Precursors of short gamma-ray bursts in the SPI-ACS/INTEGRAL experiment

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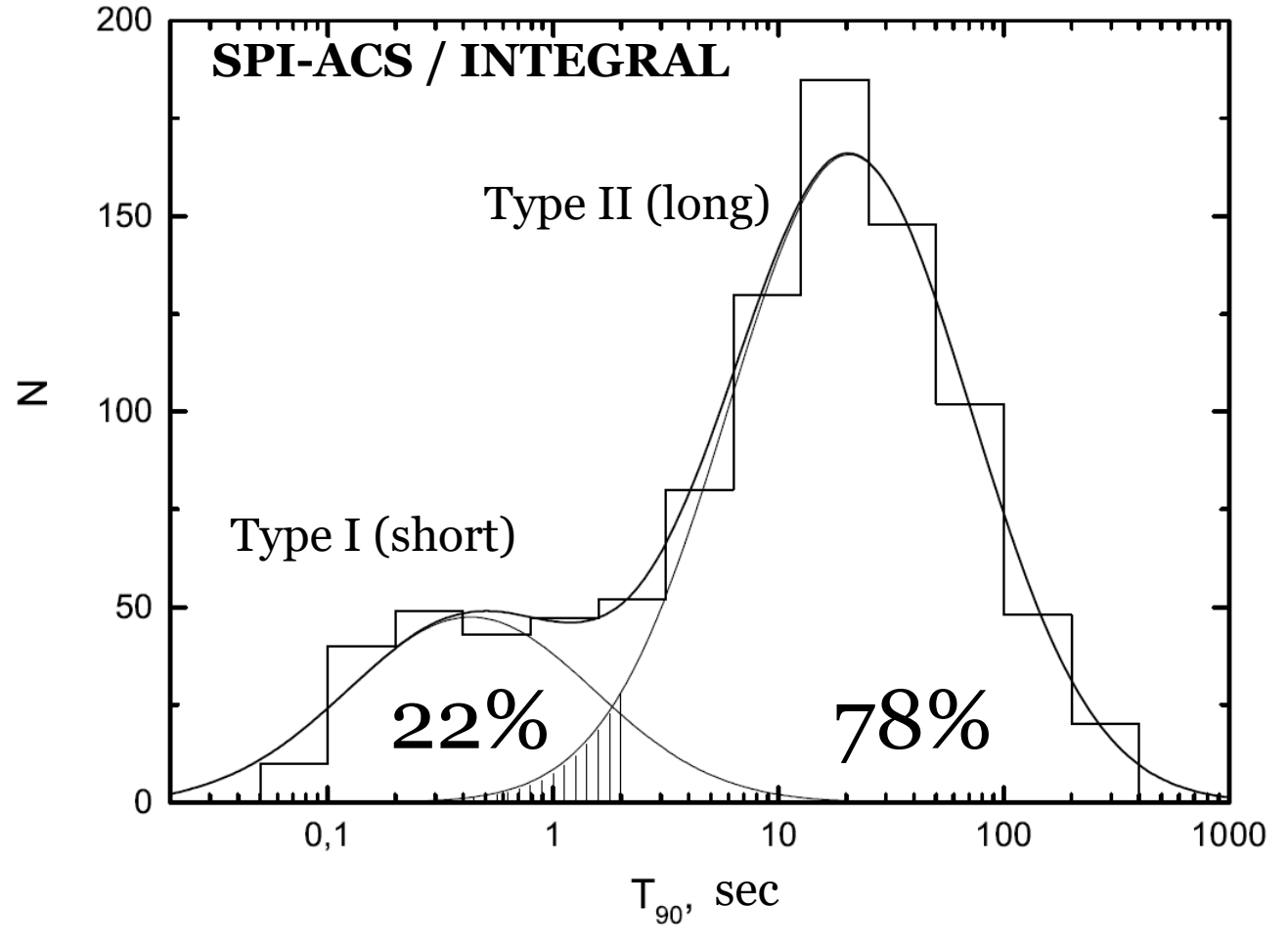
GRB classification

- Type I GRB (T90 < 2 sec) is associated with merger of compact objects in binary system (NS + NS or NS + BH) and possible kilonova

- Type II GRB (T90 > 2 sec) is associated with core collapse of very massive star and possible hypernova



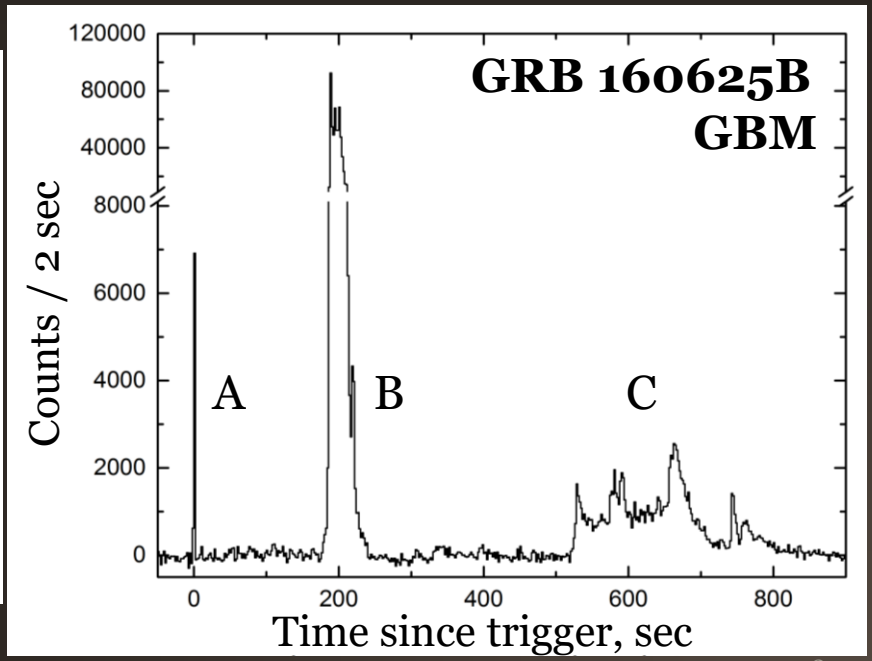
Precursors of Type II (long) GRBs

- Precursor is weaker and shorter episode of emission comparing to the main prompt phase and preceding it
- The first precursor candidate was found in X-rays in GRB 900126 light curve with soft thermal spectrum [Murakami+ 1991]
- The fraction of long GRBs with precursors varies from 3% up to 20% [Koshut+ 1995; Lazzati 2005, Charisi+ 2015]
- May be connected with jet break-out from the stellar surface [Zhang+ 2016; MacFadyen and Woosley, 1999]

TABLE I: Properties of Three Sub-bursts in GRB 160625B.

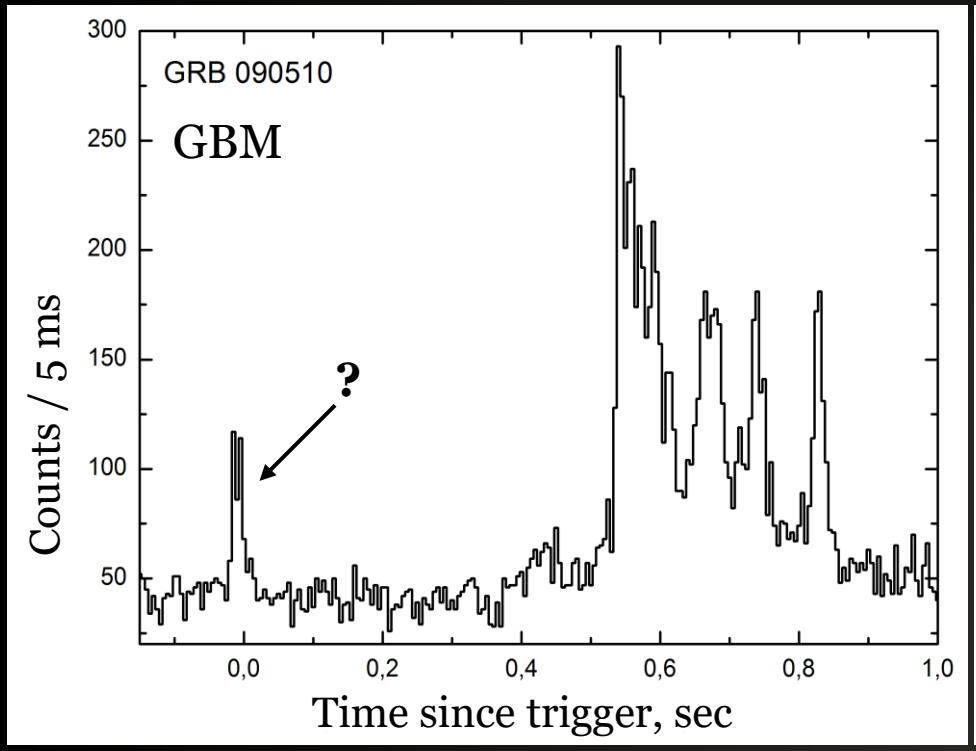
Sub-burst	A	B	C
T_{90} [s] (15 - 350 keV)	$0.84^{+0.03}_{-0.01}$	$35.10^{+0.13}_{-0.23}$	$212.22^{+0.95}_{-2.27}$
waiting time [s]	-	~ 180	~ 339
lag $(15-25:50-150keV)$	0.007 ± 0.013	0.80 ± 0.05	-0.06 ± 0.30
E_p (keV) (time-integrated)	66.8 ± 1.8	$448.8^{+4.42}_{-4.22}$	$290.5^{+95.0}_{-55.7}$
fluence (erg cm^{-2})	$1.75 \pm 0.05 \times 10^{-6}$	$6.01 \pm 0.02 \times 10^{-4}$	$5.65 \pm 0.02 \times 10^{-5}$
F_p (erg cm^{-2} s^{-1})	$2.42 \pm 0.11 \times 10^{-6}$	$7.31 \pm 0.13 \times 10^{-5}$	$5.80 \pm 0.13 \times 10^{-7}$
$E_{\rm iso}$ (erg)	$8.86 \pm 0.24 \times 10^{51}$	$3.05 \pm 0.01 \times 10^{54}$	$2.87 \pm 0.01 \times 10^{53}$
$L_{\rm p,iso}$ (erg s^{-1})	$1.23 \pm 0.05 \times 10^{52}$	$3.71 \pm 0.06 \times 10^{53}$	$2.94 \pm 0.07 \times 10^{51}$
z	1.406±0.001		
Most energetic LAT photons	15.3 GeV (346.2 s); 6.95 GeV (793 s); 5.4 GeV (573 s)		

