

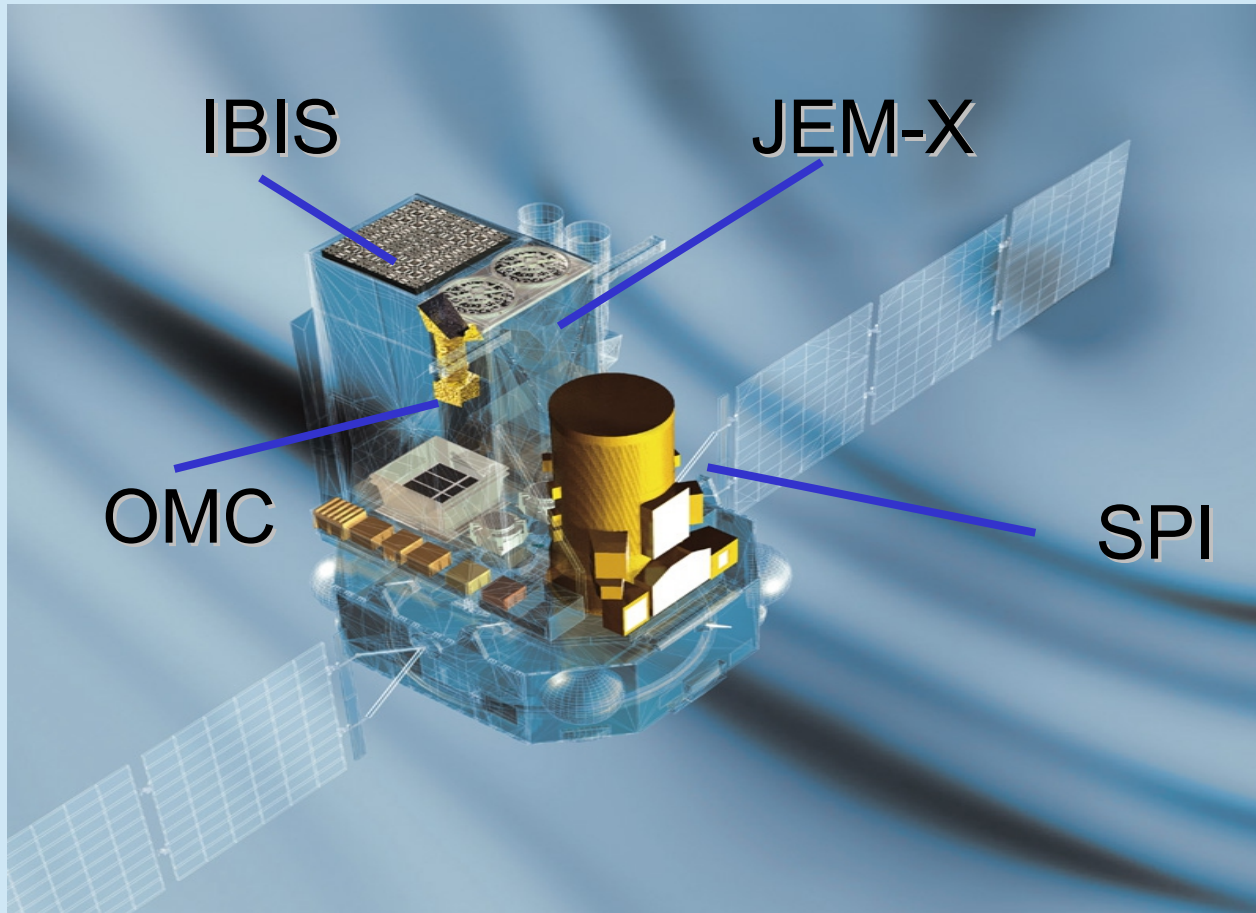
Known and unknown GRBs registered by IBIS/ISGRI aboard INTEGRAL



I. Chelovekov, S. Grebenev,
A. Pozanenko, P. Minaev

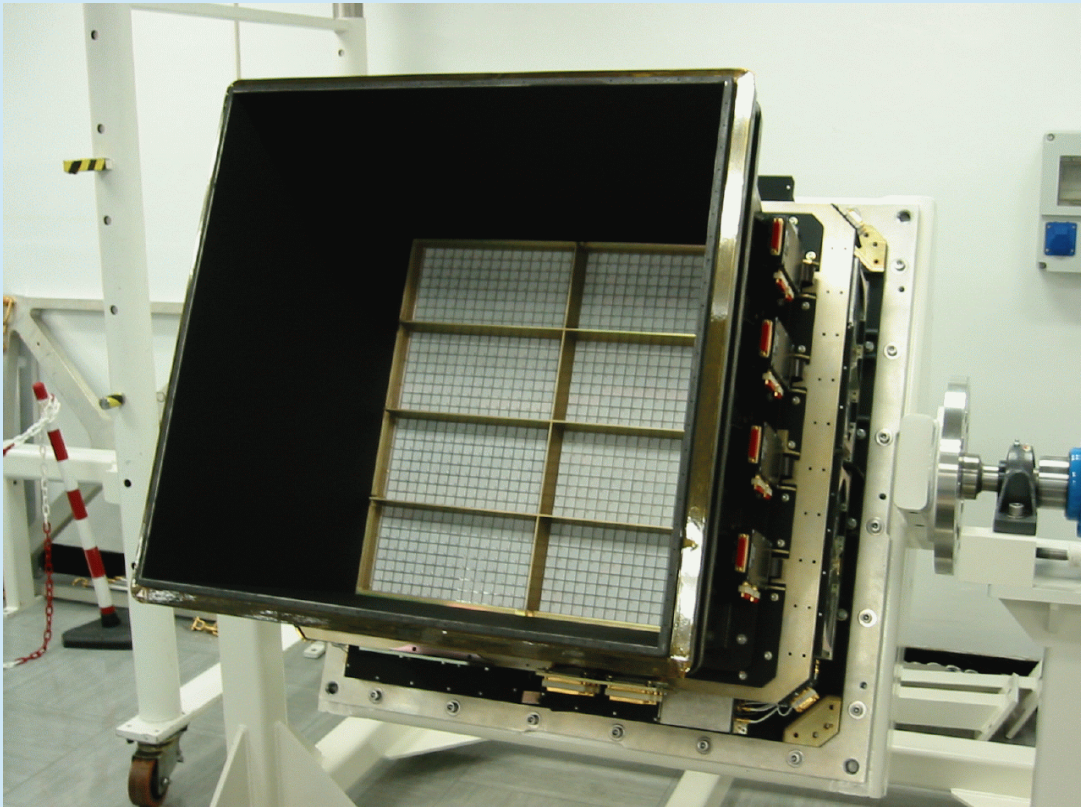
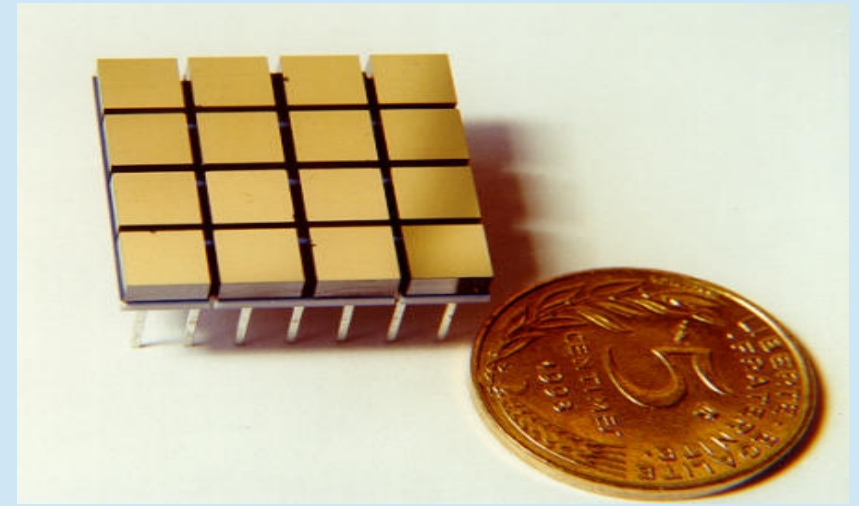
*Space Research Institute
Russian Academy of Sciences*

International Gamma-Ray Astrophysics Laboratory



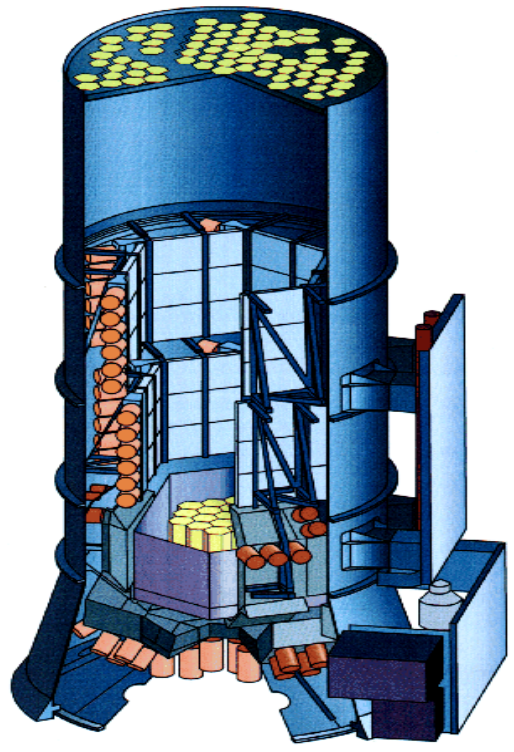
- was launched at a high apogee orbit by PROTON on October 17, 2002 (~25 months before the launch of SWIFT)
- has 4 instruments on board (no GRB monitors but IBIS, SPI and sometimes JEM-X are capable to detect GRBs)
- observes the sky ~85% of the whole time during already ~17 years.

IBIS (*I*mager on *B*oard the *I*NTEGRAL *S*atellite)

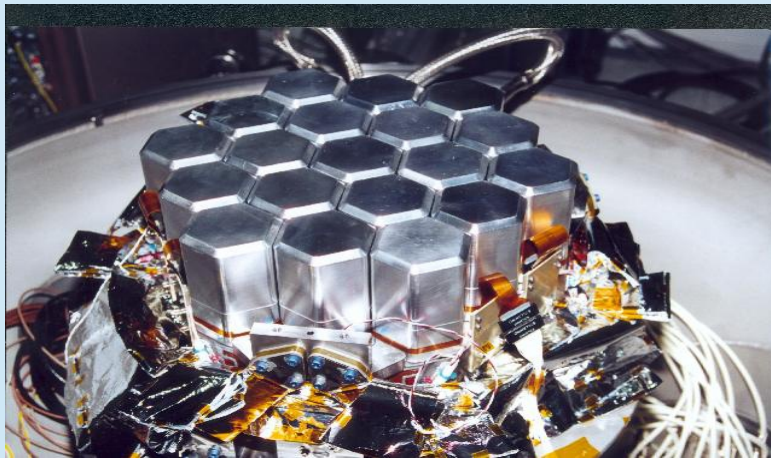


- Two position-sensitive detector layers:
 - ISGRI (16384 CdTe elements of $4 \times 4 \times 2 \text{ mm}^3$ with total area 2600 cm^2)
 - PICsIT (4096 CsI elements $9 \times 9 \times 30 \text{ mm}^3$ with total area 2890 cm^2)
- Energy band 15 keV - 10 MeV
- Field of view $29^\circ \times 29^\circ$
- Angular resolution 12 arcmin

SPI (*SP*ectrometer for *INTEGRAL*)



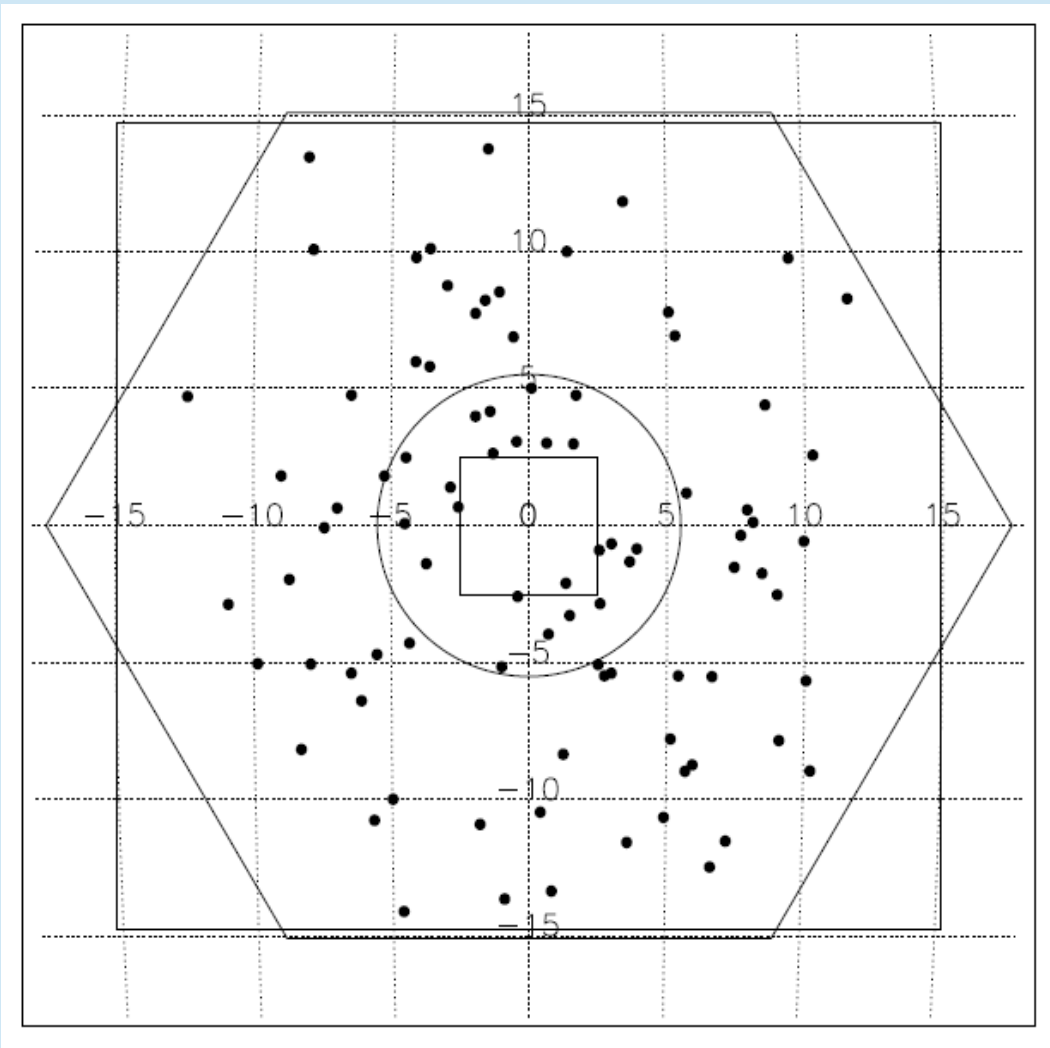
- 19 Ge detectors
- Area 500 cm²
- Energy band 20 keV - 8 MeV
- Field of view 32° (hexagonal)
- Angular resolution 2.5°
- Anticoincidence shield (ACS - 91 BGO crystals each with a volume of 790 cm³)



IBAS (INTEGRAL Burst Alert System)

