Timing properties of the GRBs observed by INTEGRAL/SPI-ACS

Volodymyr Savchenko

Moscow 2013

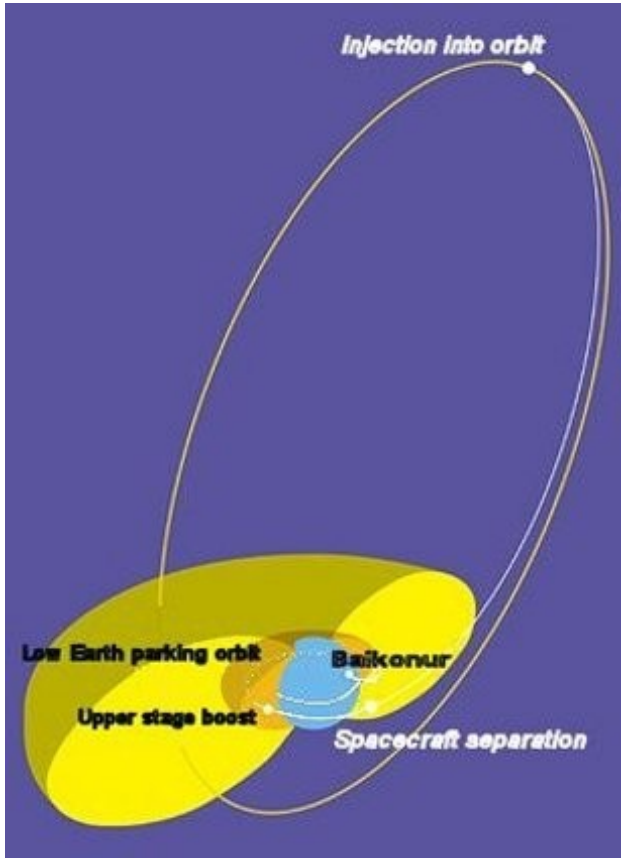
Plan of the talk

- INTEGRAL/SPI-ACS GRB sample
- Other GRB-like activity in SPI-ACS
- INTEGRAL/ISGRI and a special GRB

INTEGRAL

INTErnational Gamma-RAy Laboratory (ESA, Russia, NASA)

Launched in 2002, still almost perfect health, will operate at least till 2015



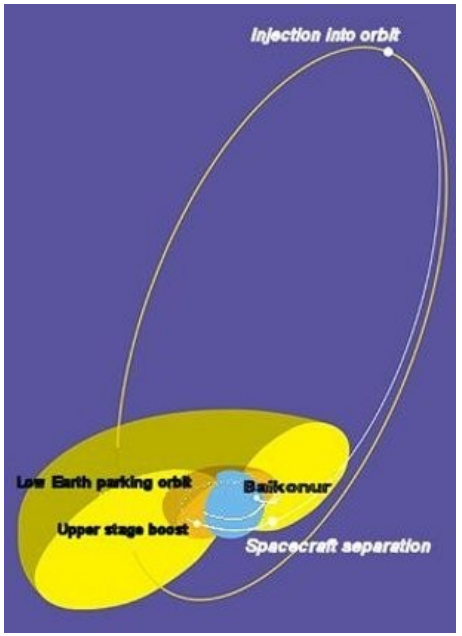
Highly eccentric orbit with the period of 2.7 days

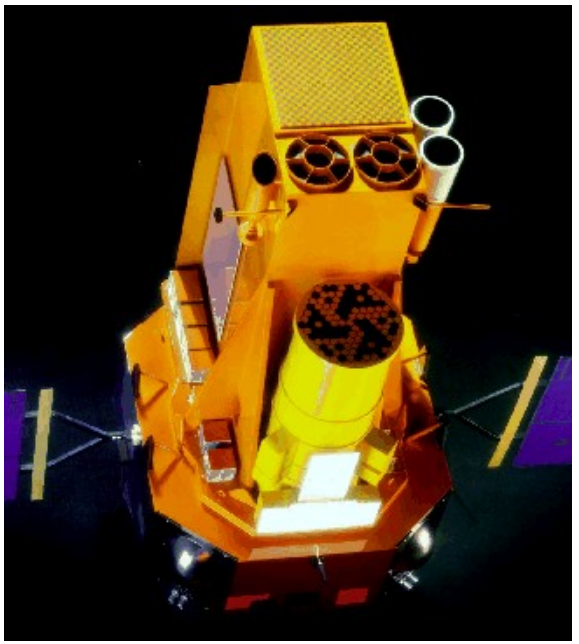
INTEGRAL

Allows uninterrupted observations for 2.7 days in stable conditions: essential for transients