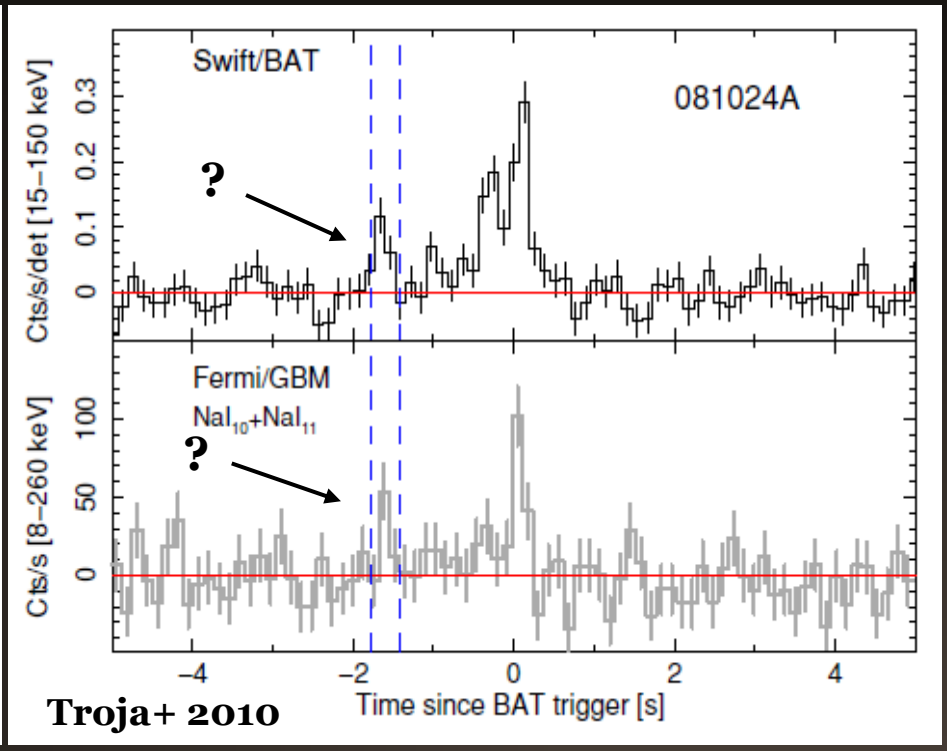
Zhang+ 2016 arXiv:1612.03089



Precursors of Type I (short) GRBs

- Were found in 10% of short BAT/Swift bursts [Troja+ 2010]
- May be connected with the interaction of two neutron star magnetospheres prior to a double neutron star merger [Hansen+ 2001]





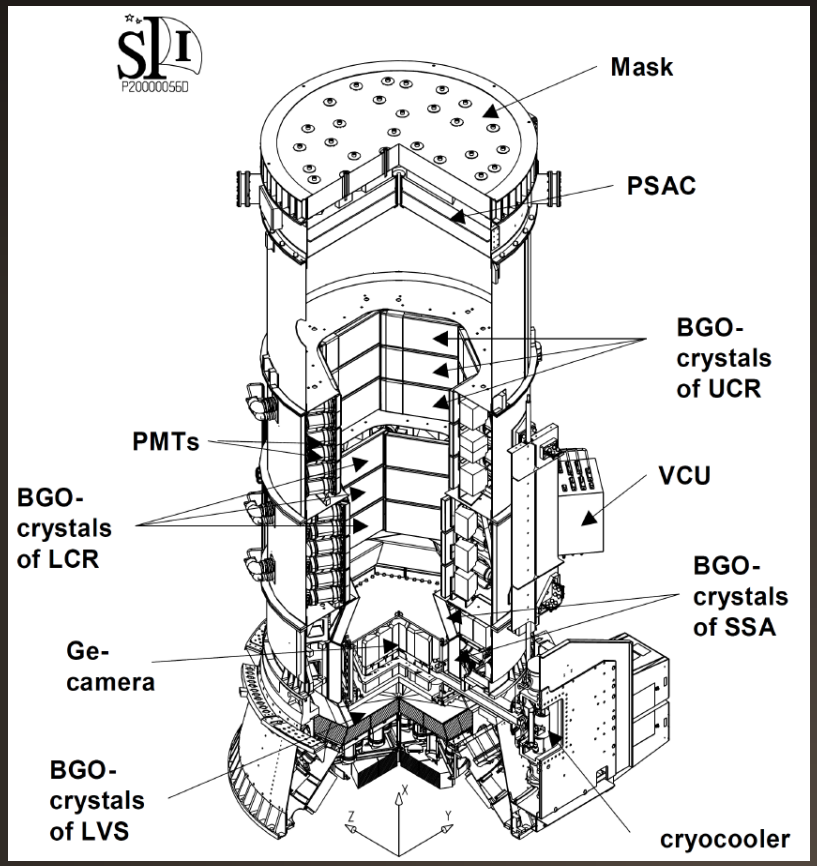
Are they real?

Definition of precursor should be more restrictive...

SPI-ACS / INTEGRAL experiment

[Anti-Coincidence Shield of the SPI spectrometer]

- Consists of 91 BGO crystals with total geometric area of 5250 cm²
- Omnidirectional
- Single energy channel [80, 10000] keV
- 50 ms time resolution
- Stable background at ~ 1000 sec time scales



Our Type I GRB sample and data analysis

- Our total sample consists of 519 bursts with T90 < 2 sec, registered by SPI-ACS/INTEGRAL in 2002-2014 and confirmed by other experiments

- **Data analysis:**

- Background modeling in [-150; -50] and [+100; +200] sec time intervals

- Searching for precursor candidates with S/N > 6σ at time scales 0.1 sec and 5 sec in time intervals [-5; -2] sec and [-50; -2] sec, correspondingly

- Detailed analysis of precursor candidates (their duration, hardness ratio, variability, energetic spectrum, spectral lag, position at Amati diagram) in data of various experiments

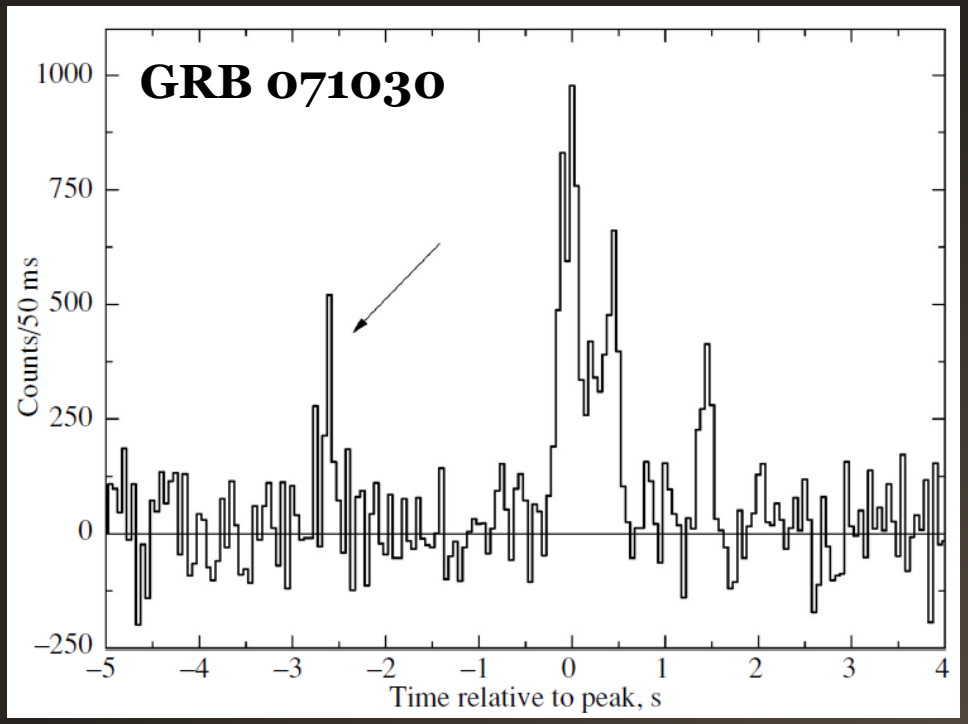
- Searching for regular precursor in averaged light curve of 372 brightest bursts of our sample at time scales from 0.1 sec to 48 sec in time interval [-50; -2] sec

Precursor candidates, GRB 071030

Table 1. Precursor candidates for short GRBs of the SPI–ACS/INTEGRAL experiment

GRB	Start time of main phase, UTC	Time relative to main phase, s	Significance of precursor, σ	Off-axis[1], deg	Detection by other spacecraft[2]
071030	08:52:43.75	2.5	6.3	–	Suz [7], Kon [8]
090510 [3]	00:22:59.8	0.45	4.3	140.8 [4]	Fer [9], Swi [10], Kon [11], Agi [12], Mes [13], Suz [14]
100717	08:55:05.85	3.3	12.8	40.6 [5]	Fer [13], Swi [13], Mes [13], Agi [13]
130310	20:09:40.9	4.55	10.0	59.8 [6]	Fer [15], Kon [16], Mes [17], Suz [17], Hend [17]