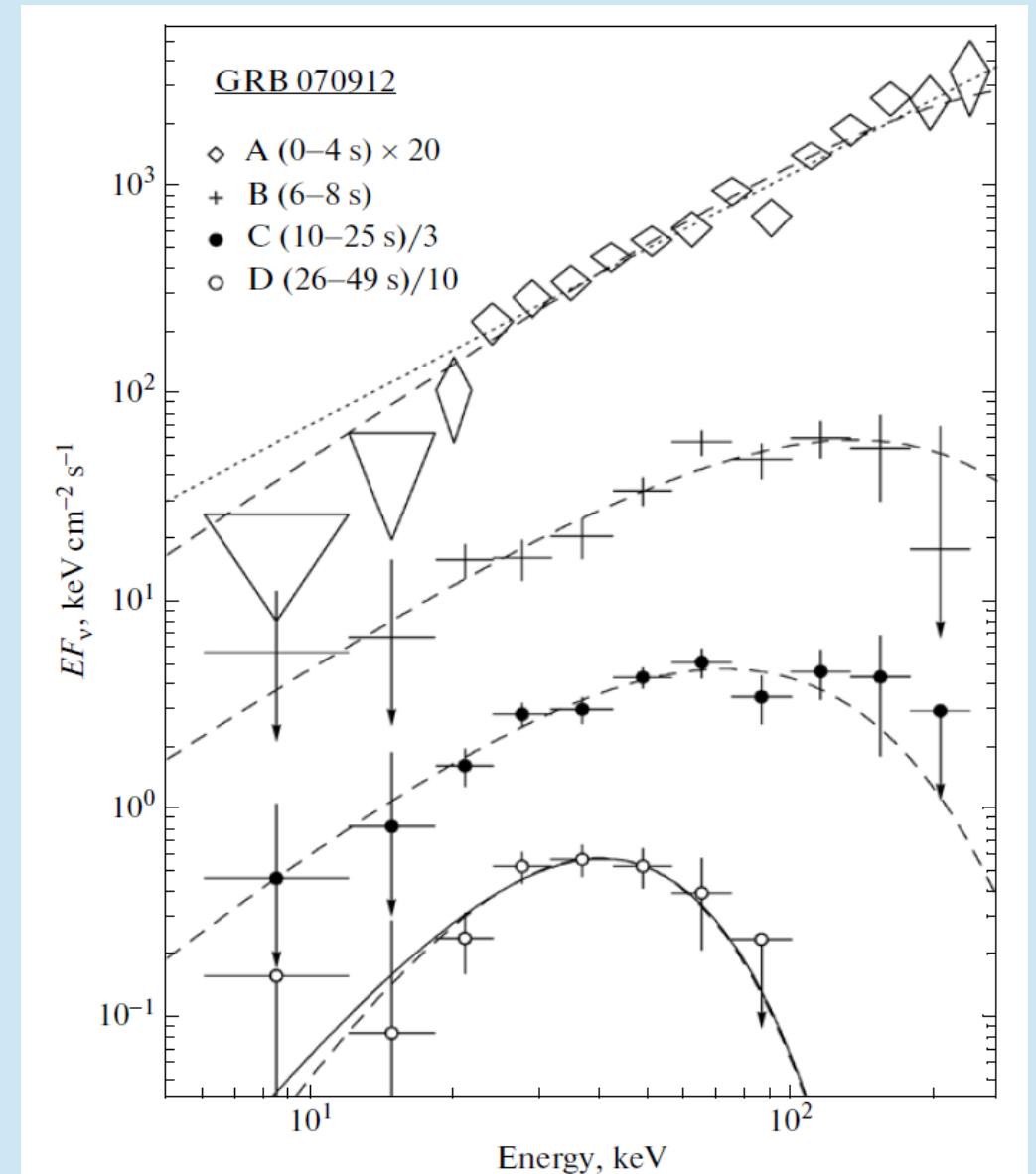
- was developed to detect and locate in real time GRBs serendipitously observed by INTEGRAL (Mereghetty 2013)
- runs automatically at the INTEGRAL Science Data Centre (ISDC), where the satellite data are received with a delay of only a few seconds
- distributes the sky coordinates of GRBs occurring in the IBIS FOV via Internet in real time (Thanks to IBAS, INTEGRAL has been the first mission to distribute in real time the positions of GRBs with arcminute accuracy !)
- has localized currently 131 GRBs
- also provides the light curves for GRBs detected with SPI/ACS

INTEGRAL GRBs



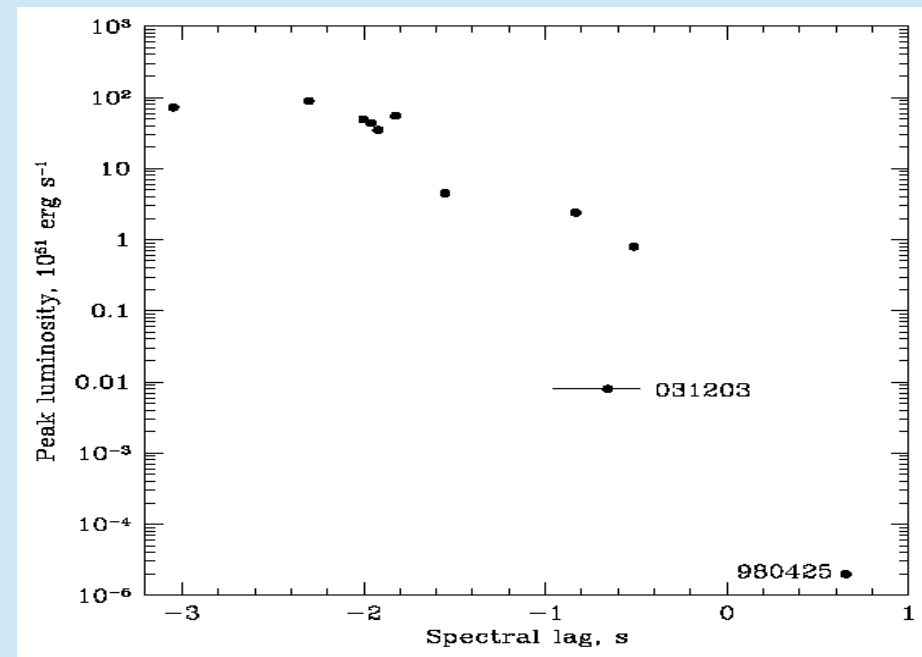
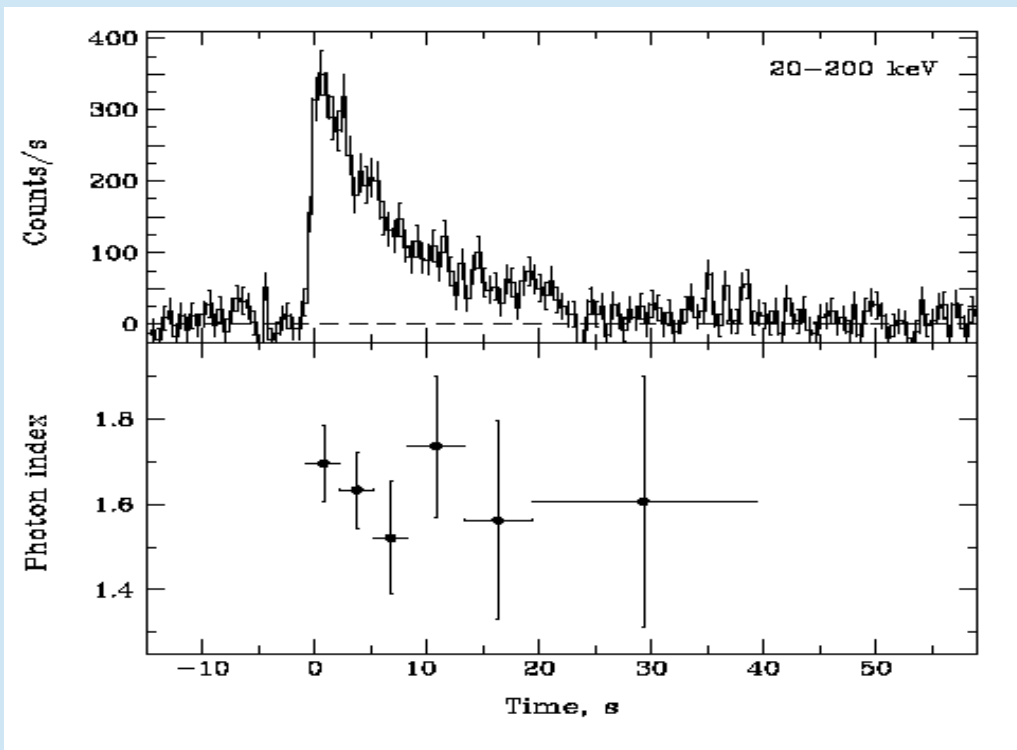
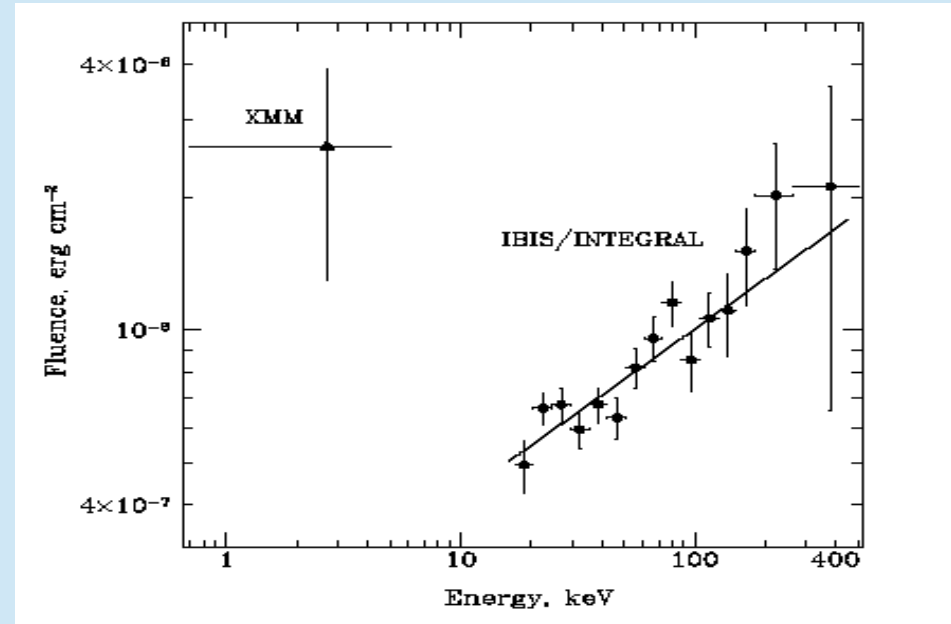
Distribution of the first 90 GRBs detected by IBAS over the instruments FOVs (from Mereghetti 2013)

JEM-X has detected only few GRBs because of its narrow FOV but the obtained information was valuable (from Minaev et al. 2012)



GRB031203

An apparently normal ($E_{\text{peak}} > 190$ keV) γ -ray burst with an unusually low luminosity. At $z=0.106$ its isotropic γ -ray energy $< 10^{50}$ erg is three orders of magnitude smaller than that of cosmological population. This showed that GRBs are not "standard candles" (Sazonov et al., Nature, 2004)

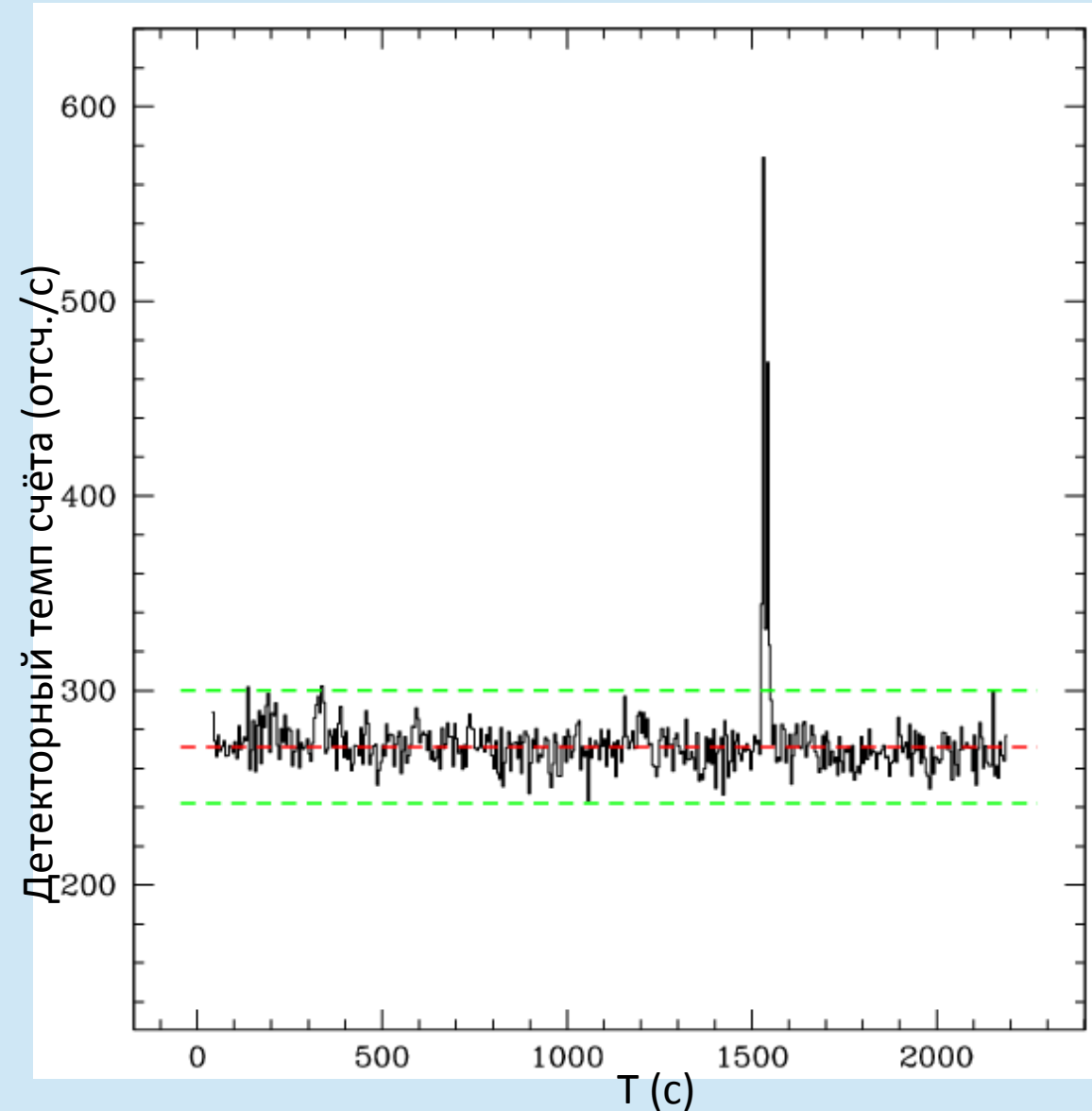


Our search for GRBs in the IBIS/ISGRI archival data

- Two GRBs have been serendipitously detected by us in the IBIS/ISGRI FOV but omitted by IBAS - GRB 060428C (Grebenev, Chelovekov 2006) and GRB 070912 (Minaev et al. 2012)
- These findings stimulated our global search for GRBs in the IBIS/ISGRI archival data obtained in Feb 2003 - Jan 2018.
- We used an experience obtained by us during the search for type I X-ray bursts in the archival data of IBIS/ISGRI and JEM-X (Chelovekov et al. 2006; 2011; 2017).
- First, we analyzed the IBIS/ISGRI detector 30-100 and 100-500 keV light curves with 5-s time bins collecting all excesses exceeding the local level of mean count rate by $>3 \sigma$.