No on-board trigger: all information is always preserved

Constant tracking with ground stations: data arrives and analysed in seconds after the event





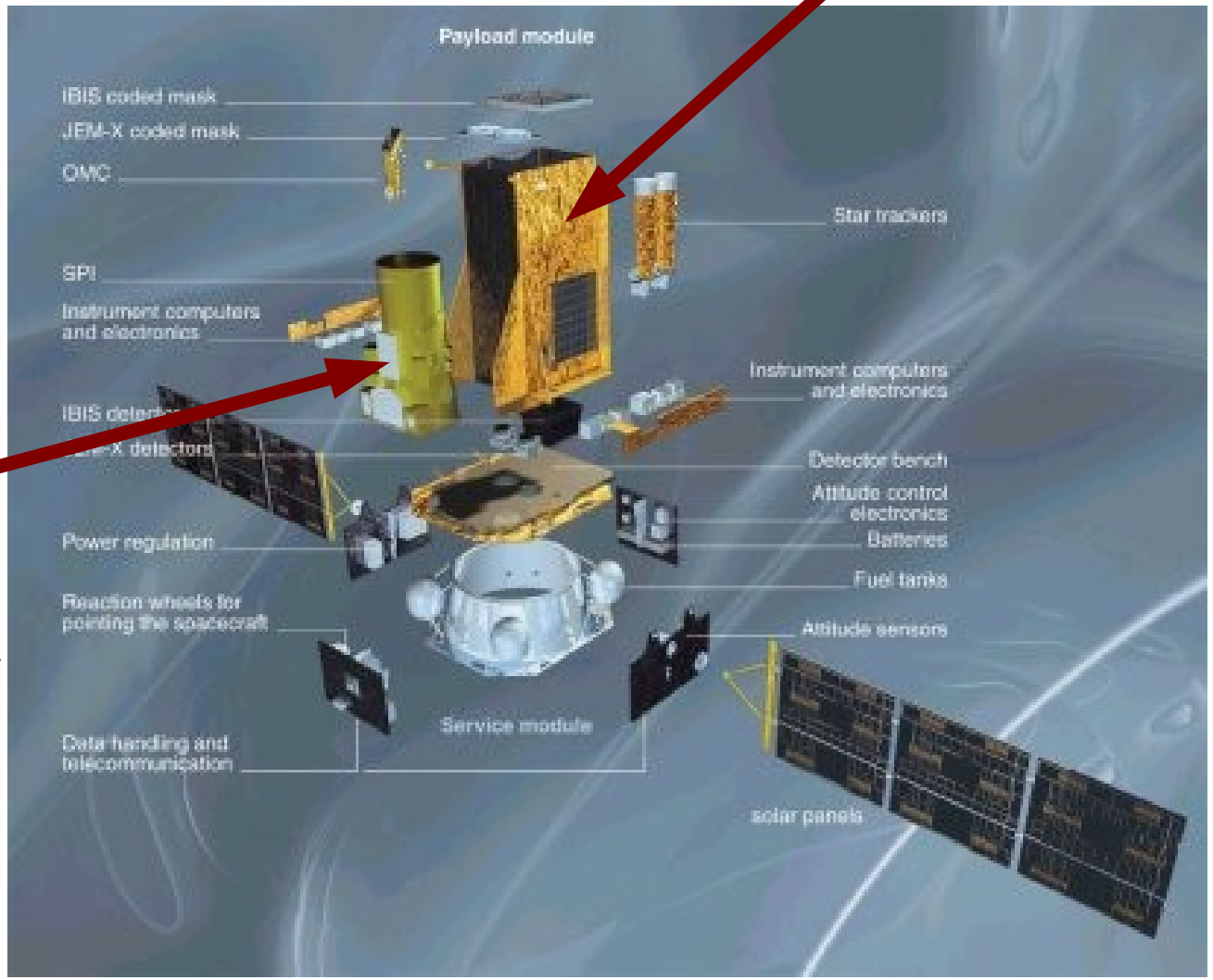
Highly eccentric orbit with the period of 2.7 days

INTEGRAL instruments

IBIS (ISGRI+PICsIT):