- Precursor candidate was not confirmed by other experiments
- Light curve of main phase consists of several pulses with comparable properties (duration, peak flux, fluence)



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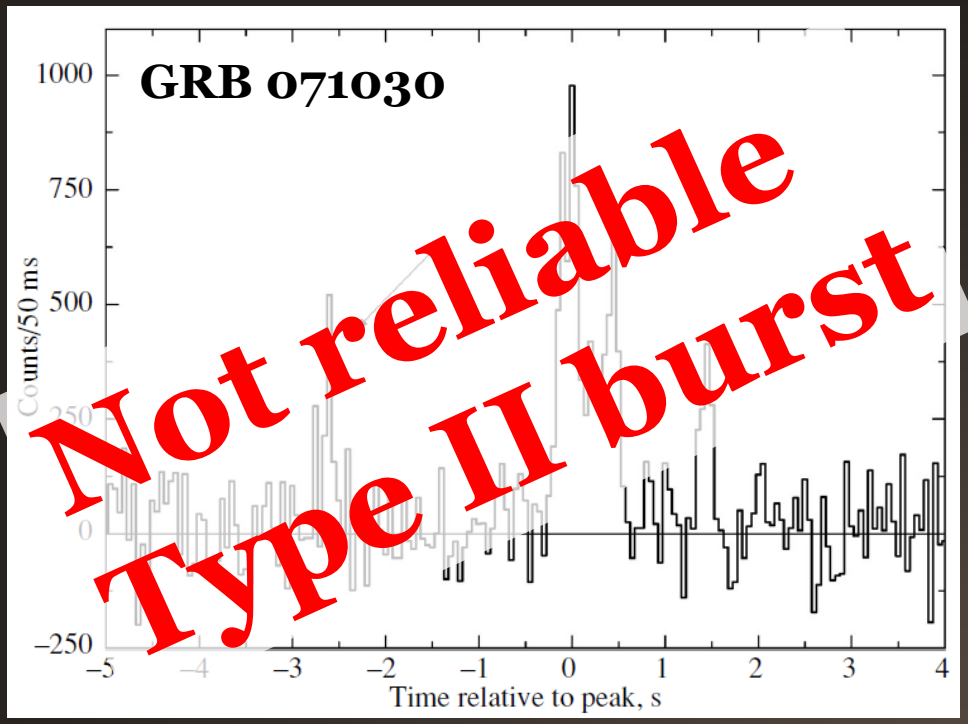
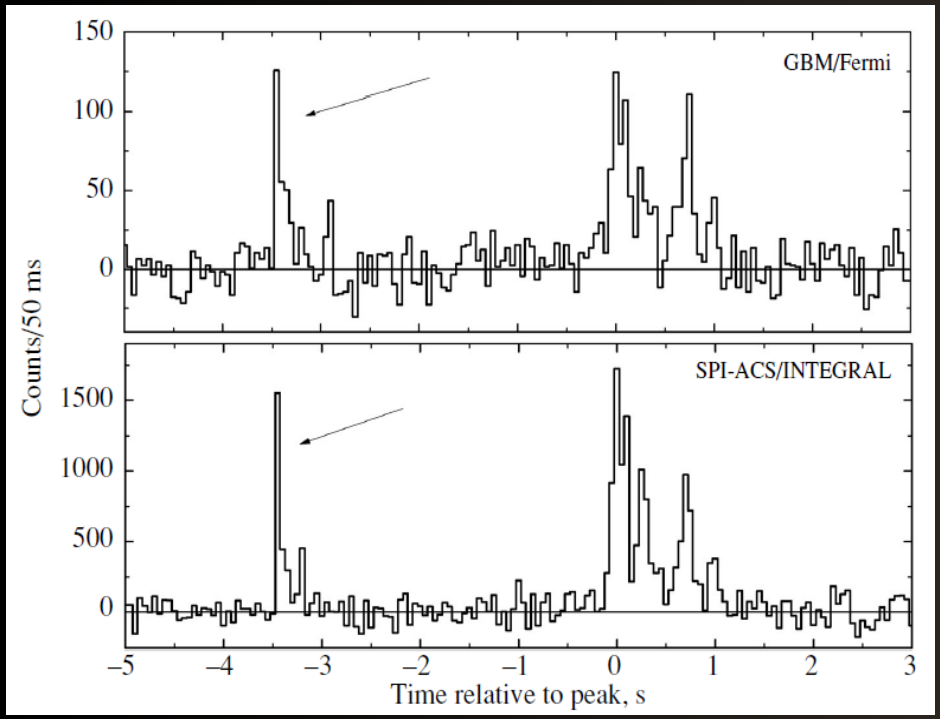
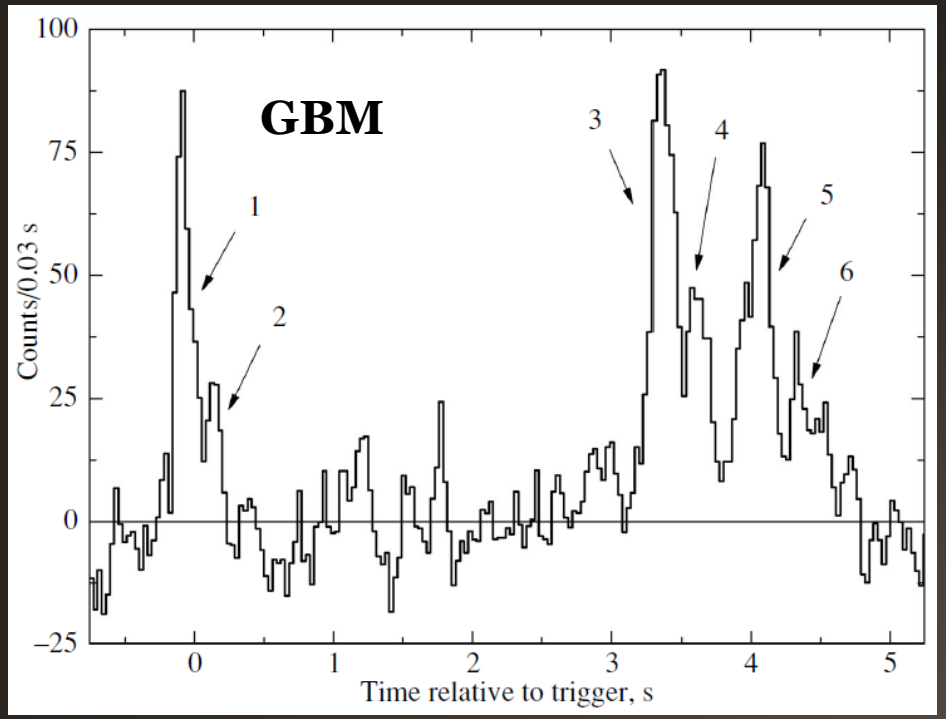


Precursor candidates – GRB 100717

- Also found in GBM/Fermi data
- Light curve of both precursor candidate and main phase consists of several pulses with comparable properties (duration, peak flux, fluence, hardness ratio)
- Energetic spectrum of precursor candidate (Ep = 0.7 ± 0.5 MeV) is comparable with one of the main phase (Ep = 1.2 ± 0.7 MeV).





