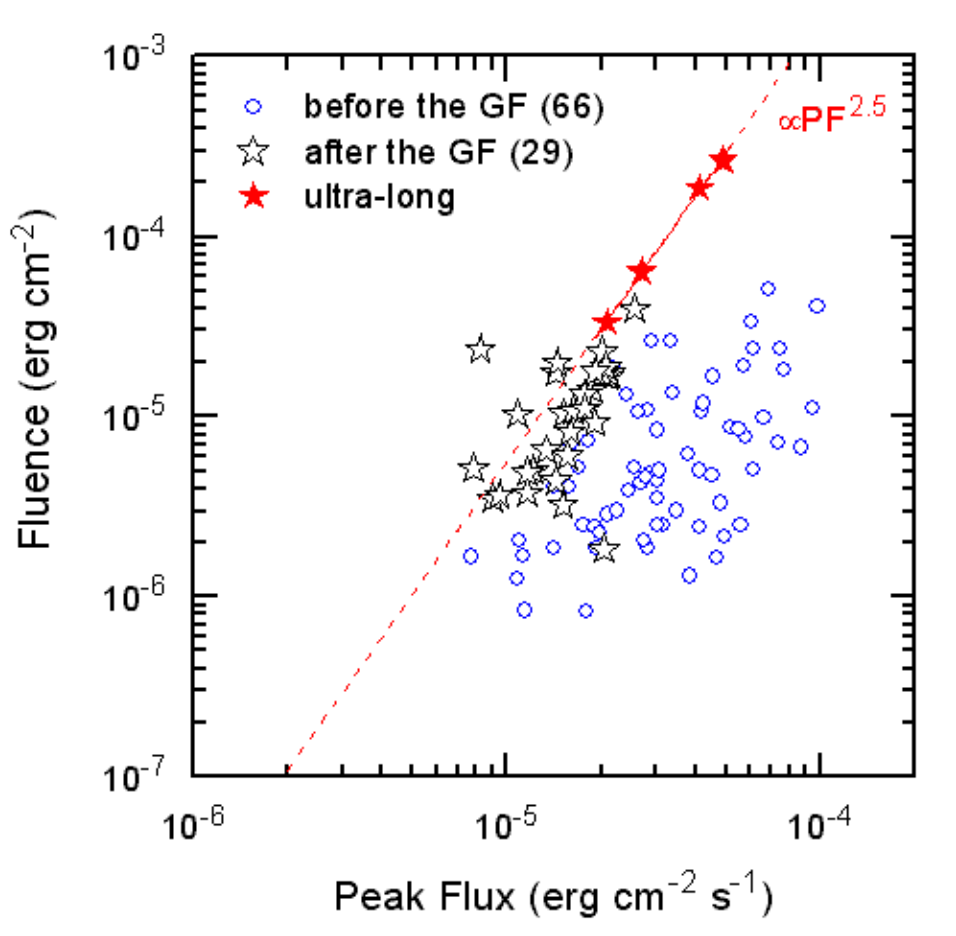
- Also, as with post-flare SGR 1900+14 bursts, some bursts are unusually long

SGR 1806-20 – “ultra-long” bursts



- Four bursts, T_{90} ~ 8-30 s (2-3 orders of mag longer than typical short bursts)
- Smooth, single-peak lc’s, Pulsating tails (like GF tails)