Our search for GRBs in the IBIS/ISGRI archival data

Number of sessions (each of 3600/1800 s)	143 000 scws
Total exposure	405 Ms
Energy band	X: 30-100 keV G: 100-500 keV
Time bin	5 s (for search) 1 s (for analysis)
Number of detected events	230 000



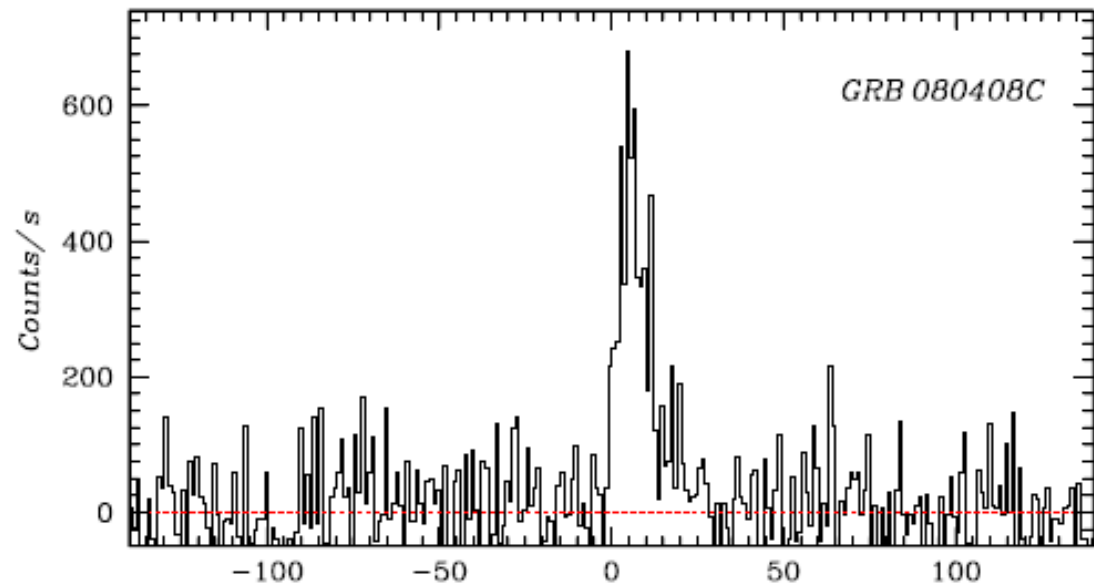
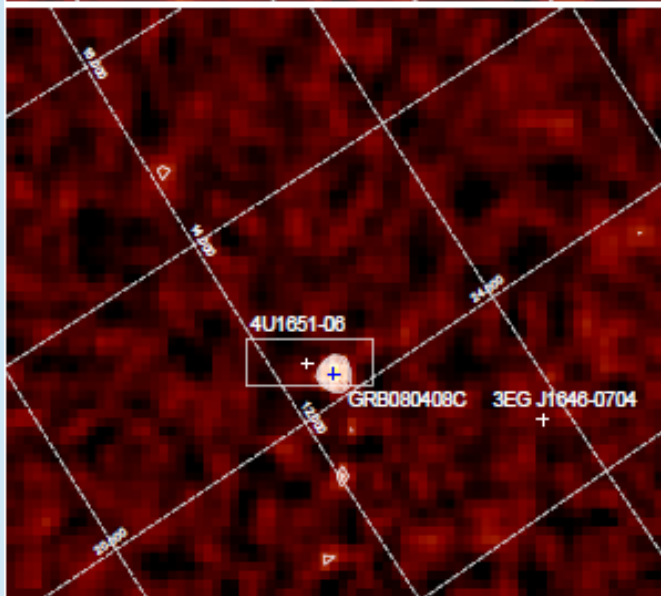
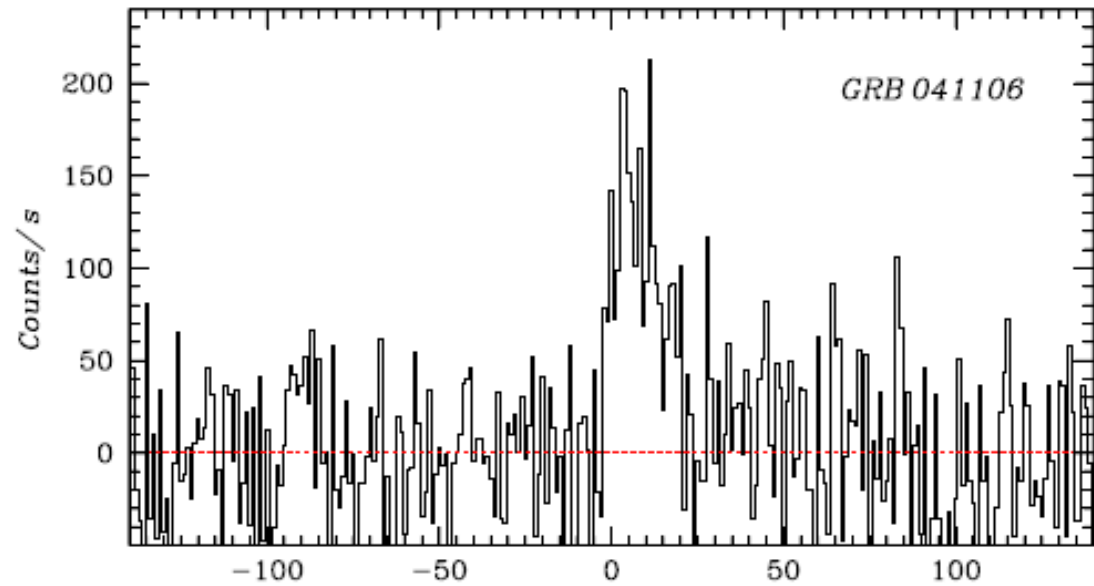
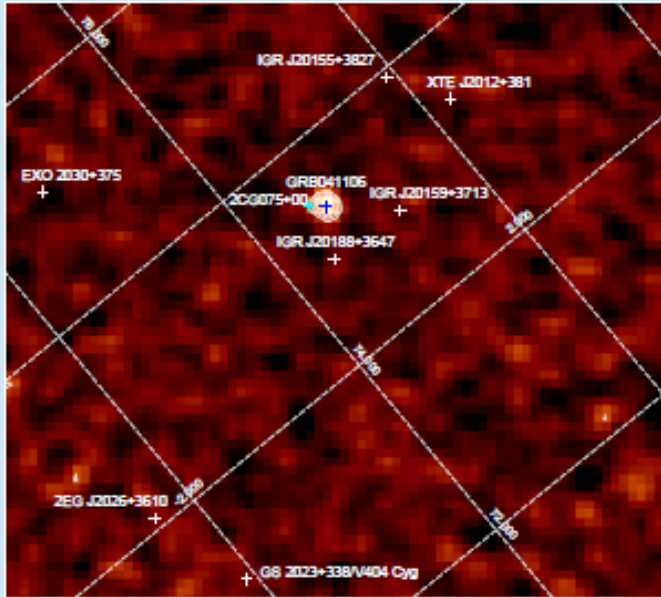
Our search for GRBs in the IBIS/ISGRI archival data

- Second, we have tried to reconstruct the sky images within the IBIS/ISGRI FOV for all the detected events and found their probable sources.
- Localized events have been cross-checked with the IBAS GRBs catalogue and catalogues of GRBs detected by INTEGRAL SPI (within its FOV) and PICsIT.
There were 7 new GRBs found and 4 previously known GRBs localized.
- Nonlocalized events have been cross-checked with the catalogues of SPI/ACS and PICsIT events and the combined GRBs catalog (IPN master lists by K. Hurley).
There were ~890 previously known GRBs confirmed, 110 of them were detected in only one experiment before IBIS/ISGRI.

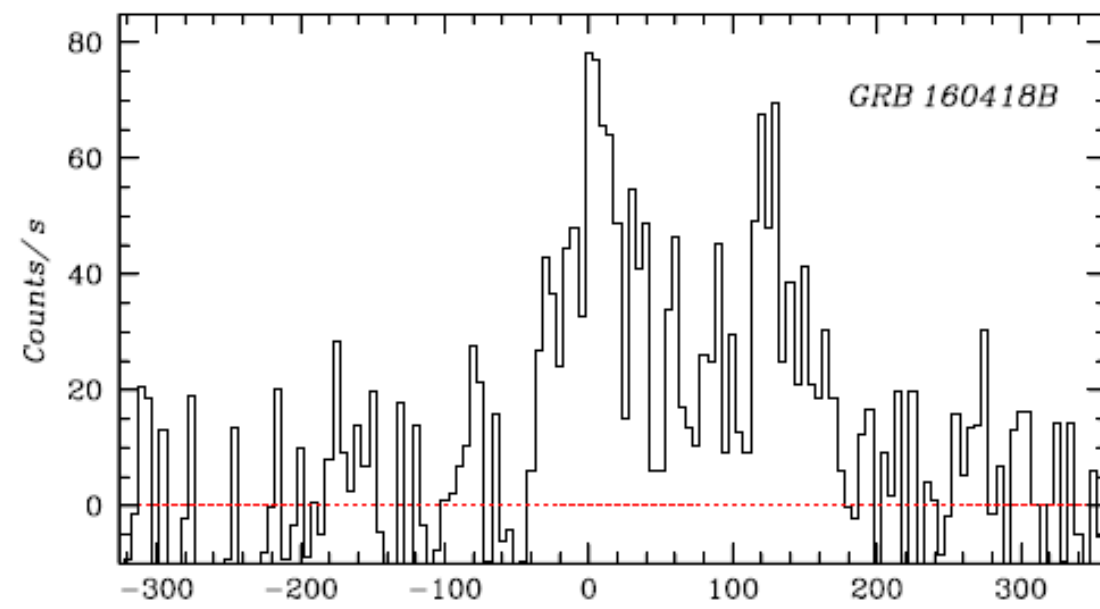
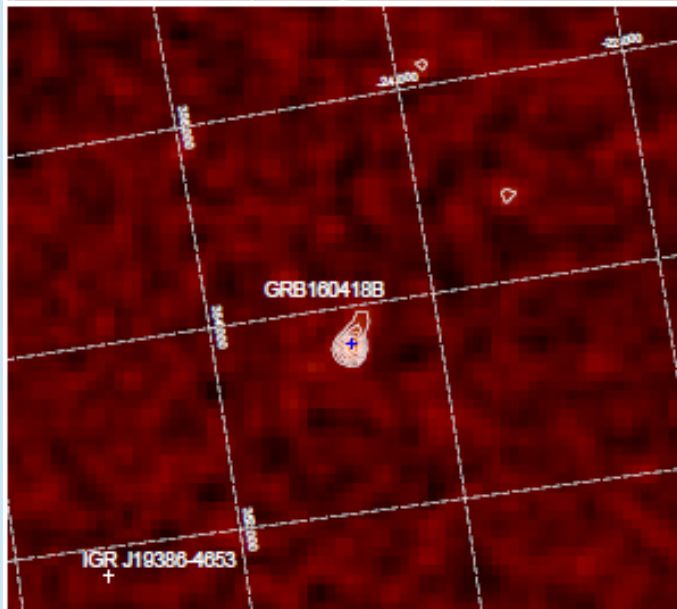
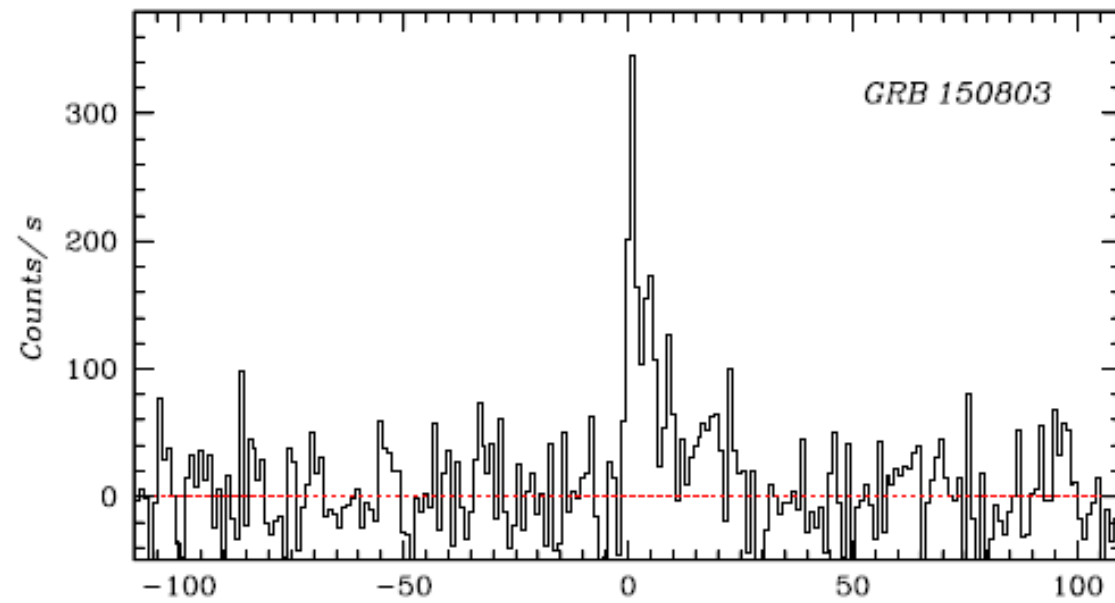
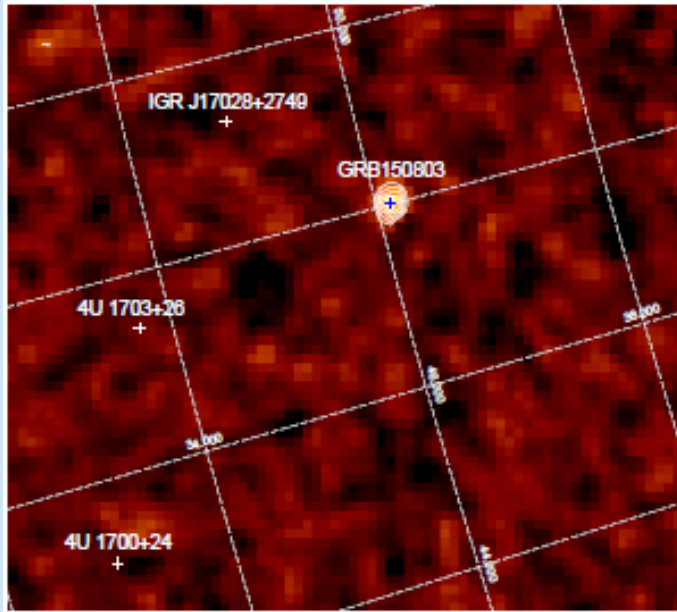
New GRBs found within IBIS FOV

Всплеск (дата)	ΔE^a	T_0^b (UTC)	δT^B	T_c^F	T_{90}^D	C_p^e	$S/N^{\text{ж}}$		F^3	Координаты ^И	
							LC	IM		R.A.	Decl.
		hh:mm:ss	с	с	с	отсч/с	σ	σ	отсч.	град.	град.
GRB 041106	X	01:06:08	1	23	39	212	5.3	8.7	2496	304.749	37.295
GRB 080408C	X	18:33:54	1	21	19	669	10.4	11.5	5331	253.382	-6.694
GRB 111130	X	18:42:15	1	21	44	465	9.9	11.5	3721	345.757	48.929
	G	18:42:20	1	19	40	259	6.3	—	1604		
GRB 131107	X	07:53:57	1	14	42	248	7.2	11.3	1794	123.378	-16.632
GRB 150803	X	08:32:28	1	12	19	344	9.3	7.6	1776	254.055	27.121
	G	08:32:28	1	6	9	158	4.5	—	502		
GRB 160418B	X	04:20:43	5	214	179	75	3.8	7.8	1204	291.830	-44.660
GRB 161209	X	02:07:42	1	17	15	1193	17.3	26.6	9474	193.437	3.072
	G	02:07:48	1	15	25	289	4.1	—	1878		