20keV – 10MeV

12' angular resolution



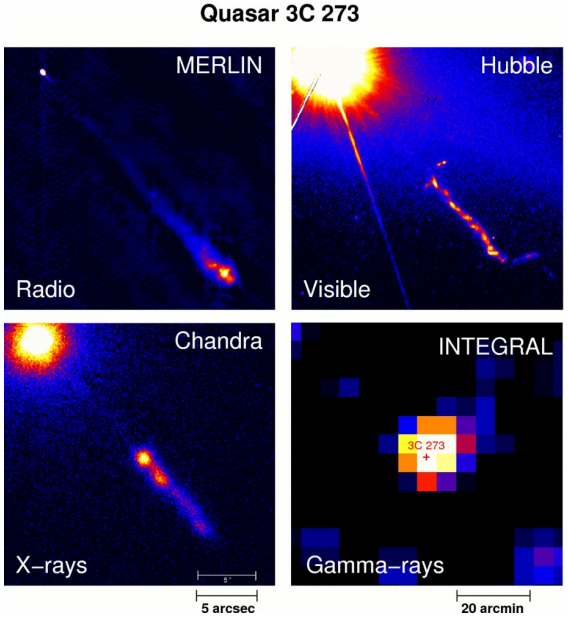
SPI

100 keV – 10 MeV

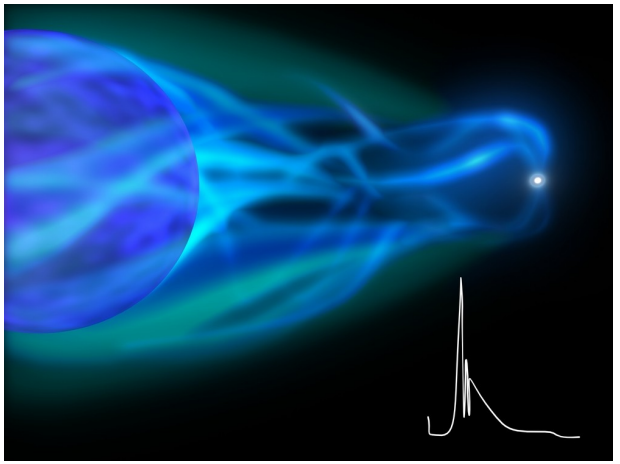
spectral resolution

2 keV at 1 MeV

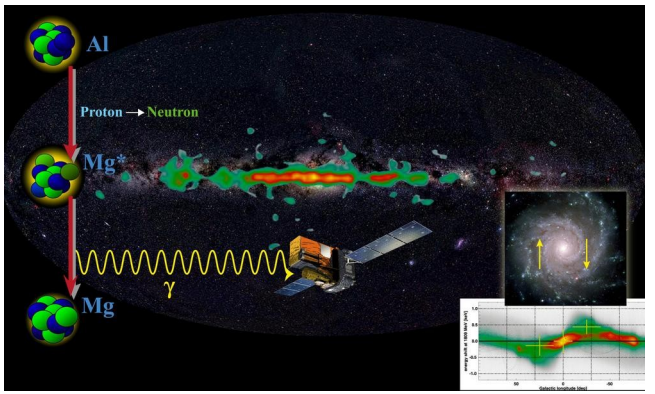
INTEGRAL highlights

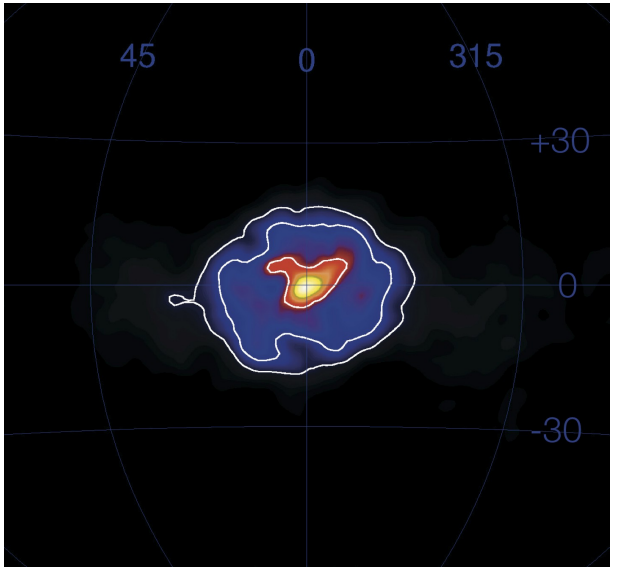