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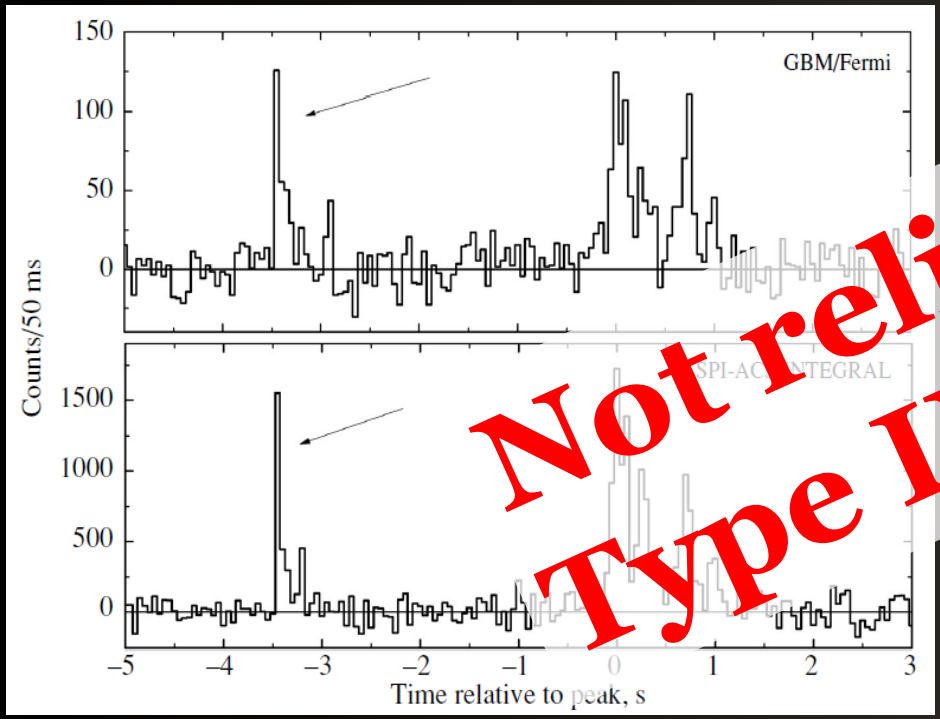
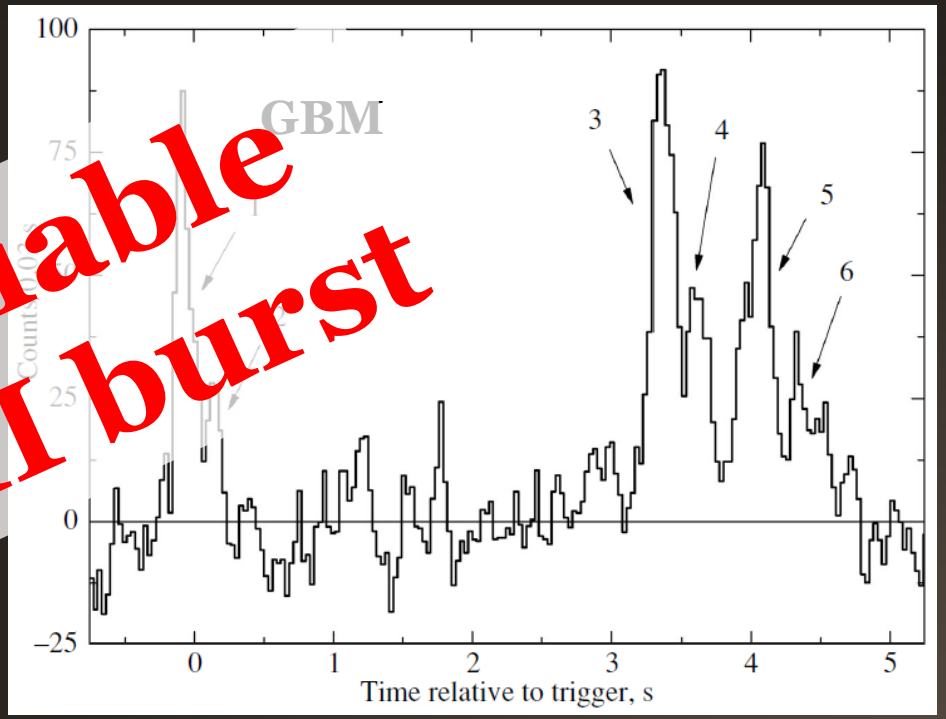
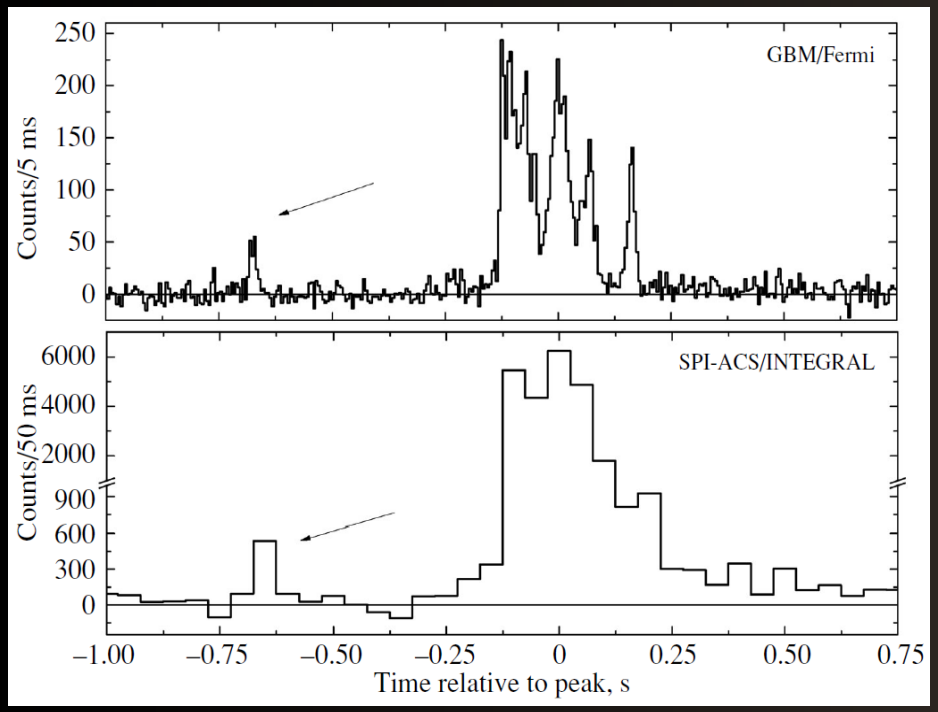


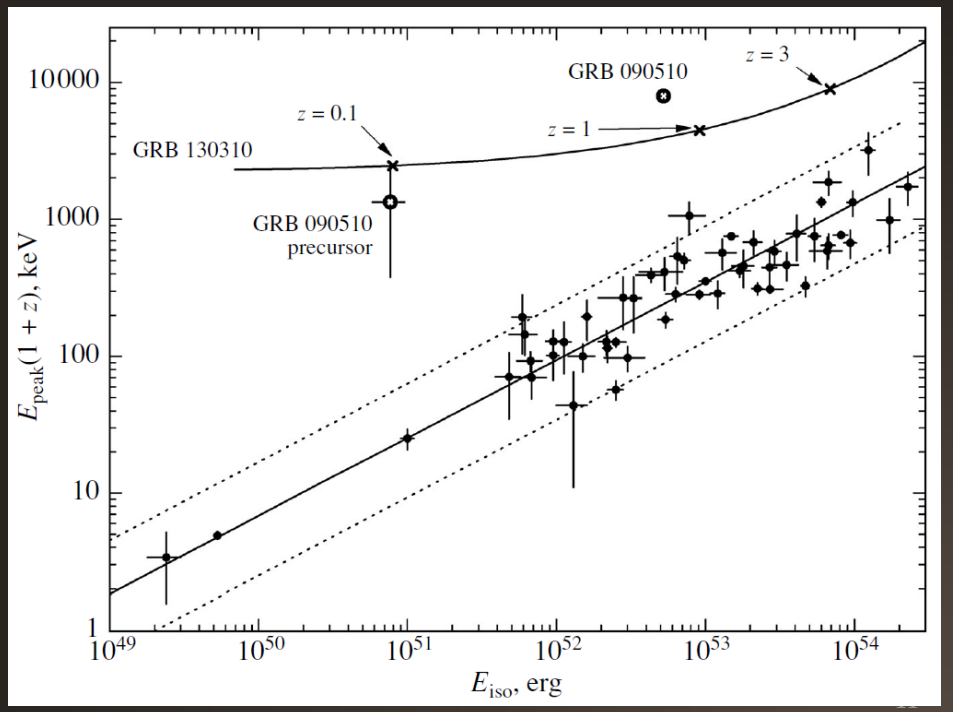


Not reliable
Type II burst

GRB 090510 - candidate from [Troja+ 2010]

- Precursor was found in BAT/Swift, GBM/Fermi [Troja+ 2010] and also in SPI-ACS/INTEGRAL
- T90, peak flux, fluence, hardness ratio are comparable with the ones of the last pulse from main phase
- The energetic spectrum of the precursor candidate is typical for regular short bursts (Ep = 0.7 ± 0.4 MeV)
- On Amati diagram precursor candidate and main phase are above main correlation region





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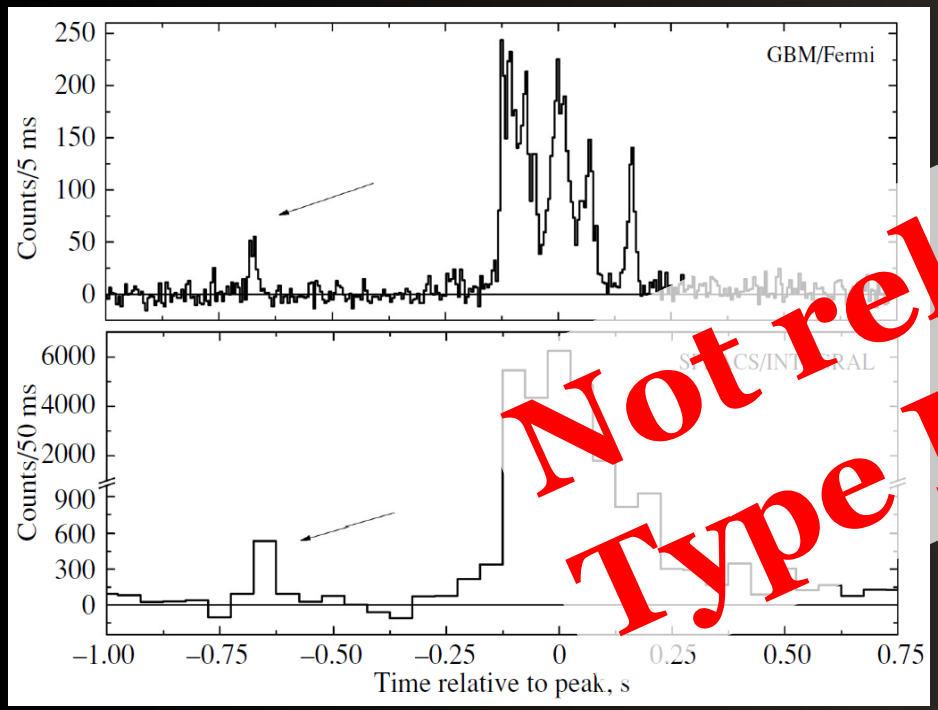
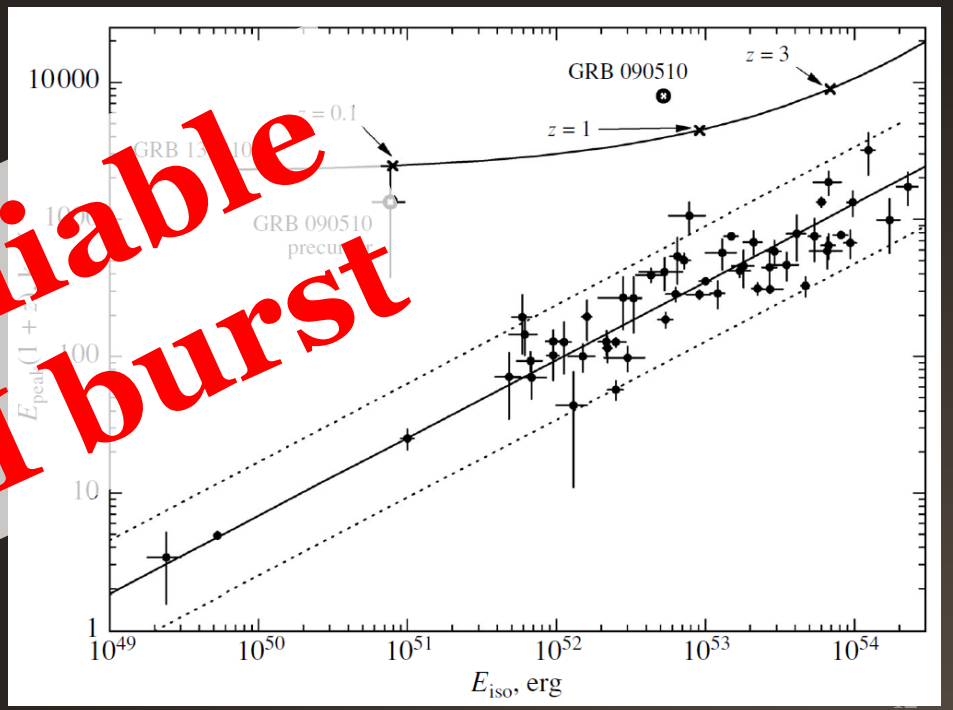
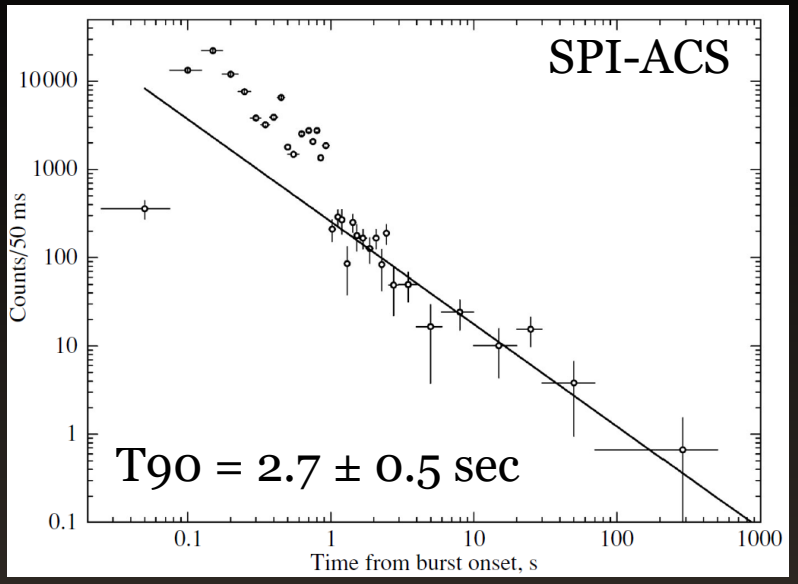