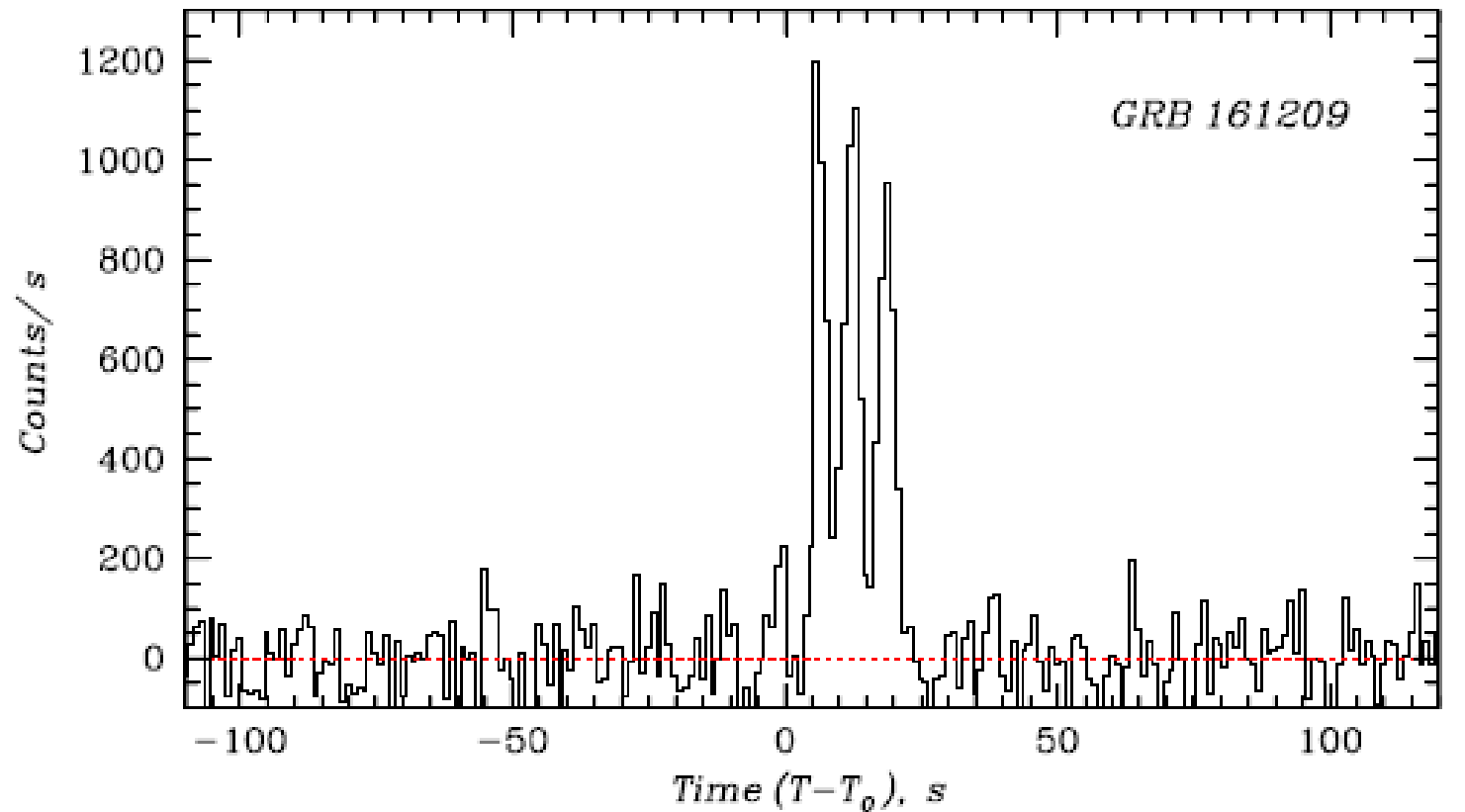
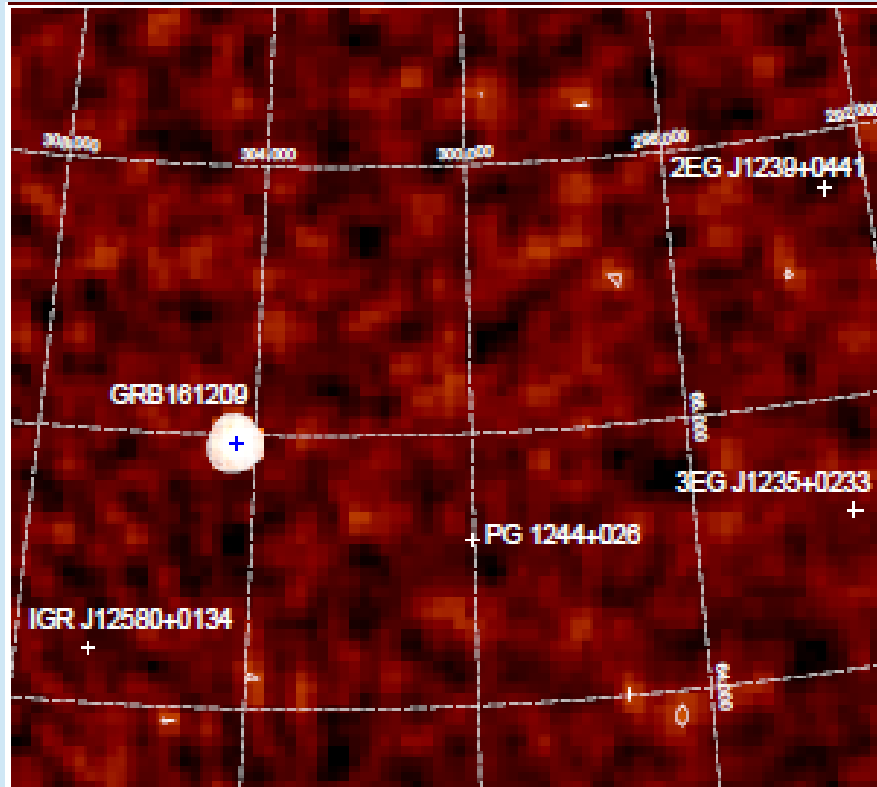
New GRBs found within IBIS FOV