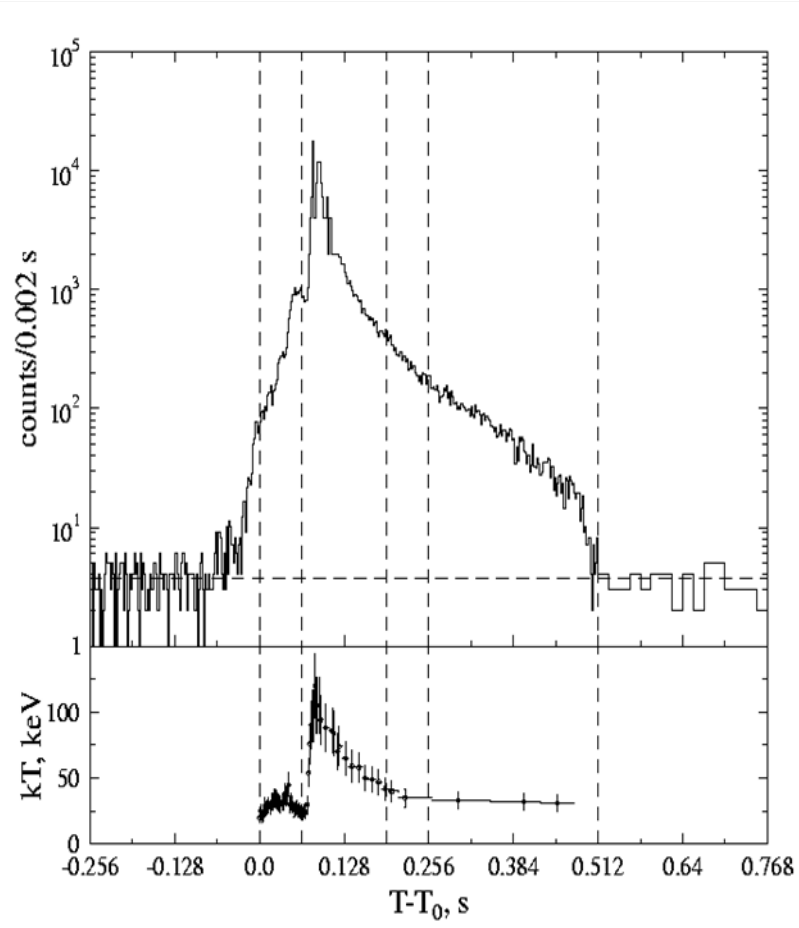
SGR 1806-20 “ultra-long” bursts



- “U-L” burst fluences:
  $0.3\text{-}2.6\times10^{-4}$ erg cm^{-2}
  $Q=0.4\text{-}3\times10^{42}$ d_{10}erg

- Prominent fluence-peak flux correlation
  $S\propto F_{max}^{2.5}$
  (Pal’shin et al., 2013)

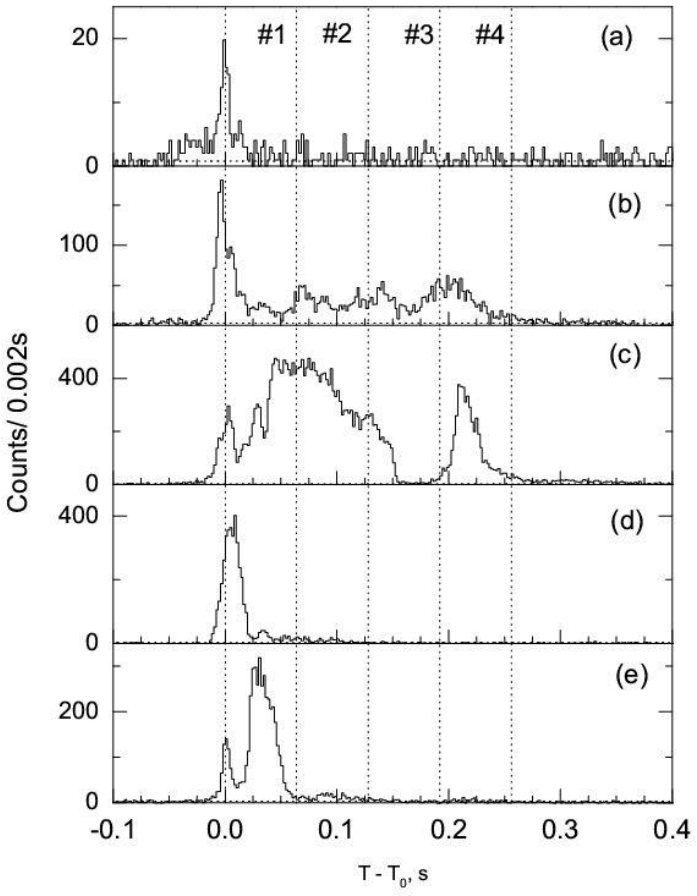
“New” SGRs- SGR 1627-41



- Discovered by CGRO and precisely localized by IPN in **1998**
  (*CGRO, Ulysses, Wind*;
  Kouveliotou et al., 1998,
  Woods et al. 1999, Hurley et al. 1999)
- **Konus-Wind**: 13 short bursts, spectral evolution
  (Mazets et al., 1999)
- **June 18, 1998 “not-so-giant” flare**
  F_{max} = 3×10^{-2} erg cm^{-2} s^{-1}
  S = 8×10^{-4} erg cm^{-2}
  kT_{OTTB} ~100 keV at peak