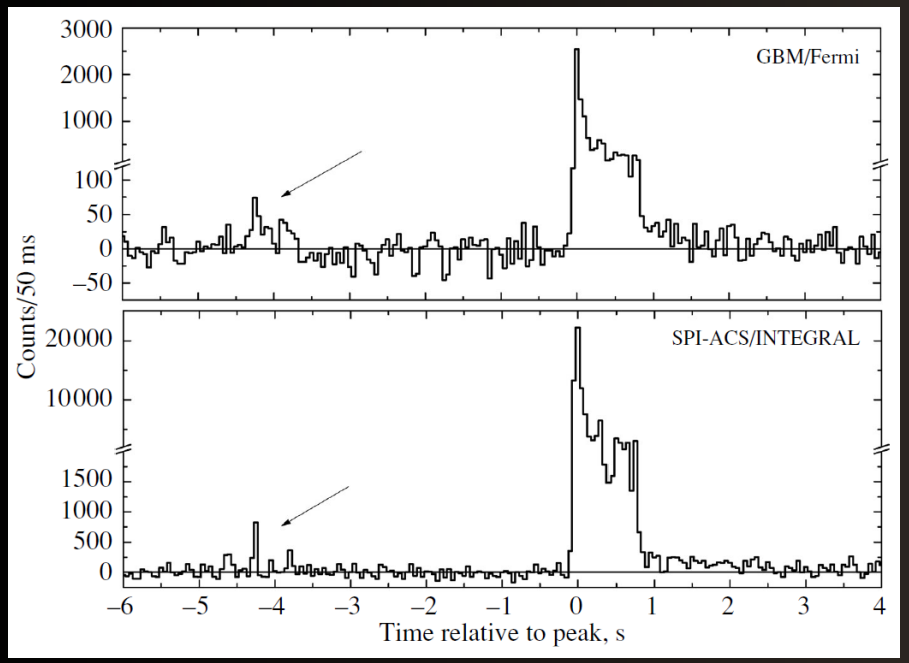


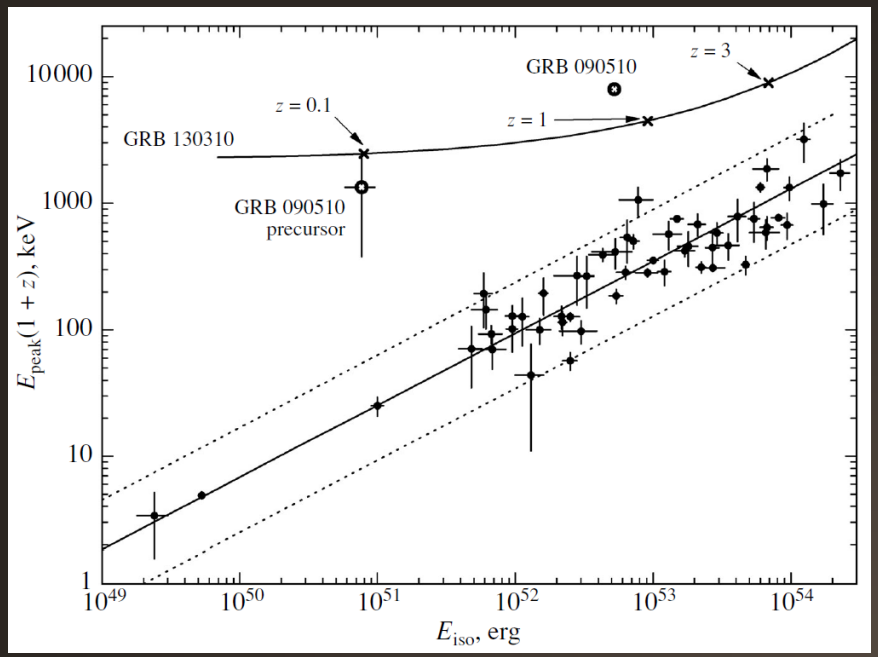
Not reliable Type I burst

Precursor candidates – GRB130310

- Precursor candidate is 30 times fainter and 3 times shorter than main phase, but has comparable hardness ratio
- Extended emission with duration of ~500 sec was found with power law decay ($\alpha = -1.16 \pm 0.13$)
- Hard energetic spectrum of main phase ($E_p = 2.2 \pm 0.2$ MeV)
- On Amati diagram main phase lies above main correlation region







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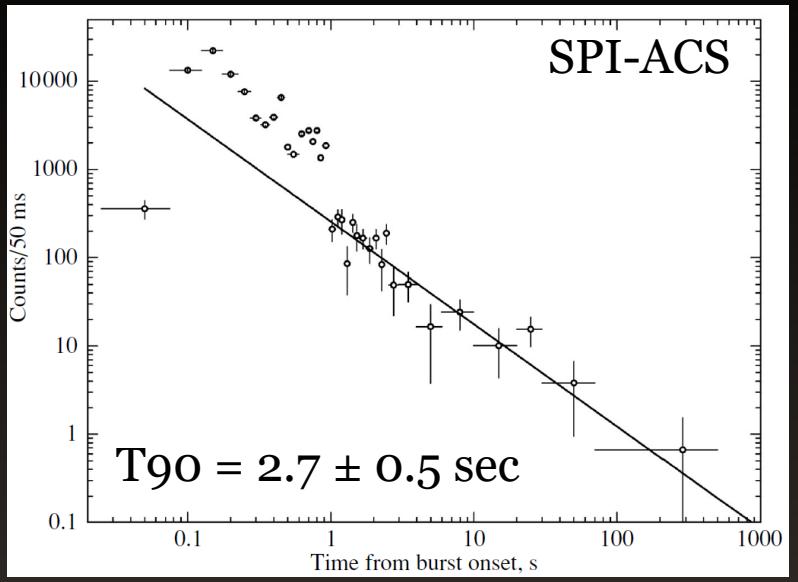
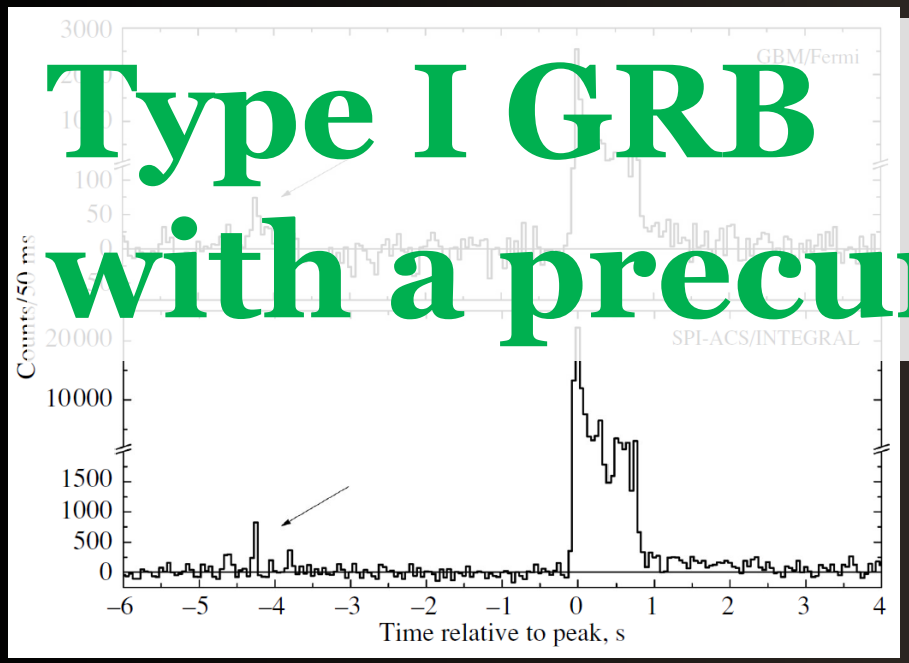
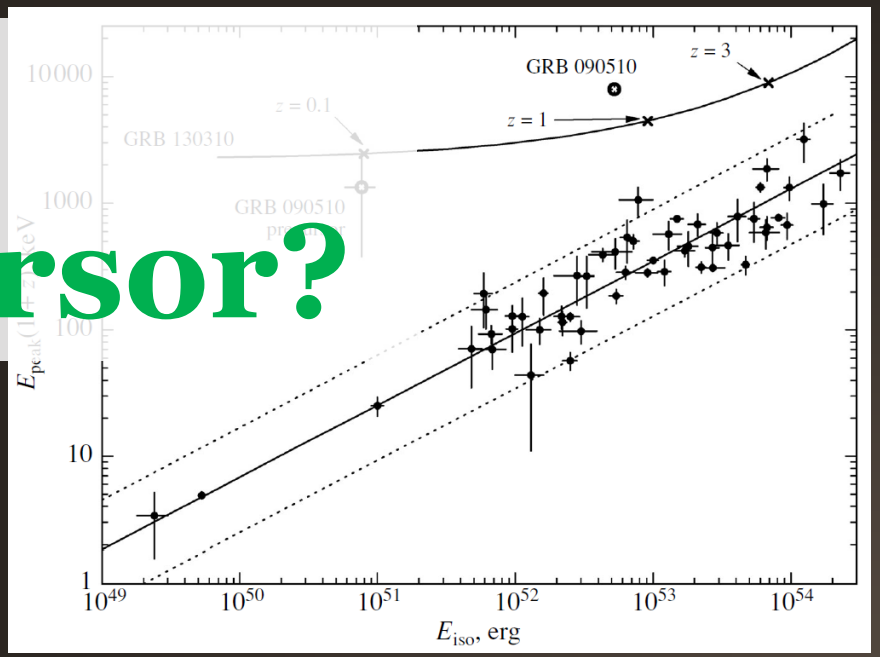