New GRBs found within IBIS FOV

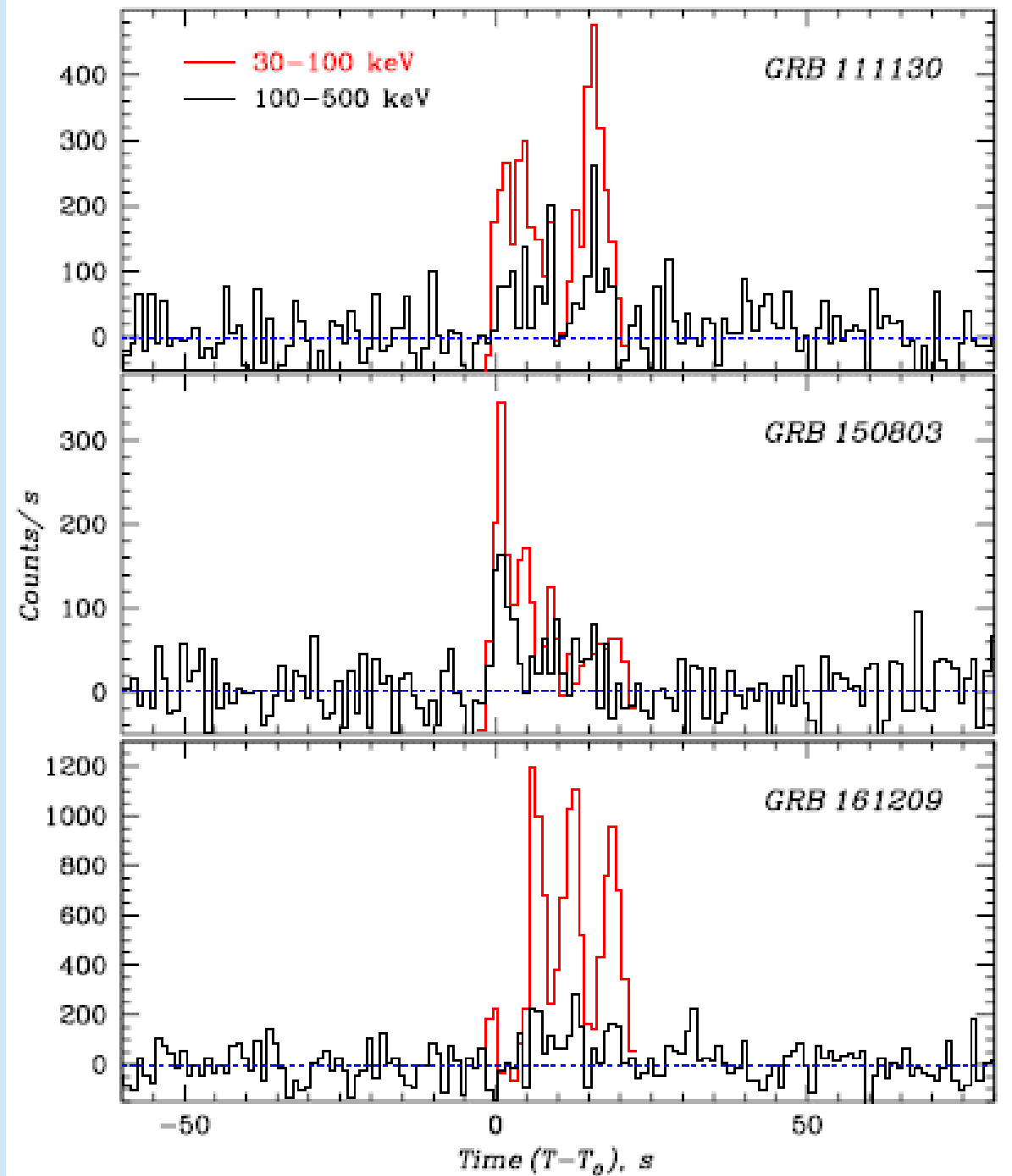


New GRBs found within IBIS FOV

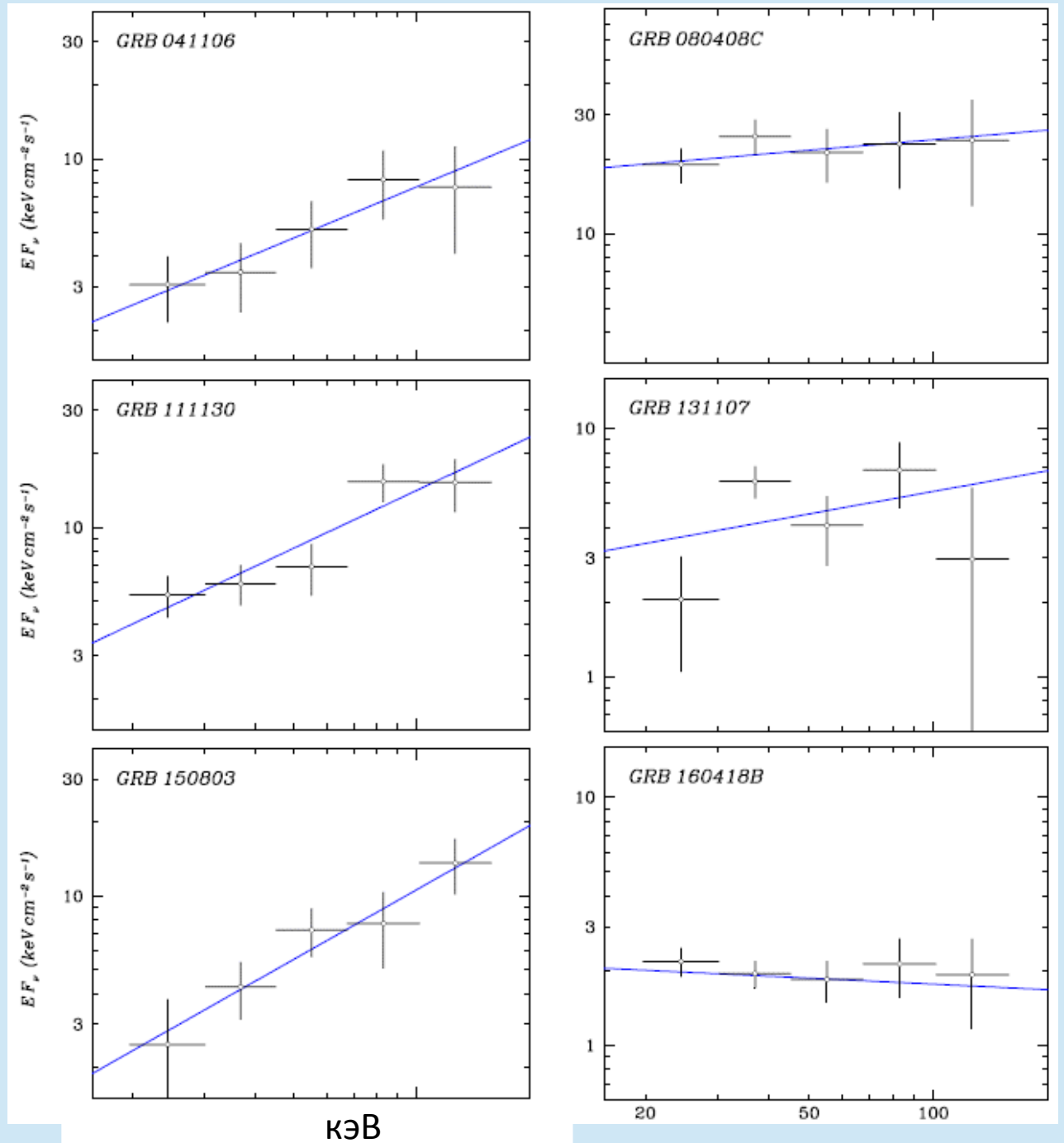


Detection of GRBs in the hard 100-500 keV band

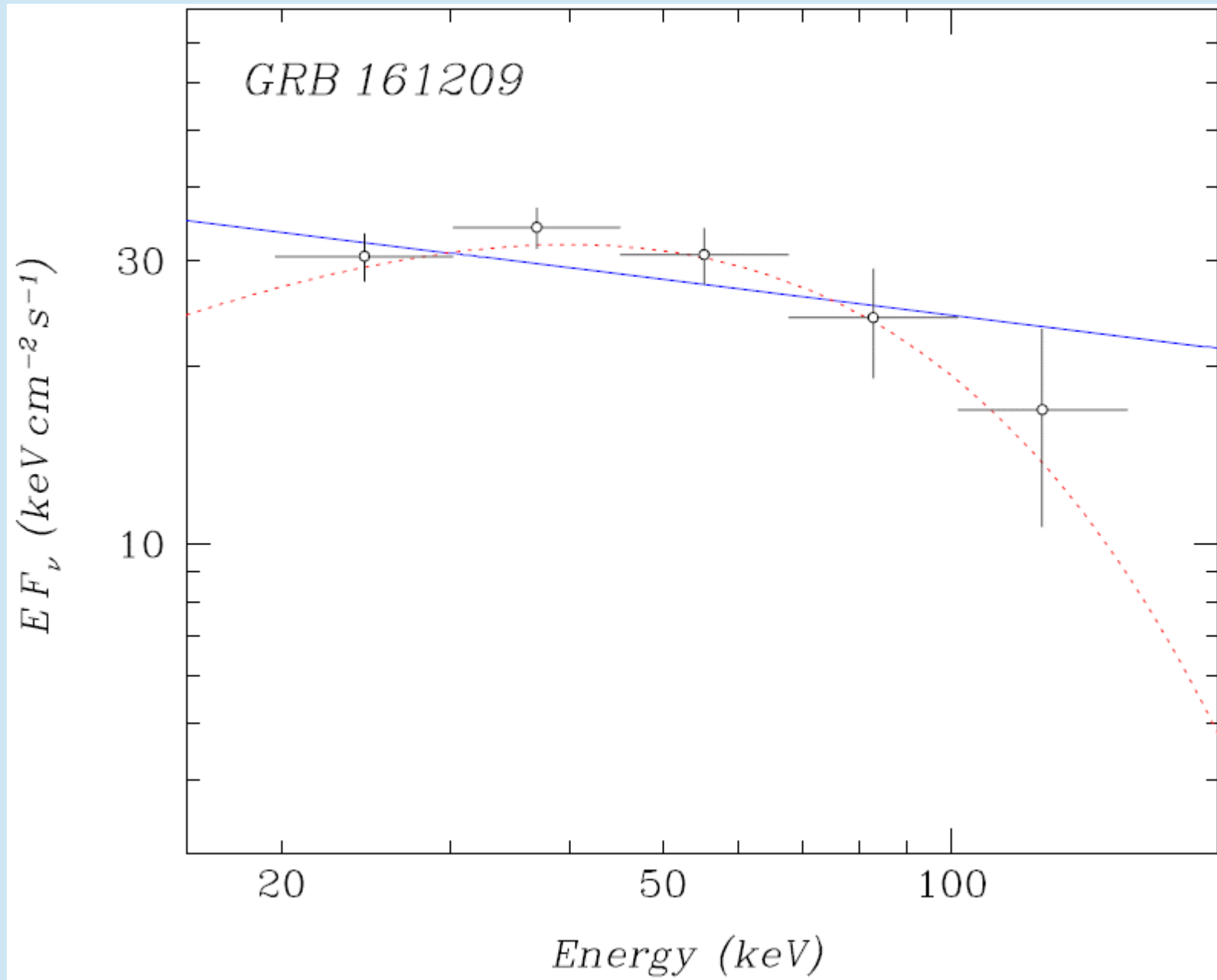
GRB 111130 and GRB 161209 are just very bright, but GRB 150803 is extremely hard



X-ray spectra of 7 new GRBs found within IBIS FOV

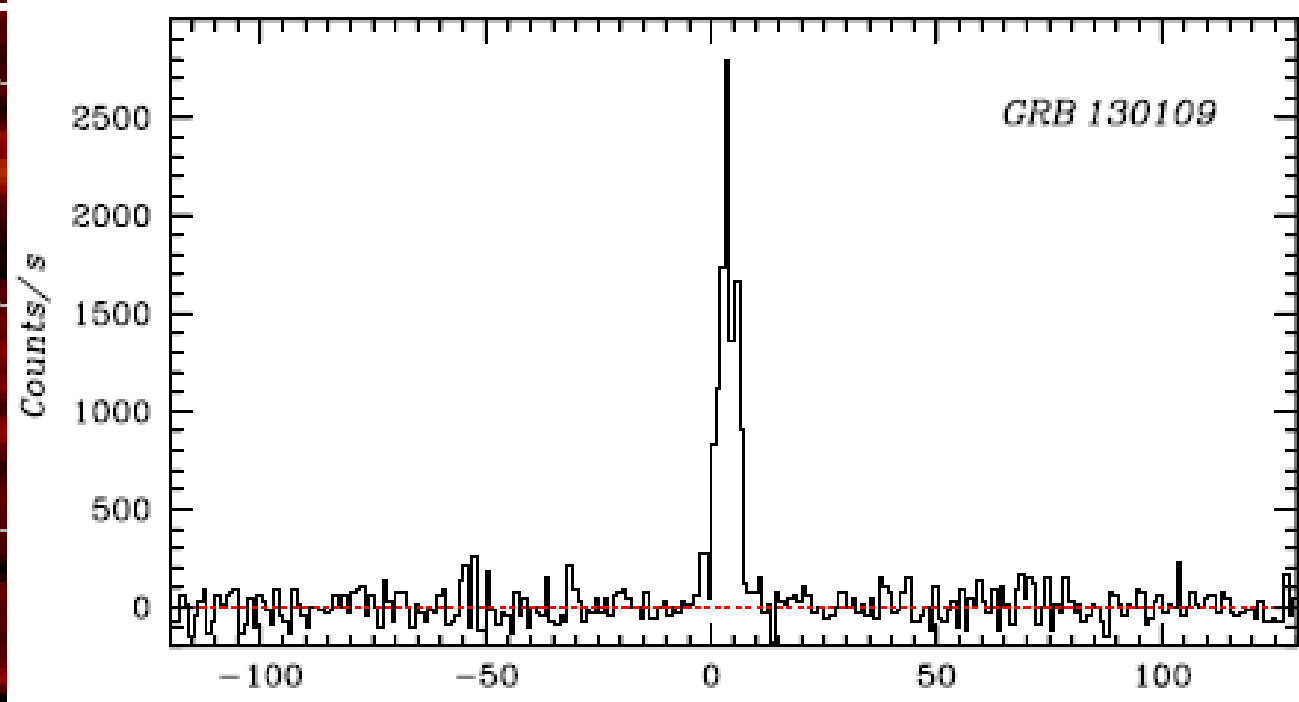
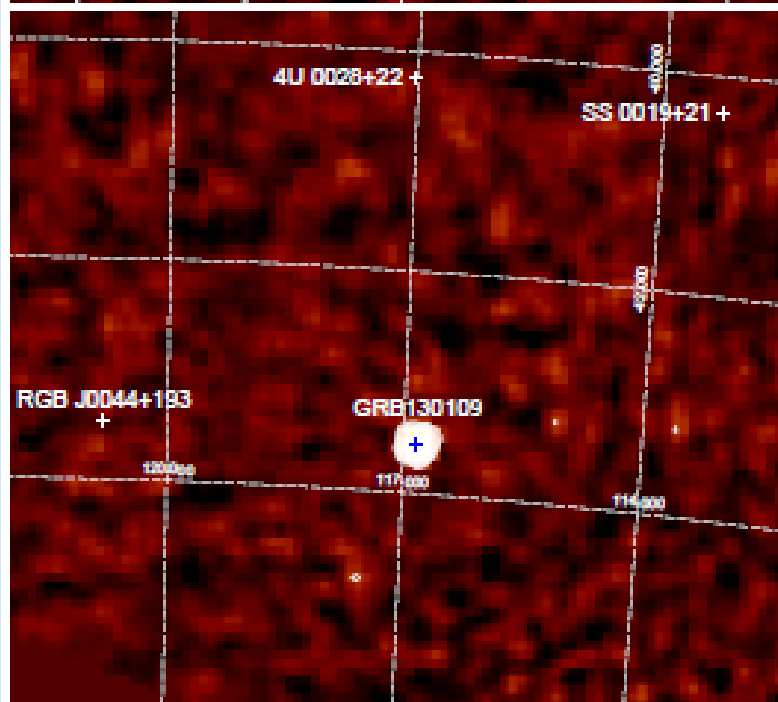
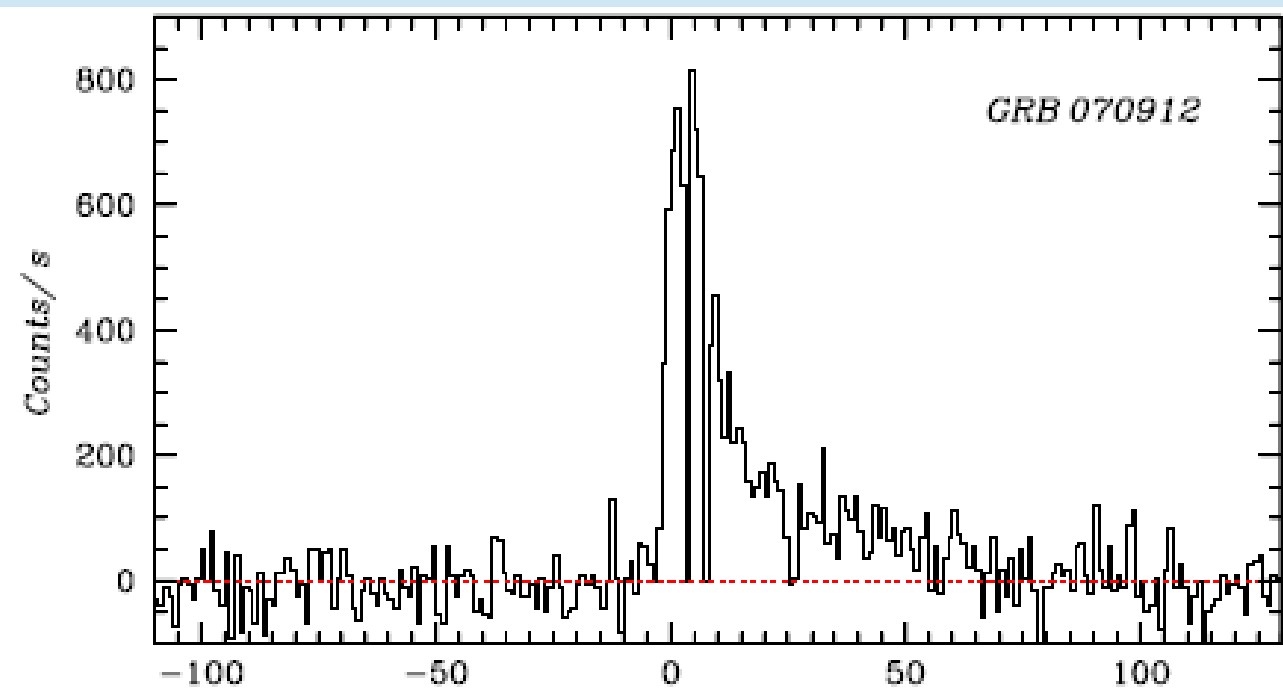
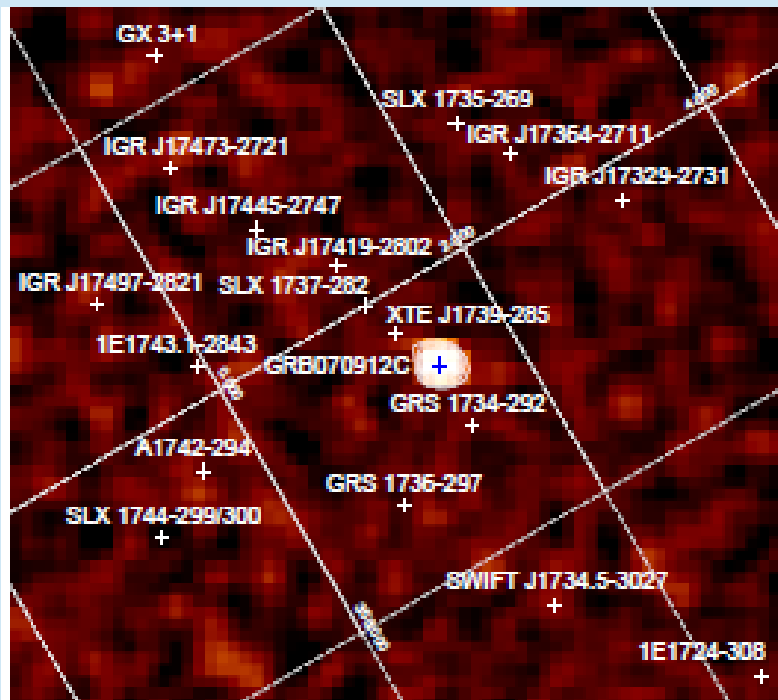