  Q ~ 1x10^{43} erg (10 kpc)
  approaching the GF range

“New” SGRs – SGR 0501+4516



- **SGR 0501+4516**

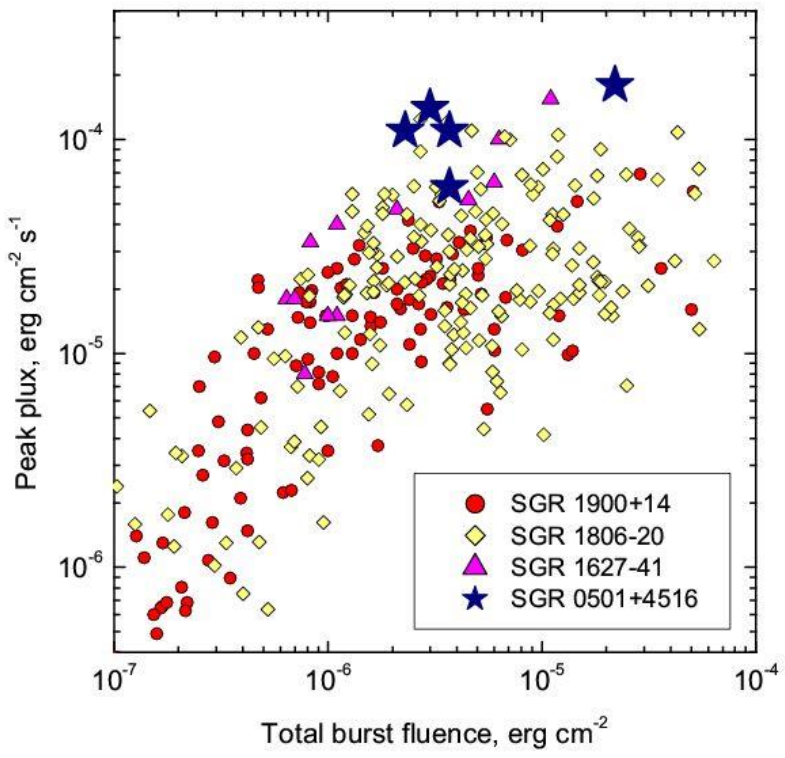
  5 short KW bursts in August, 2008 (Aptekar et al., 2009)

  Light curves and spectra are typical of known SGRs

  High peak fluxes

  (~10^{-4}erg cm^{-2} s^{-1})

SGR 0501+4516



- **SGR 0501+4516**
  5 short KW bursts in August, 2008 (Aptekar et al., 2009)

  High KW peak fluxes suggested a nearby source, in agreement with the proximity of the source direction to the young SN remnant HB09 @ 1.5 kpc (Gaensler& Chatterjee, 2008)

- $L_{max} \sim (2\text{-}5)\times10^{40}\ d_{1.5}$erg s^{-1}
- $Q \sim (0.6\text{-}6)\times10^{39}\ d_{1.5}$erg

SGR/AXP 1E1547-5508

AXP 1E1547-5408

- 21 bright short KW bursts in January-March 2009

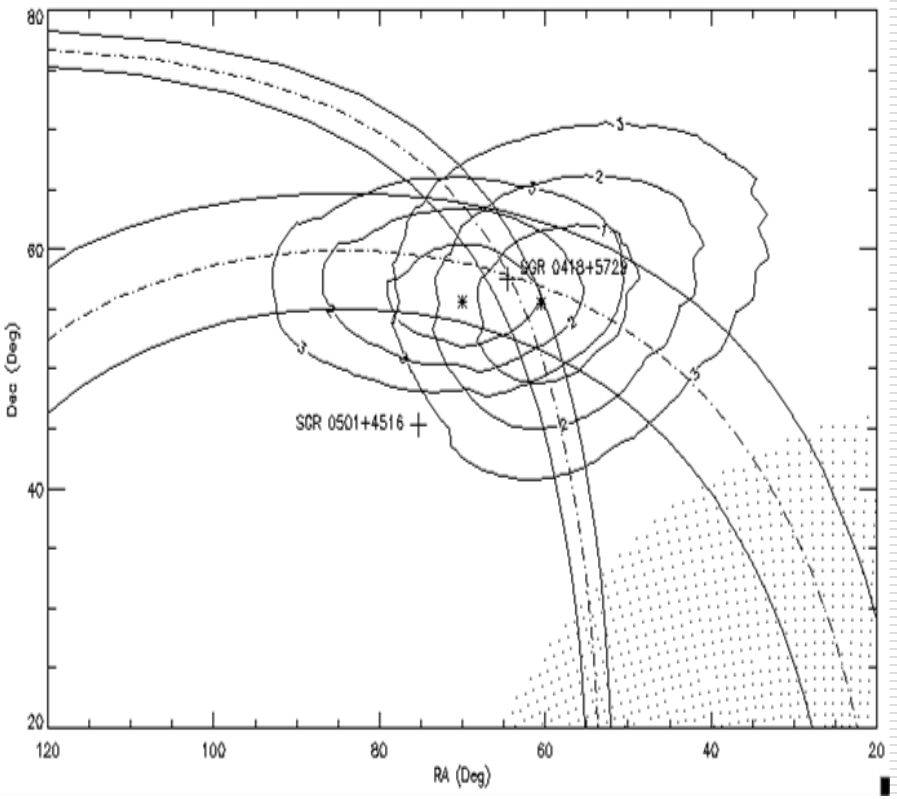
090123 burst:

S ~ 2.6×10^{-4},

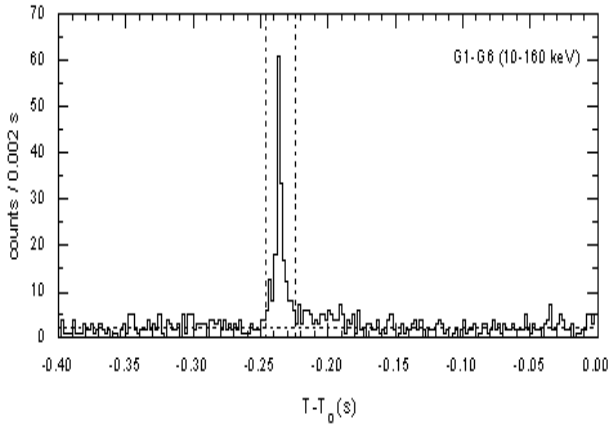
kT_{OTTB} ~ 70 keV,

resembles SGR 1627-41

SGR 0418+5729

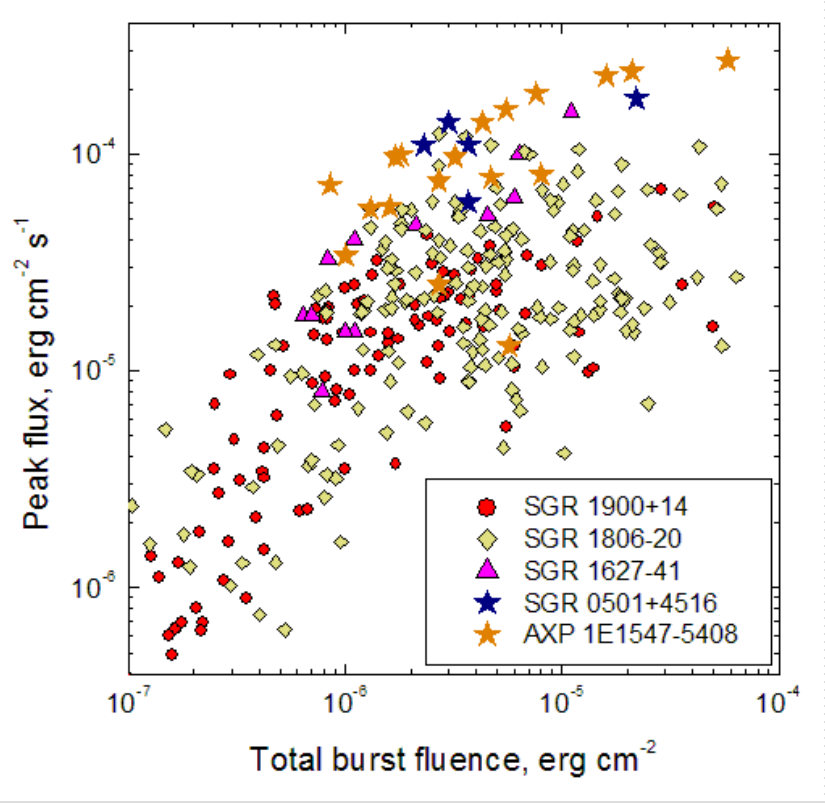


- Discoverred with Fermi-GBM, Konus-RF, and Swift-BAT; van der Horst et al. (2009)



(Golenetskii et al., 2009)

Konus SGRs Summary (1994-now)



- SGR 1900+14 - 75 bursts (KW+Hel)
- SGR 1806-20 - 150 bursts (KW+Hel+KA3)
- SGR 1627-41 - 14 bursts (KW)
- SGR 0501+4516 - 5 bursts (KW)
- AXP 1E1547-5408 - 21 burst (KW+KRF)
- SGR 1801-23 - 1 burst (KW)
- SGR 0418+5729 - 1 burst (KRF)

267 short SGR bursts

Second Konus SGR Catalog
(in preparation)

- ~175 SGR triggers since the first catalog
- **Instruments and Observations**: timeline, spacecraft, detectors
- **Data reduction procedures**: parameter definitions, temporal analysis and spectral fits, special cases
- **Tables**:
  - general burst parameters (instrument ID, trigger time, Earth-crossing time)
  - durations (T100, T90), peak count rate time
  - time-integrated and time-resolved spectral fits (OTTB, CPL, 2BB)
  - energetics (peak fluxes and total fluences)
- **Special cases** (hard bursts, “u-long” bursts, bursts clusters)
- **Statistics and correlations**
- **Online Supplements** (tables, plots, FITS light curves, spectra)