Type I GRB with a precursor?





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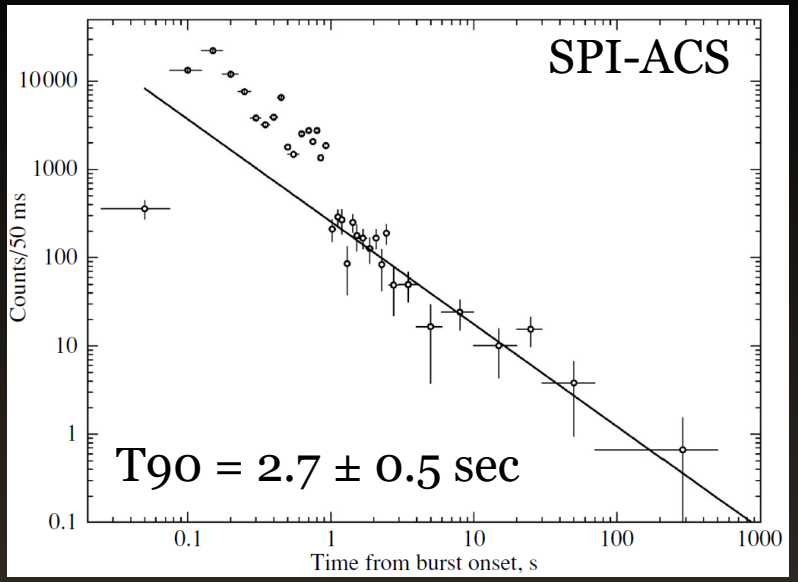
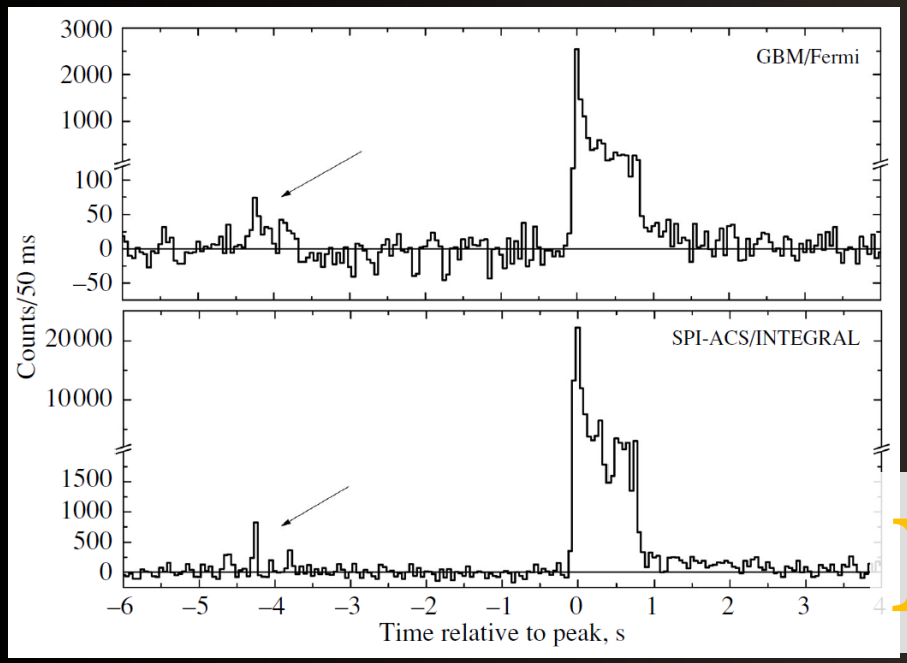
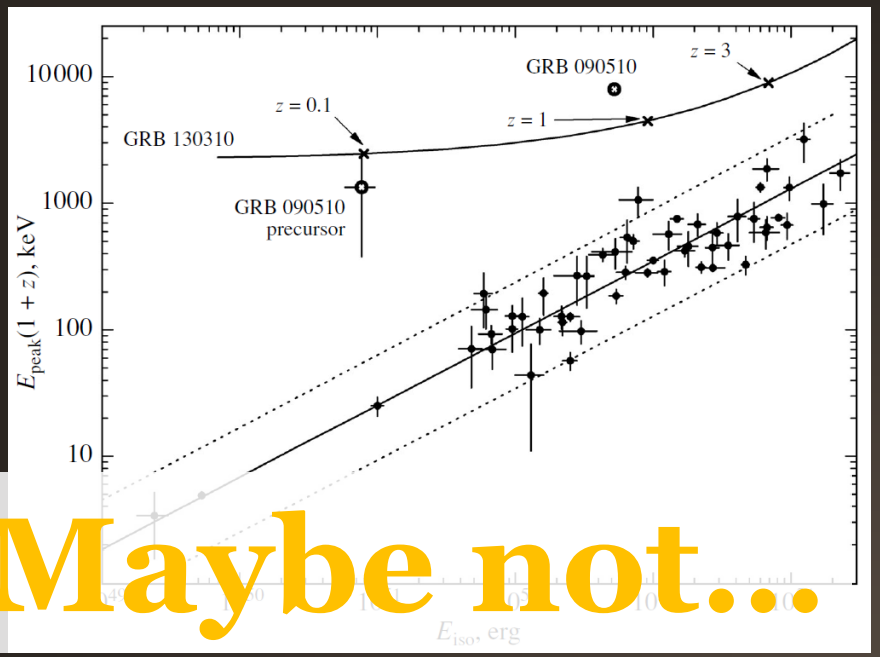
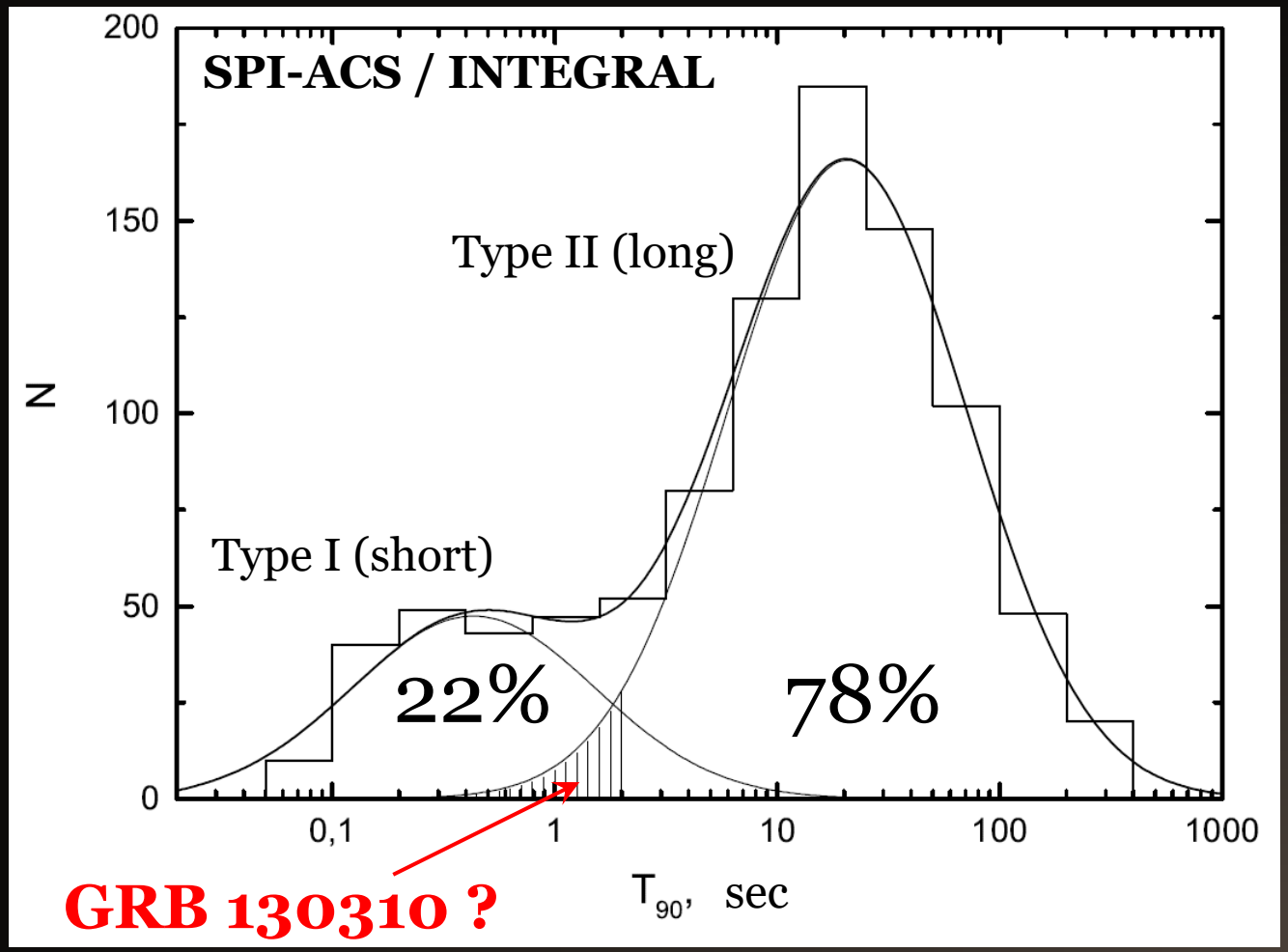