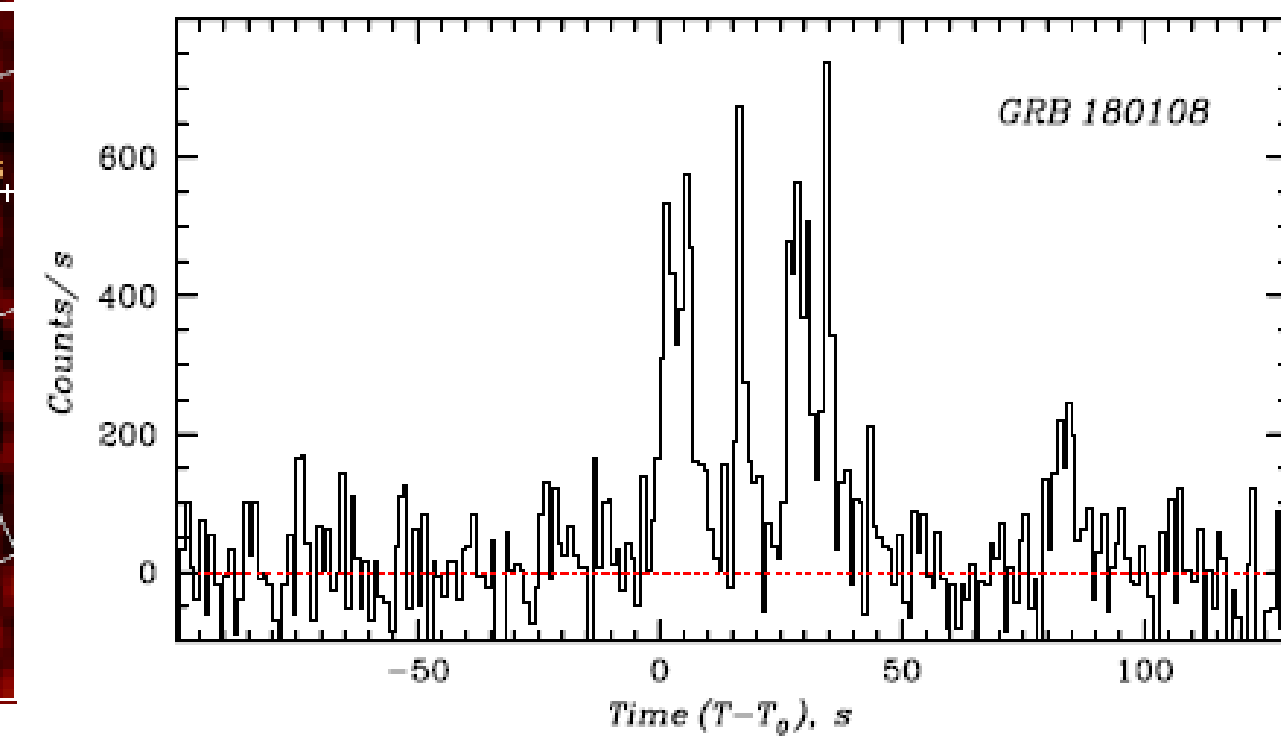
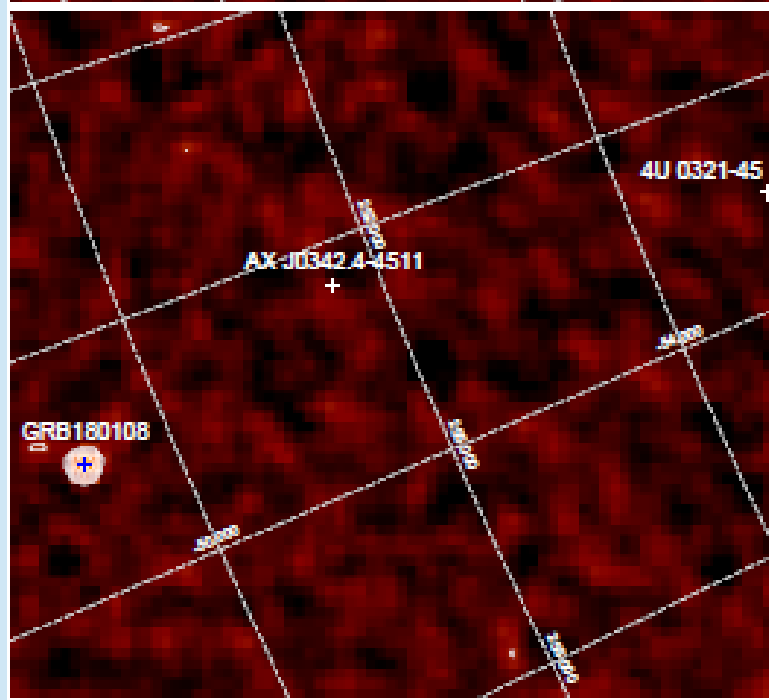
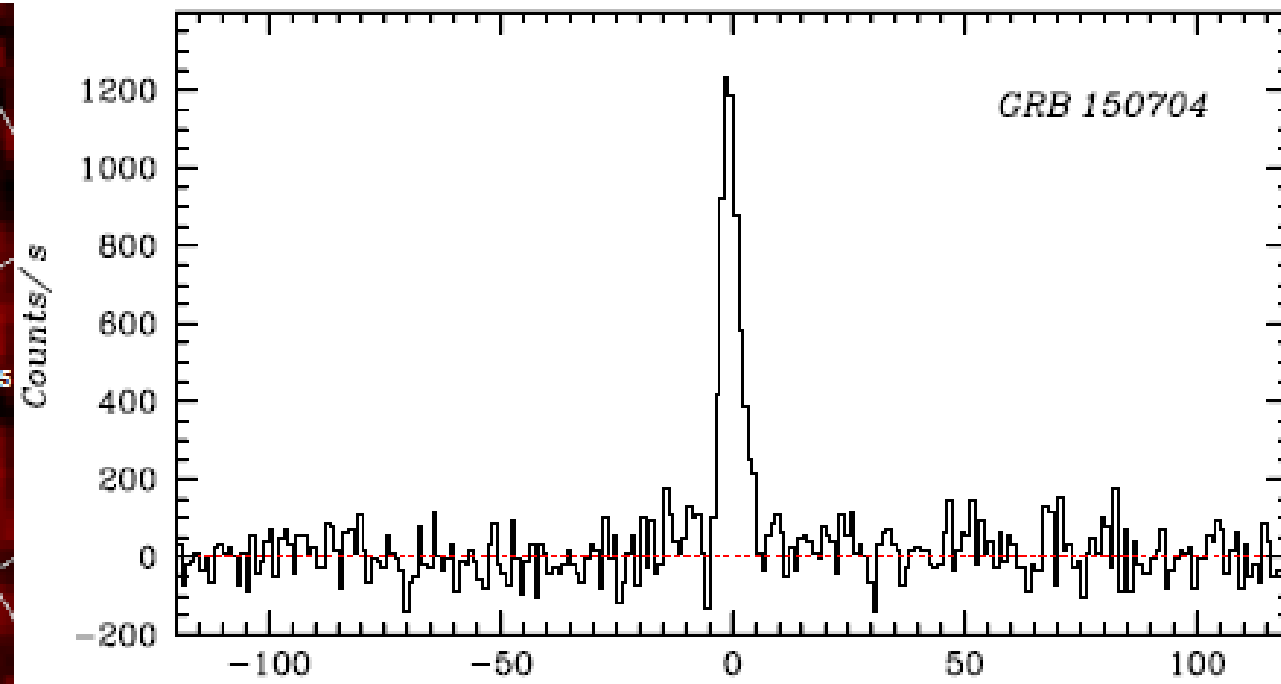
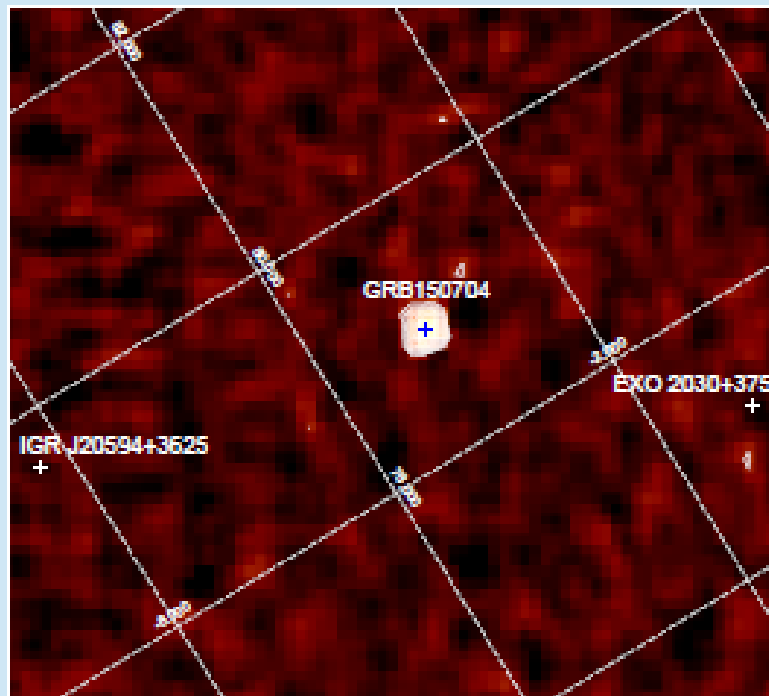
Spectrum of GRB 161209 allows a high energy cutoff (E_{peak}) to be measured



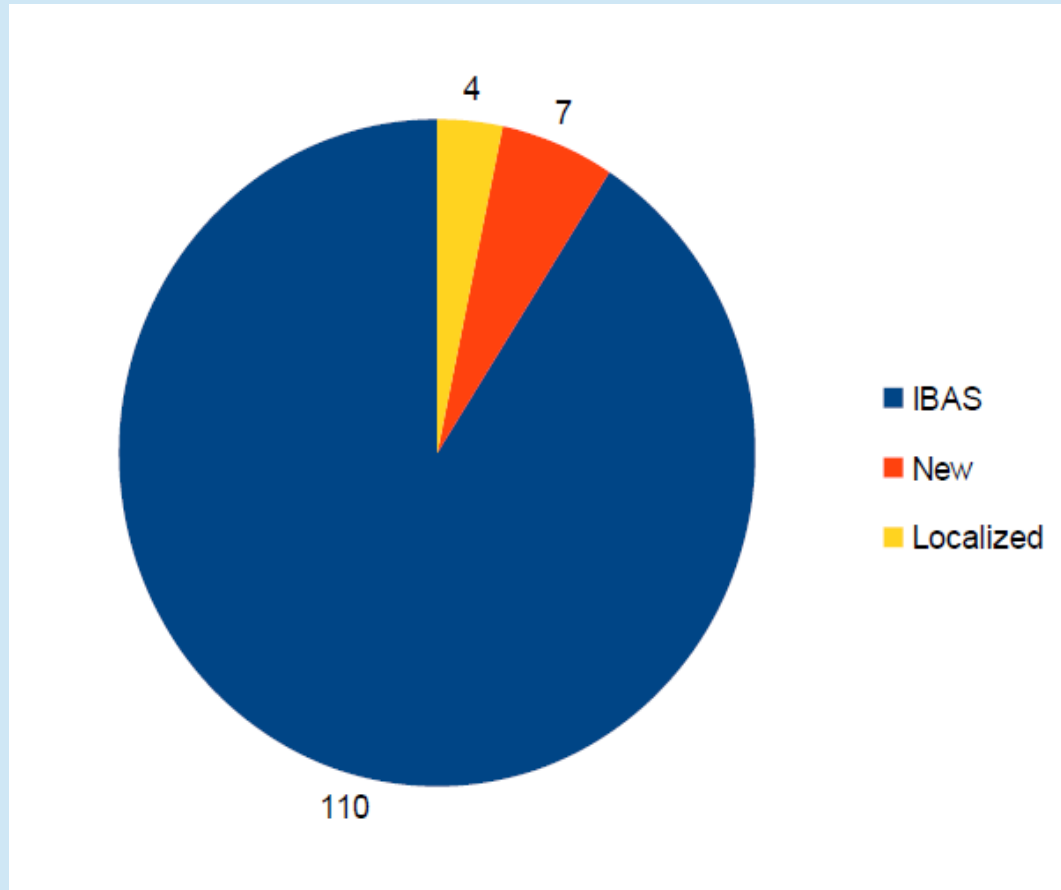
Localization of previously known GRBs

Всплеск (дата)	ΔE^a	T_0^b (UTC)	T_c^b	T_{90}^g	C_p^d	S/N^e		$F^ж$	Координаты ^з		Миссия ^и
						LC	IM		R.A.	Decl.	
		hh:mm:ss	с	с	отсч/с	σ	σ	отсч.	град.	град.	
GRB 070912	X	07:32:21	27	41	816	19	14.5	11238	264.608	-28.706	ASIJ <u>K</u> ^к
	G	07:32:21	13	36	390	10	—	3280			
GRB 130109	X	04:56:25	7	9	2787	35	19.5	9770	8.180	19.085	K
	G	04:56:25	9	17	726	9	—	2751			
GRB 150704	X	02:14:09	9	34	1231	21	14.2	6815	311.343	37.927	<u>K</u>
	G	02:14:09	8	15	498	9	—	2126			
GRB 180108	X	10:15:37	31	52	734	11	8.4	9240	58.711	-46.267	K



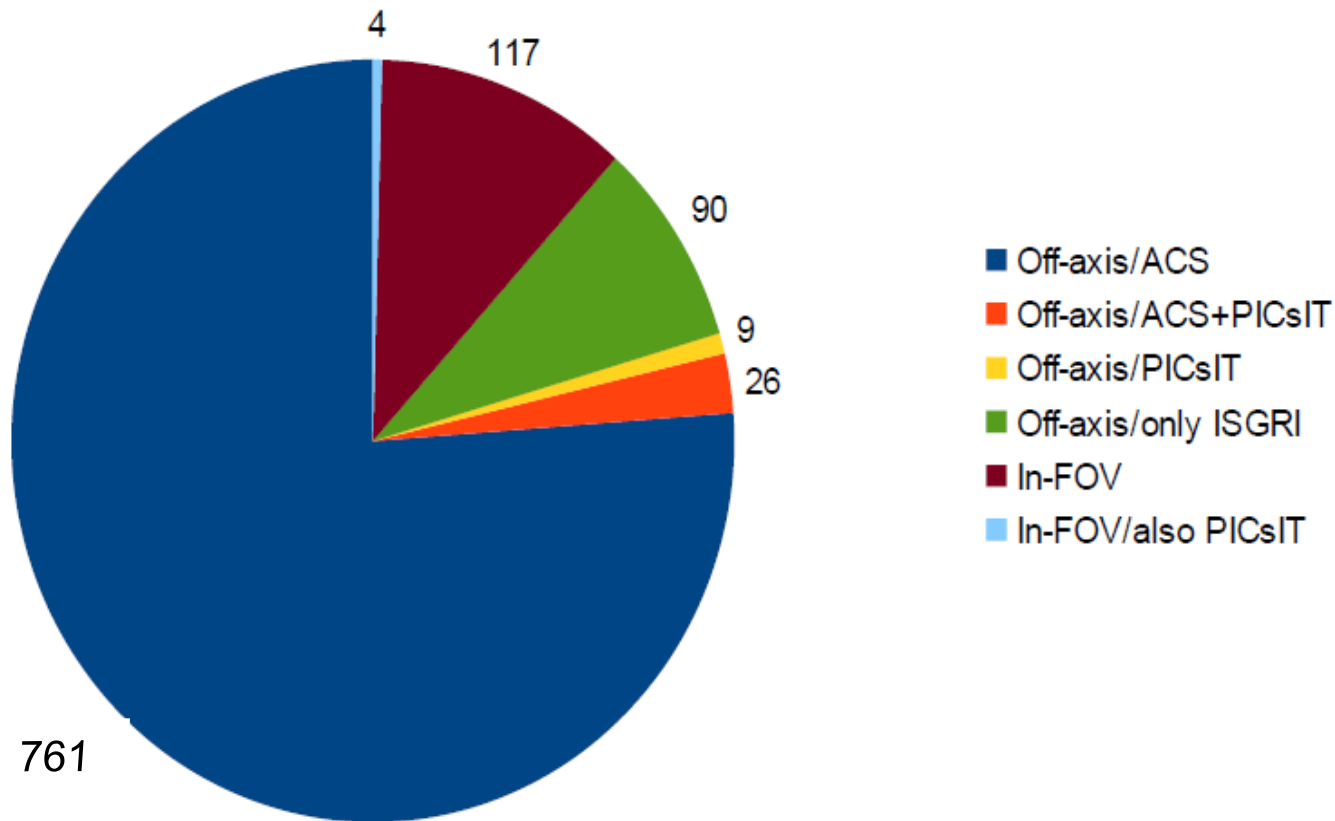


GRBs found within IBIS FOV



7 new GRBs and 4 known but newly localized GRBs add 10% to the GRBs found by IBAS within IBIS/ISGRI FOV

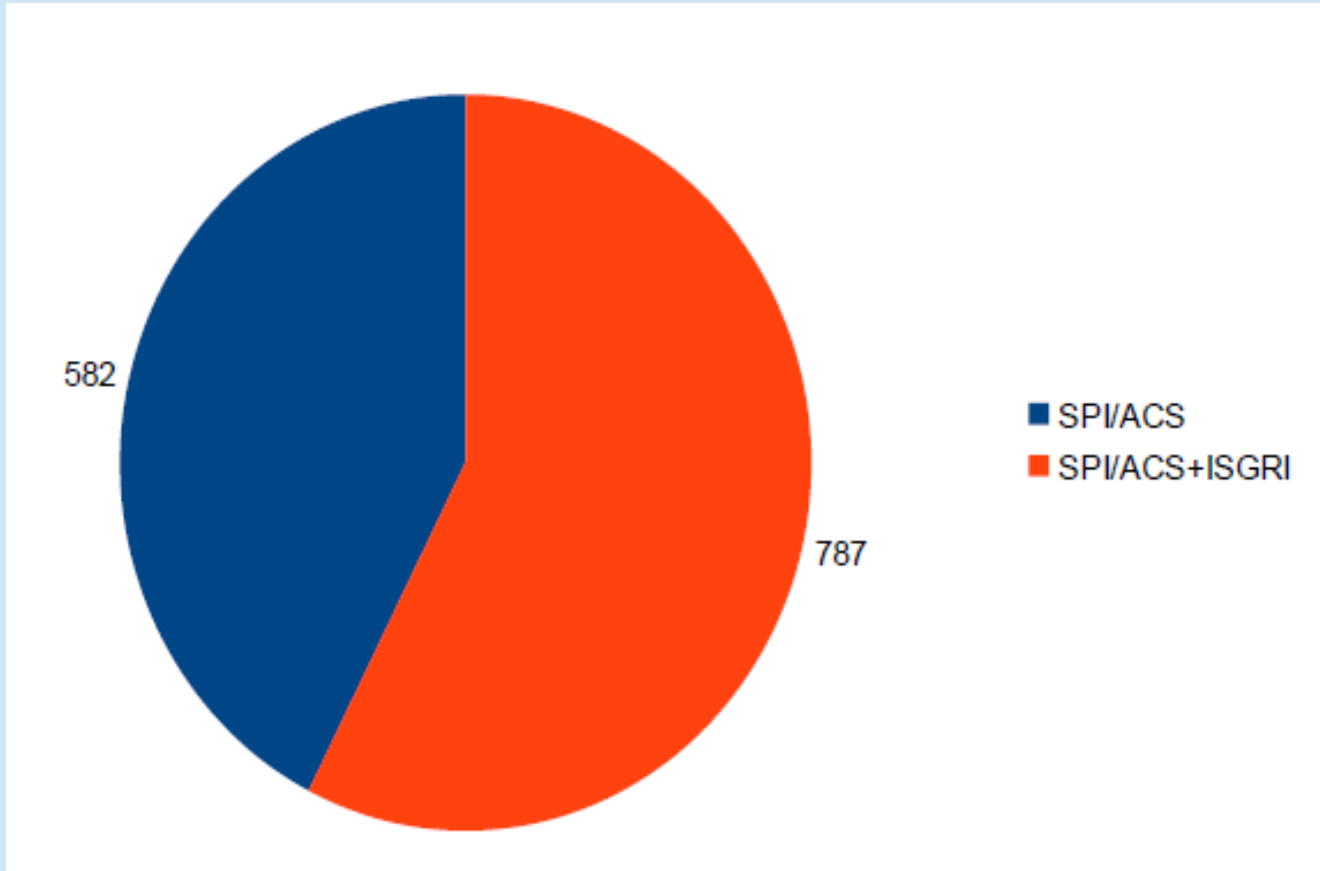
GRBs found by IBIS/ISGRI



1010 GRBs in total (121 in FOV and 889 outside FOV)

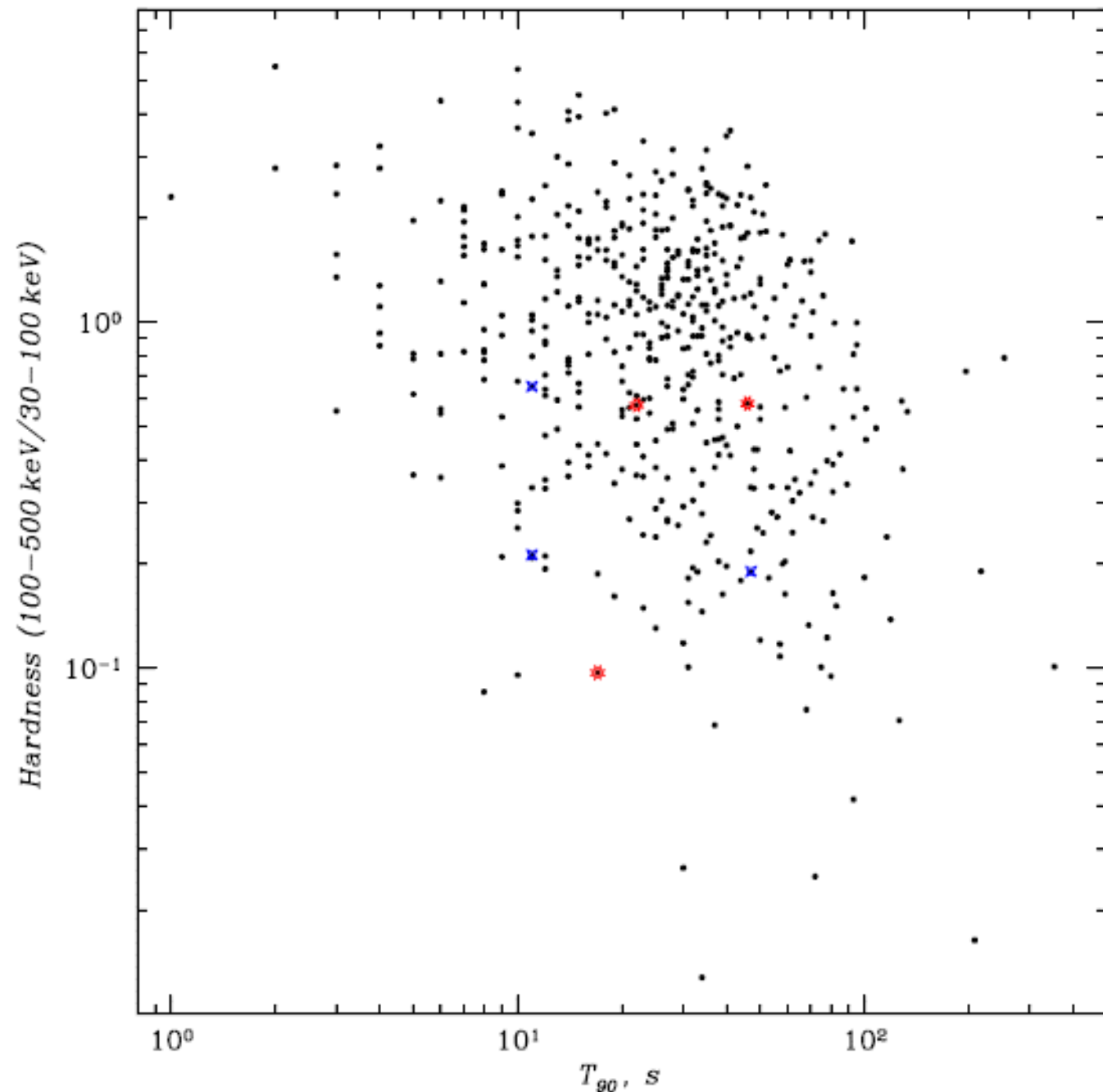
There is a significant fraction of off-axis ISGRI GRBs (~90) not detected by SPI/ACS.

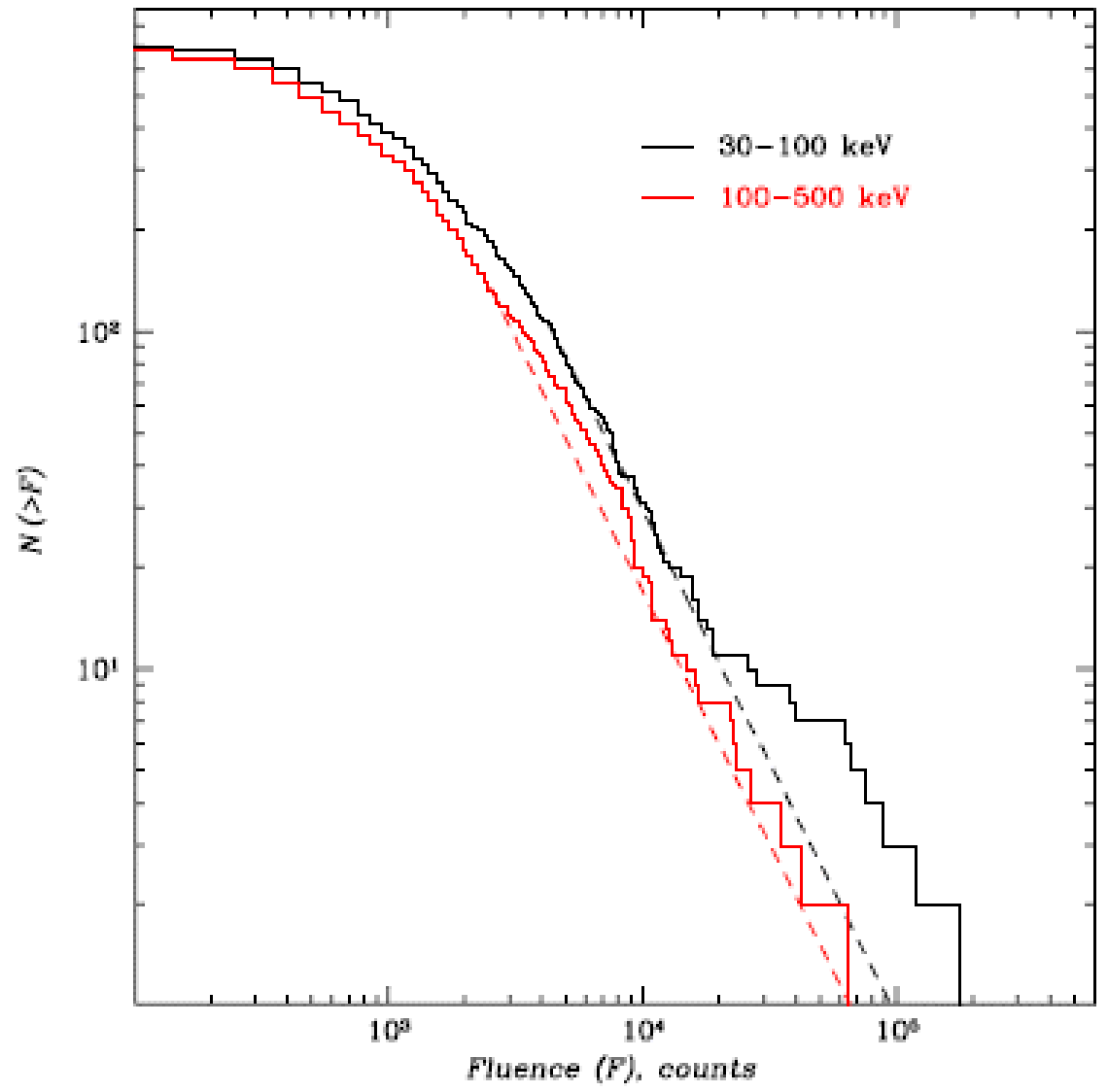
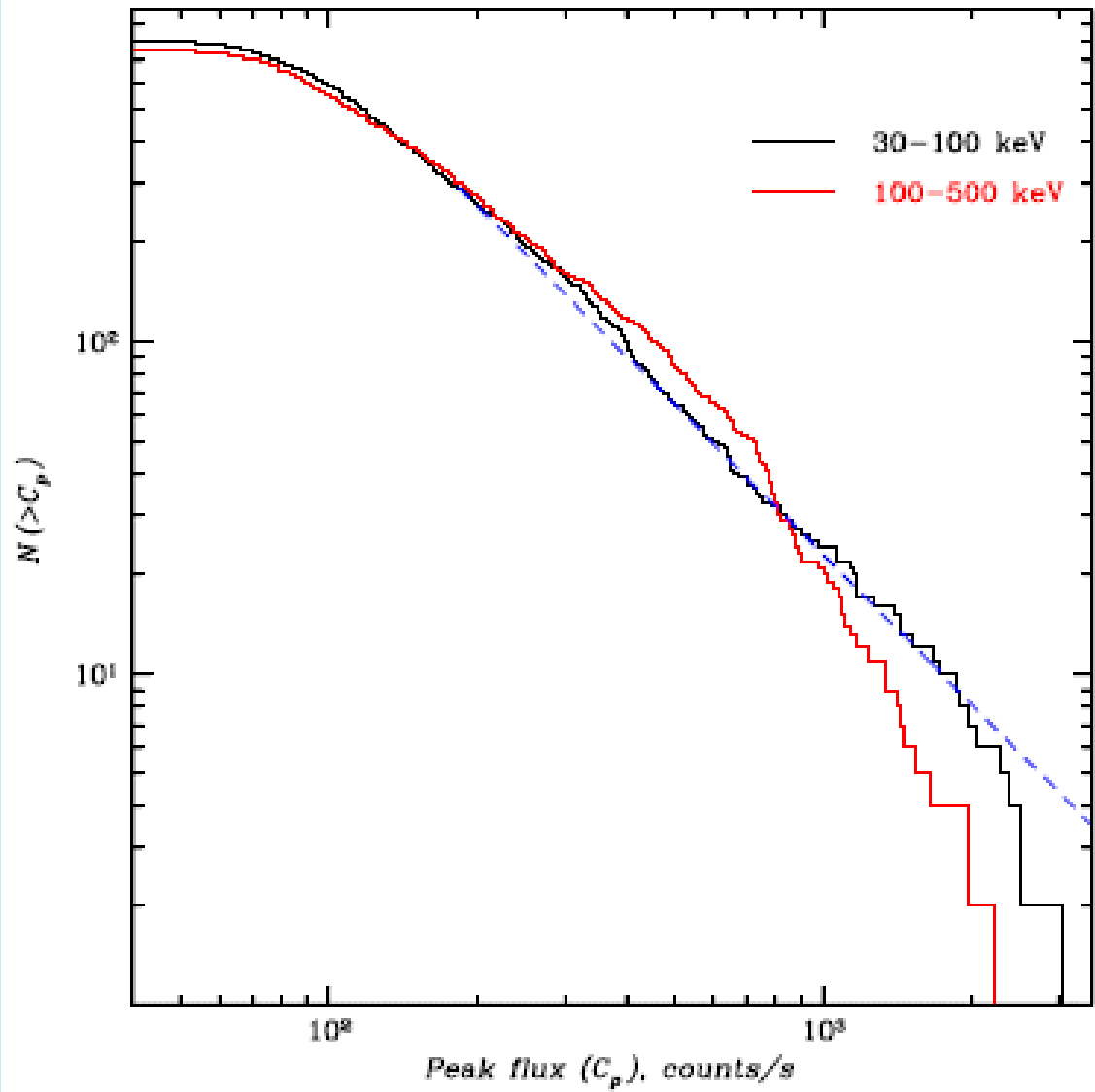
GRBs found by IBIS/ISGRI