Maybe not…

GRB classification and GRB 130310

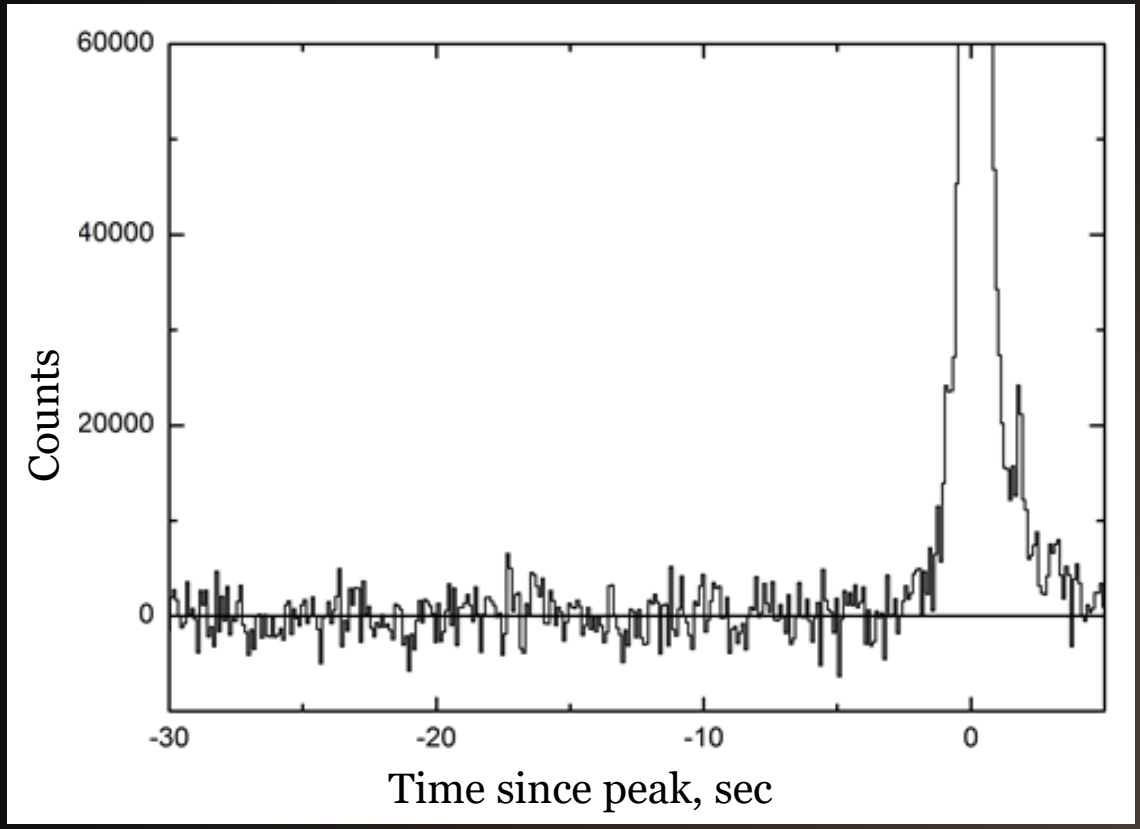


It could be a Type II burst…

Precursor in averaged light curve

- Any statistically significant regular precursor in averaged light curve of 372 brightest type I bursts was not found at time scales from 0.1 s to 48 s (time interval [-50; -2] sec)

- The possible regular precursor is weaker than main phase of the burst more than 30 times (the most conservative upper limit) at 3σ level



To conclude…

- Individual light curves of 519 type I bursts and averaged light curve of 372 brightest type I bursts were analyzed to search for precursors
- Any reliable precursor candidates in individual light curves are not found
- Any regular precursor also was not found in averaged light curve
- **We have not found any evidences of the precursor existence for type I (short) bursts in energy range above 80 keV**

See details in our paper:

P. Minaev, A. Pozanenko, Astron. Lett., Vol. 43, p. 1-20 (2017) arXiv:1612.02418

THANK YOU FOR YOUR ATTENTION!

Table 2. Comparison of the properties of the precursor candidates and the main GRB phase in the energy range (8, 900) keV based on GBM/Fermi data

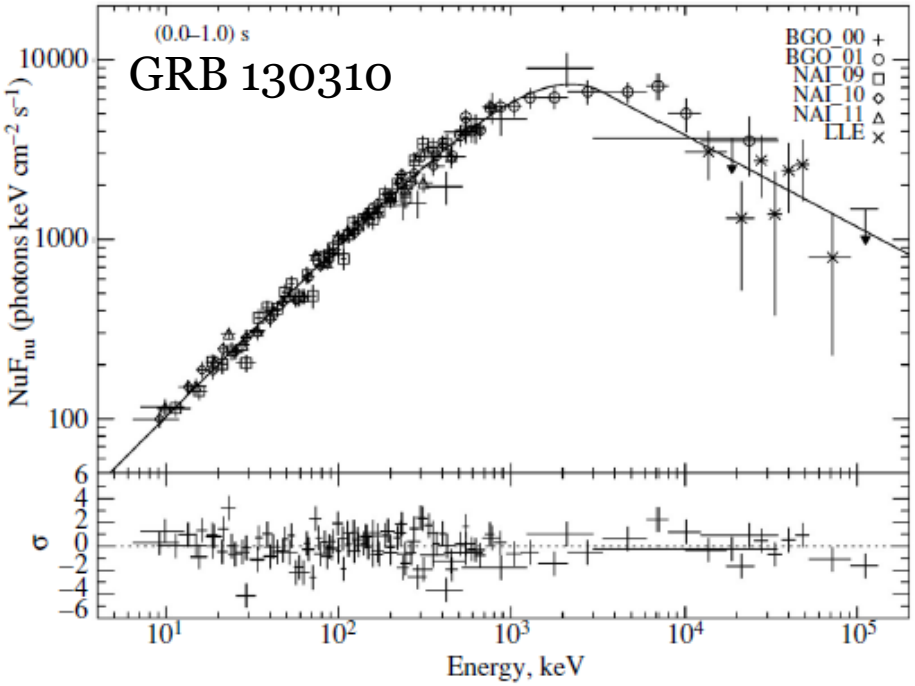
GRB	Light-curve component [1]	Significance, σ	T_{90}, s	Fluence, 10^2 counts	Peak flux, [2] 10^3 counts/s	Hardness ratio[3]
090510	precursor	13.2	0.05 ± 0.02	3.0 ± 0.4	12.8 ± 1.3	0.45 ± 0.11
	main phase	82.7	0.98 ± 0.07	79.2 ± 1.9	43.7 ± 1.9	0.46 ± 0.02
100717	precursor	9.5	0.30 ± 0.05	4.9 ± 0.5	2.9 ± 0.4	0.57 ± 0.14
	pulse 1	–	0.15 ± 0.05	3.8 ± 0.4	2.9 ± 0.4	–
	pulse 2	–	0.11 ± 0.07	1.1 ± 0.3	0.9 ± 0.4	–
	main phase	18.7	1.4 ± 0.2	17.7 ± 1.2	3.1 ± 0.4	0.55 ± 0.06
	pulse 3	–	0.21 ± 0.05	6.0 ± 0.5	3.1 ± 0.4	–
	pulse 4	–	0.19 ± 0.05	2.9 ± 0.5	1.6 ± 0.4	–
	pulse 5	–	0.30 ± 0.05	5.8 ± 0.6	2.6 ± 0.5	–
	pulse 6	–	0.45 ± 0.15	3.0 ± 0.6	1.3 ± 0.5	–
130310	precursor	7.1	0.9 ± 0.2	9.8 ± 1.3	2.0 ± 0.4	0.31 ± 0.10
	main phase	134.1	2.7 ± 0.5	285.3 ± 3.7	49.3 ± 0.7	0.37 ± 0.01

[1] The values for the individual pulses of the light curve are also specified for GRB 100717.
[2] The peak flux was obtained in the light curve with a time resolution of 15 ms for GRB 090510, 30 ms for GRB 100717, and 150 ms for GRB 130310.
[3] The ratio of the fluences in the energy ranges (0.2, 0.9) MeV and (8, 200) keV expressed in raw counts.