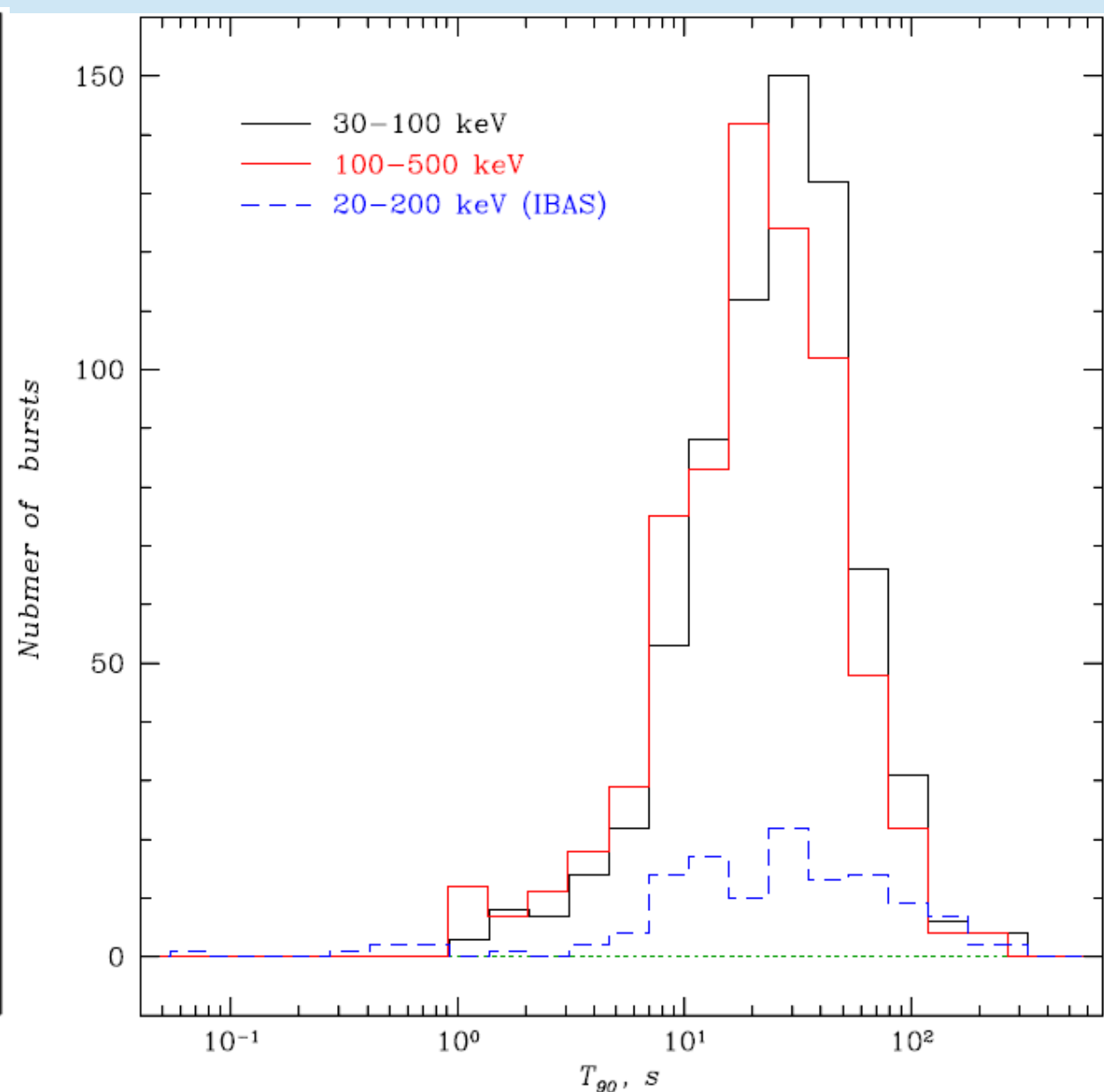
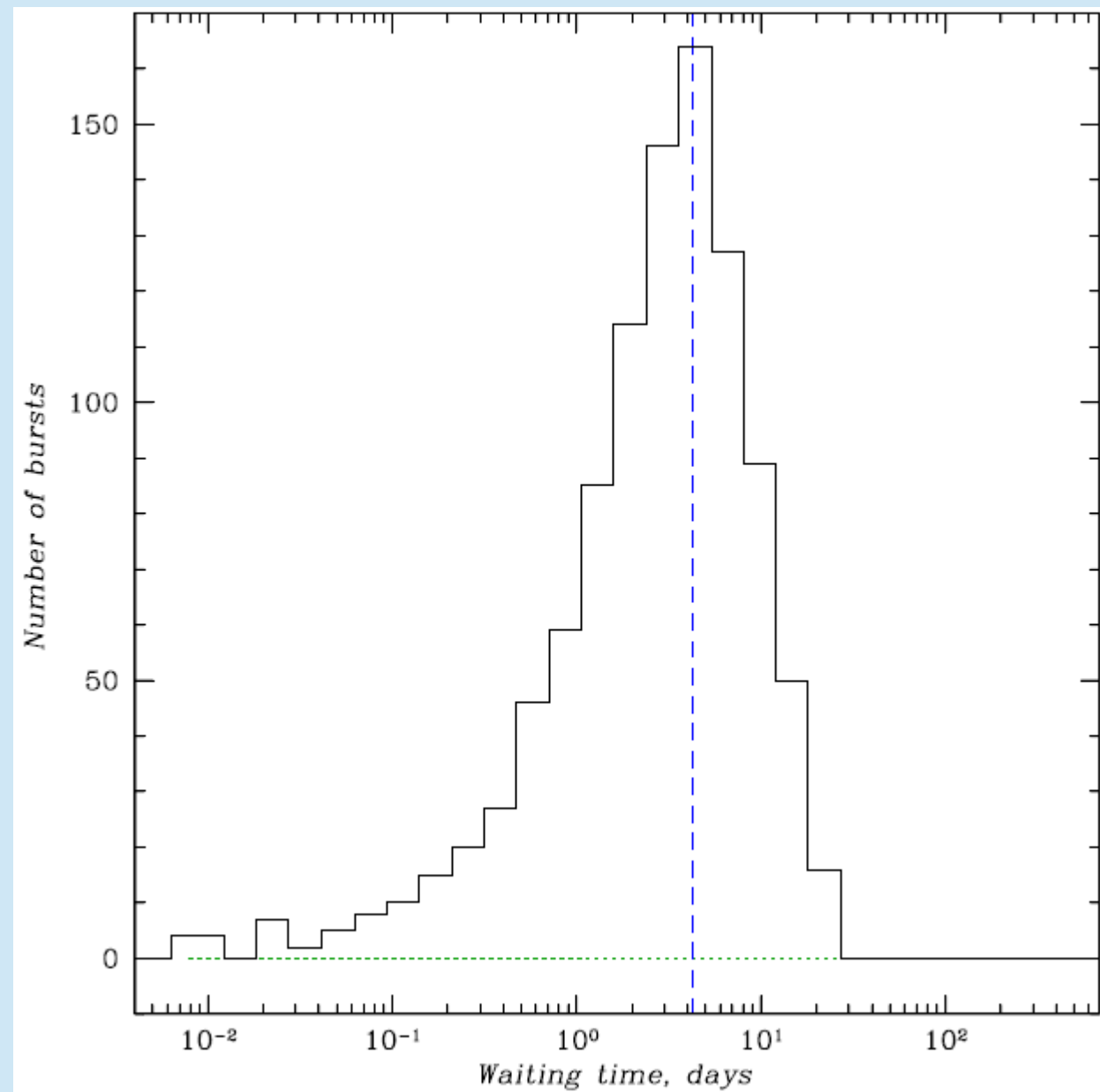


Fraction of off-axis ISGRI events among GRBs detected by SPI/ACS
(1369 ACS selected events with $T_{90} > 1$ s, $S/N > 3$, $C_p > 100$)

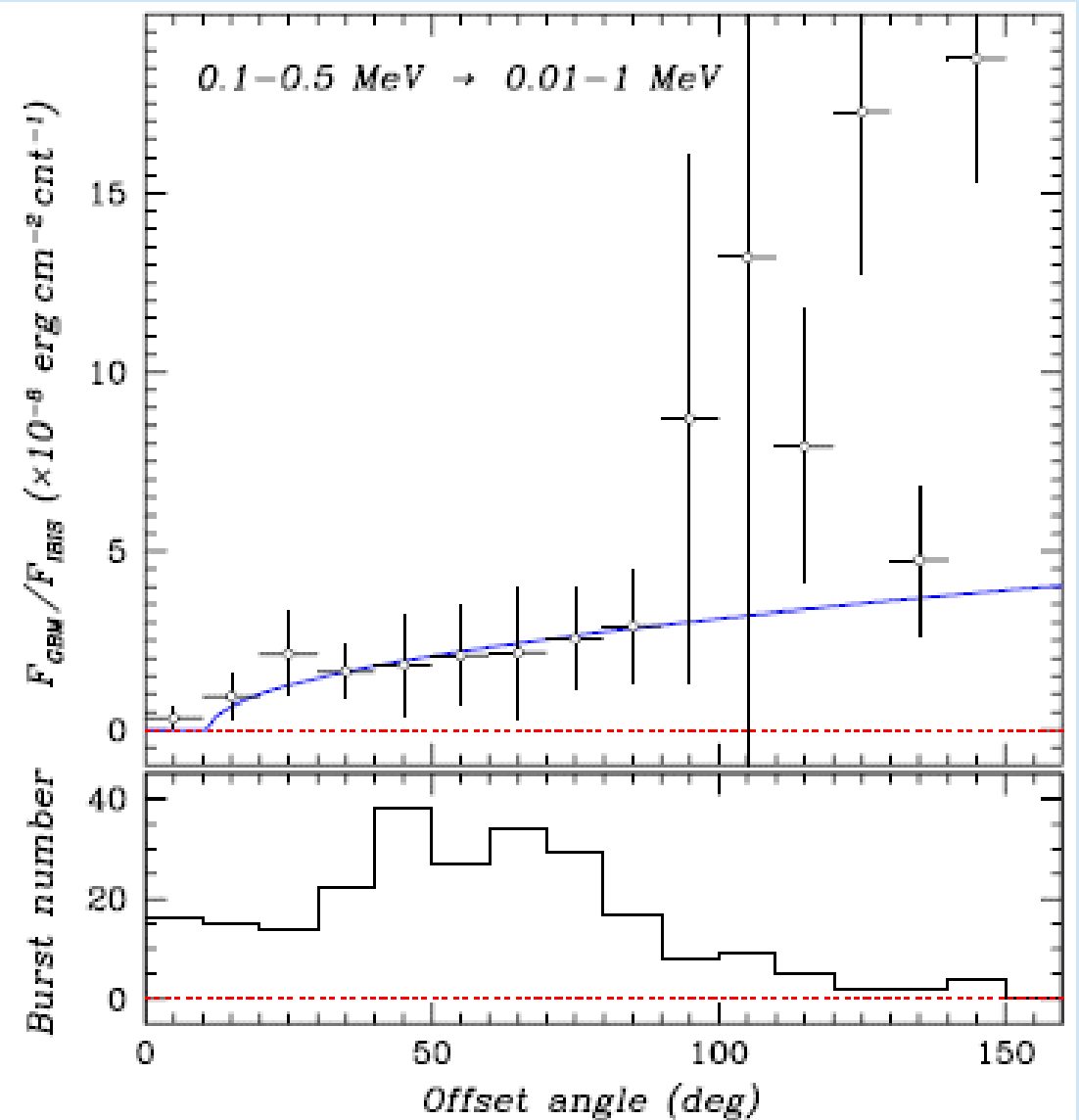
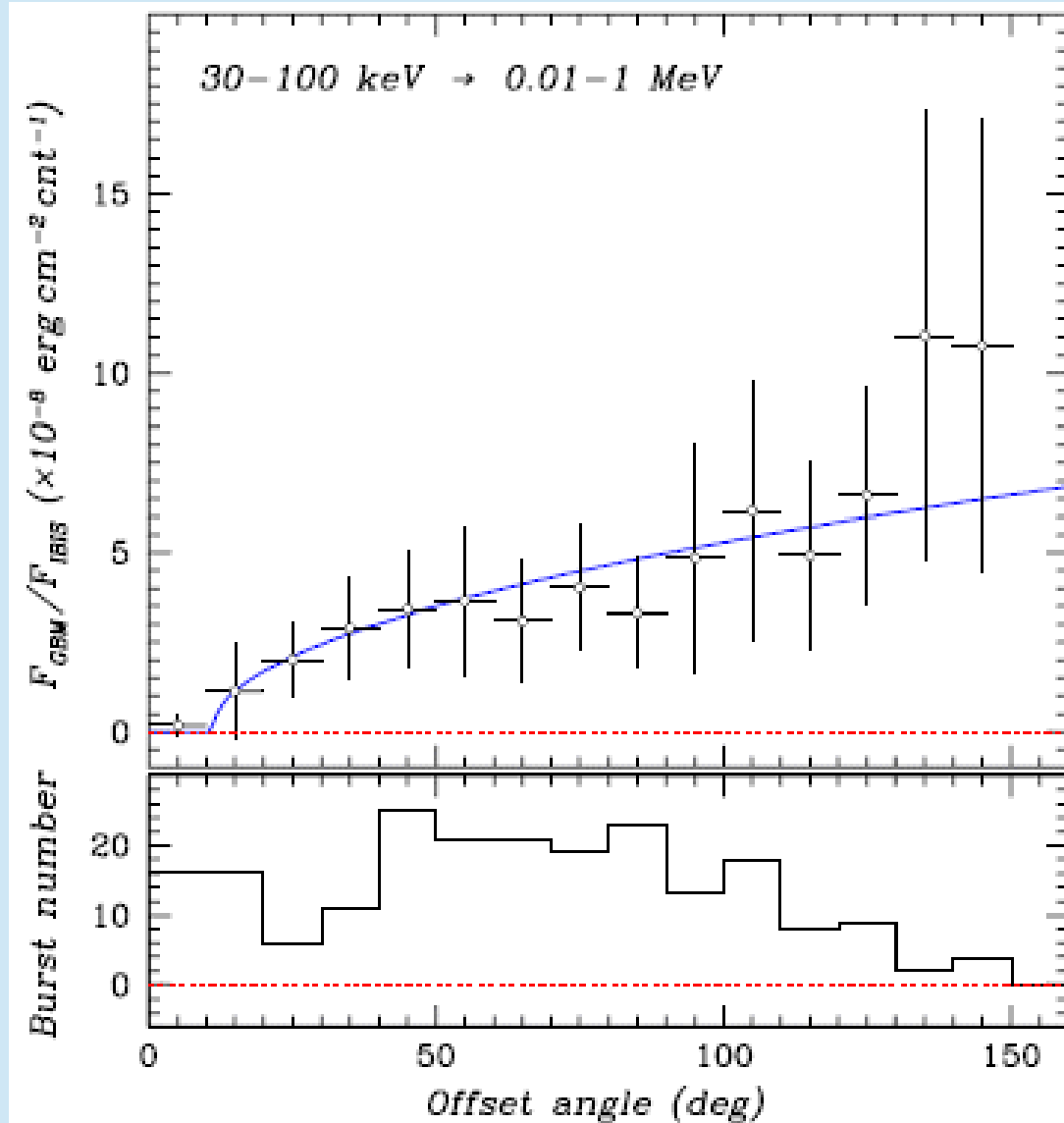
Some GRBs correlations
(all 1010
IBIS/ISGRI
events)







Observing off-axis GRBs by IBIS/ISGRI



CONCLUSIONS - 1

- 11 new well localized (<2 arcmin) GRBs were detected that is 10% of all IBAS events (7 completely new and 4 newly localized ones)
- Large amount (~ 890) of GRBs were detected outside IBIS FOV, they were previously observed by at least one other mission (110 bursts - by only one mission, mainly SPI/ACS or KONUS/Wind)
- This amount (890) is of about 2/3 of SPI/ACS GRB events (1369) detected in the same time interval, that shows a very high sensitivity of IBIS/ISGRI to off-axis bursts.
- 90 bursts of 890 were indeed not registered by SPI/ACS, that shows importance of studying the GRB population detected by IBIS/ISGRI

CONCLUSIONS - 2

- The total catalogue of GRBs detected by IBIS/ISGRI is compiled, it has 1100 events and located at <http://hea.iki.rssi.ru/integral/ibisgrbs>
- Note that there is still a huge amount of IBIS/ISGRI events that does not coincide with any known GRB and were not in the IBIS FOV
- It is necessary to monitor IBIS/ISGRI in real time for off-axis events. This may provide us with some GRBs not detected by SPI/ACS (and with spectral information on all GRBs !)
- Comparing the catalogue with that of Fermi/GBM we selected a sample of the events seen by both the missions and calibrated the flux of GRBs detected by IBIS/ISGRI strongly off-axis (outside its FOV). This calibration dependence can be used to estimate the flux from X-ray/gamma-ray counterparts of the LIGO/VIRGO GW events.

Thank you

Каталог

Всего событий	1010
Новых кандидатов в ГВ	7
Локализовано событий	4
Подтверждено событий	110
События IBAS	113
События ACS	787
События PICsIT	39
Событий вне поля зрения	886

IBIS/PICsIT

Всего событий	39
В нашем каталоге	39
В каталоге IBAS	4
Только в нашем каталоге	4
В каталоге ACS	26

SPI-ACS

Всего событий	~13500
Отобранных (S/N>3;T>1;CP>100)	1369
В нашем каталоге	787
Нет у Орли	59