Table 3. Results of our spectral analysis based on GBM/Fermi and LAT/Fermi data

GRB	Light curve component	Model [1]	α	β	E_{peak},[2] MeV	γ	Fluence, (10–1000) keV, 10^{-6} erg cm^{-2}	CSTAT/dof
090510	Main	PL				$-1.670^{+0.008}_{-0.003}$	1.82 ± 0.03	4409.3/849
	Phase	CPL	$-0.90^{+0.01}_{-0.03}$		$5.82^{+1.10}_{-0.02}$		4.08 ± 0.06	4238.5/848
		Band	$-0.73^{+0.03}_{-0.02}$	$-2.62^{+0.04}_{-0.04}$	$2.83^{+0.17}_{-0.17}$		4.52 ± 0.09	1070.2/847
		CPL + PL	$-0.69^{+0.04}_{-0.03}$		$4.36^{+0.12}_{-0.12}$	$-1.58^{+0.03}_{-0.02}$	4.28 ± 0.07	946.3/846
		Band + PL	$-0.66^{+0.05}_{-0.04}$	$-3.7^{+0.2}_{-0.3}$	$3.9^{+0.2}_{-0.2}$	$-1.60^{+0.03}_{-0.03}$	4.38 ± 0.08	928.3/845
	Precursor	PL				$-1.30^{+0.05}_{-0.04}$	0.11 ± 0.01	746.4/818
		CPL	$-0.6^{+0.3}_{-0.5}$		$0.8^{+2.2}_{-0.5}$		0.16 ± 0.02	719.5/817
		Band	$-0.5^{+0.4}_{-0.2}$	$-2.0^{+0.3}_{-0.4}$	$0.7^{+0.5}_{-0.3}$		0.15 ± 0.02	715.1/816
		kT + PL	$-1.4^{+0.1}_{-0.1}$		$0.12^{+0.03}_{-0.02}$		0.15 ± 0.02	724.0/816
	Ext. emission	PL				$-1.55^{+0.01}_{-0.01}$	0.85 ± 0.07	1148.4/609
100717	Main	PL				$-1.28^{+0.02}_{-0.03}$	1.21 ± 0.06	492.8/349
	Phase	CPL	$-0.96^{+0.08}_{-0.08}$		$4.1^{+1.8}_{-1.0}$		1.61 ± 0.09	458.3/348
		Band	$-0.71^{+0.15}_{-0.14}$	$-1.71^{+0.10}_{-0.15}$	$1.2^{+0.7}_{-0.8}$		1.66 ± 0.11	446.1/347
	Precursor	PL				$-1.35^{+0.06}_{-0.05}$	0.17 ± 0.02	421.8/349
		CPL	$-0.4^{+0.4}_{-0.3}$		$0.7^{+0.6}_{-0.4}$		0.26 ± 0.03	401.8/348
130310	Main	PL				$-1.448^{+0.005}_{-0.003}$	7.70 ± 0.07	3508.5/592
	Phase	CPL	$-1.102^{+0.010}_{-0.009}$		$3.99^{+0.18}_{-0.19}$		11.31 ± 0.12	852.2/591
		Band	$-1.033^{+0.015}_{-0.015}$	$-2.52^{+0.08}_{-0.09}$	$2.23^{+0.21}_{-0.20}$		11.79 ± 0.14	754.7/590
		CPL + PL	$-1.052^{+0.025}_{-0.016}$		$2.94^{+0.19}_{-0.21}$	$-1.43^{+0.08}_{-0.07}$	11.60 ± 0.14	790.8/589
	Main	PL				$-1.322^{+0.008}_{-0.008}$	2.27 ± 0.04	847.2/578
	Peak	CPL	$-1.184^{+0.014}_{-0.014}$		$11.8^{+1.4}_{-1.2}$		2.69 ± 0.06	693.9/577
		Band	$-1.180^{+0.012}_{-0.014}$	$-3.4^{+0.7}_{-1.3}$	$12.4^{+1.9}_{-1.6}$		2.71 ± 0.06	695.5/576
		CPL + PL	$-0.67^{+0.16}_{-0.17}$		$6.1^{+1.5}_{-1.0}$	$-1.56^{+0.05}_{-0.14}$	2.61 ± 0.06	639.9/575
		Band + PL	$-0.71^{+0.16}_{-0.13}$	$-2.5^{+0.2}_{-0.4}$	$5.5^{+1.0}_{-0.8}$	$-1.68^{+0.11}_{-0.15}$	2.65 ± 0.07	635.7/574
	Ext. emission	PL				$-1.75^{+0.03}_{-0.03}$	0.99 ± 0.06	840.6/592

[1] PL is a power law, CPL is a power law with an exponential cutoff, Band is a power law with a break (Band et al. 1993), kT is a thermal model.
[2] For the kT spectral model the E_{peak} column gives the parameter kT.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(0.0–1.0) s
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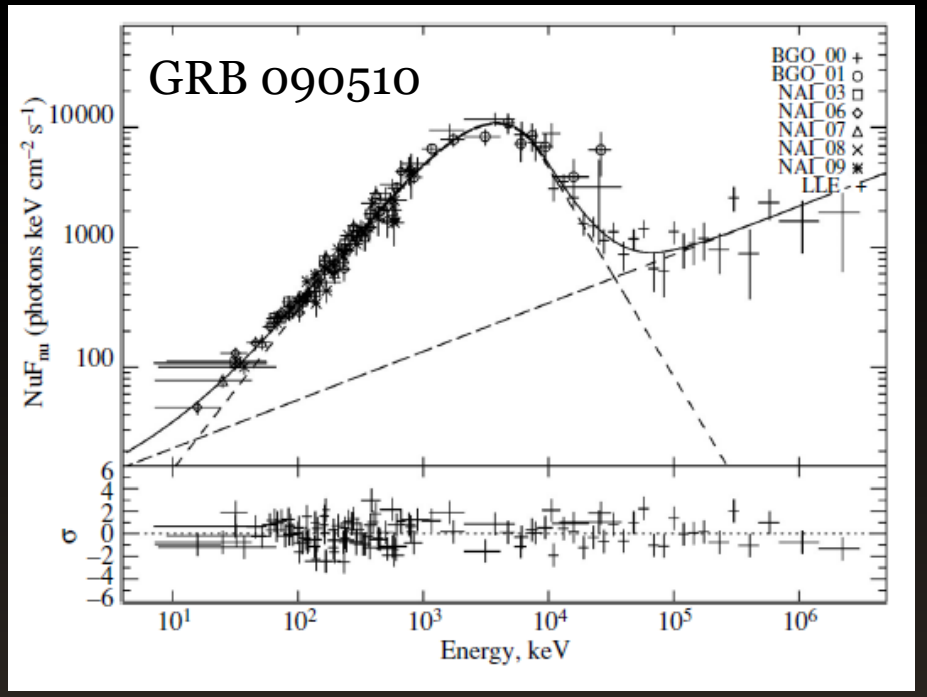
BGO_01
NAI_09
NAI_10
NAI_11
LLE
NuF$_{nu}$ (photons keV cm^{-2} s^{-1})
σ
Energy, keV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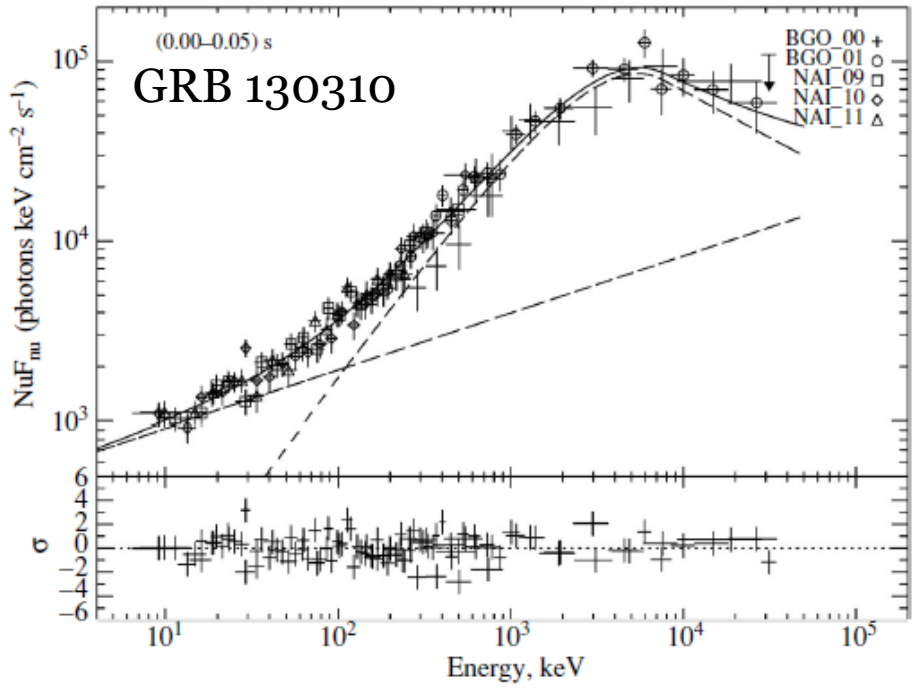
LLE
NuF$_{nu}$ (photons keV cm^{-2} s^{-1})
σ
Energy, keV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BGO_01
NAI_09
NAI_10
NAI_11
NuF$_{nu}$ (photons keV cm^{-2} s^{-1})
σ
Energy, keV