X-ray binaries, AGN, magnetars



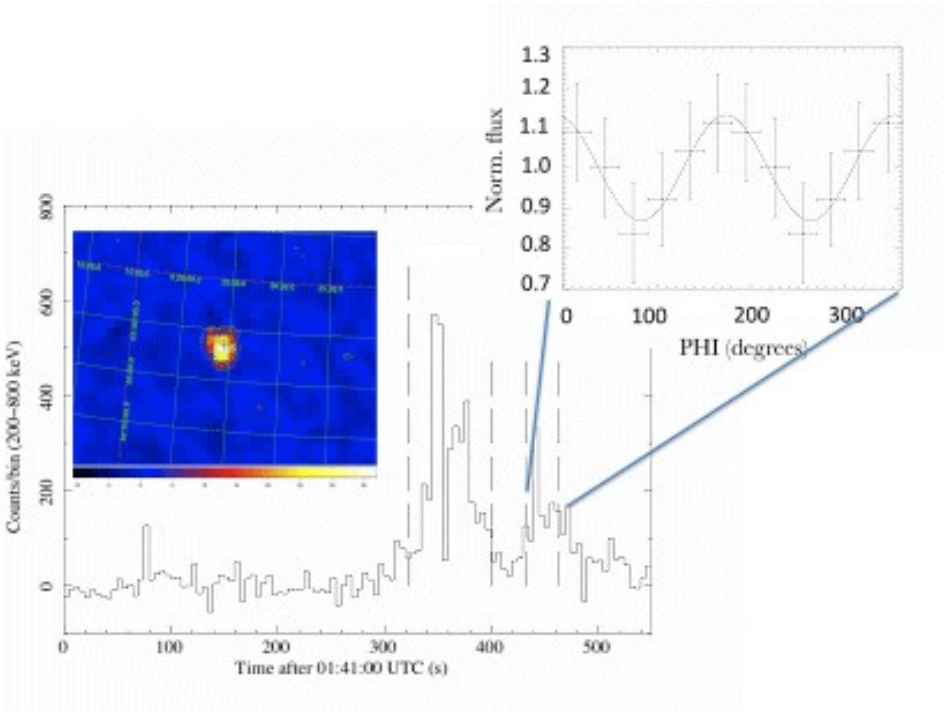
Diffuse 511 keV and Al26 lines

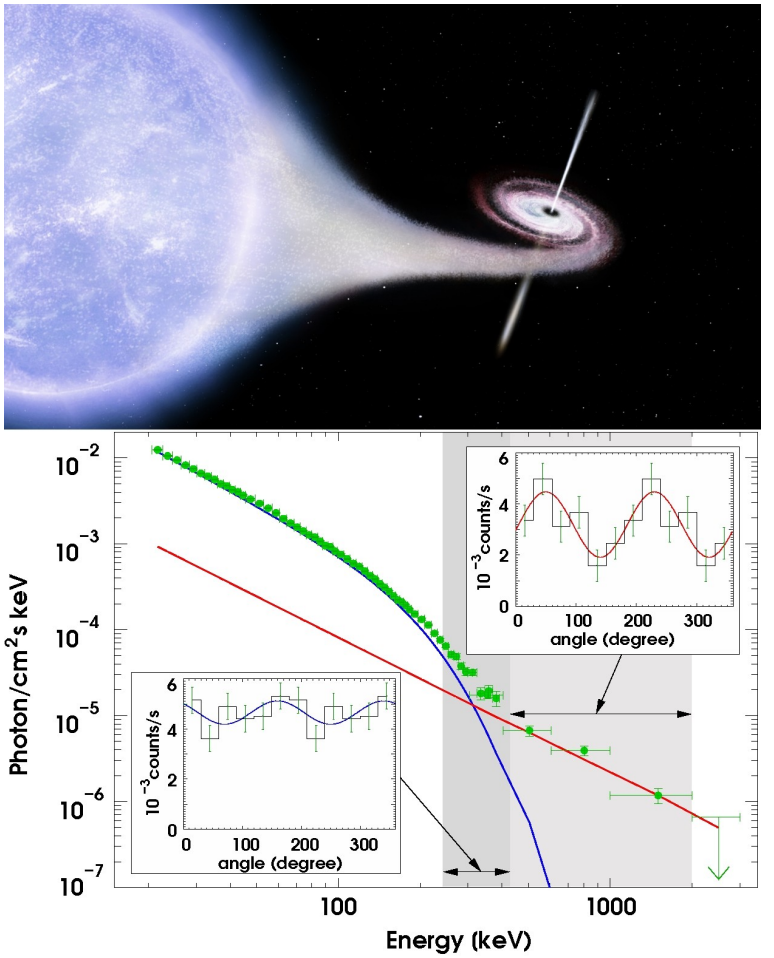




Gamma-ray polarization measurements

Both SPI and IBIS can be used to measure gamma-ray polarization by measuring direction of of Compton electron

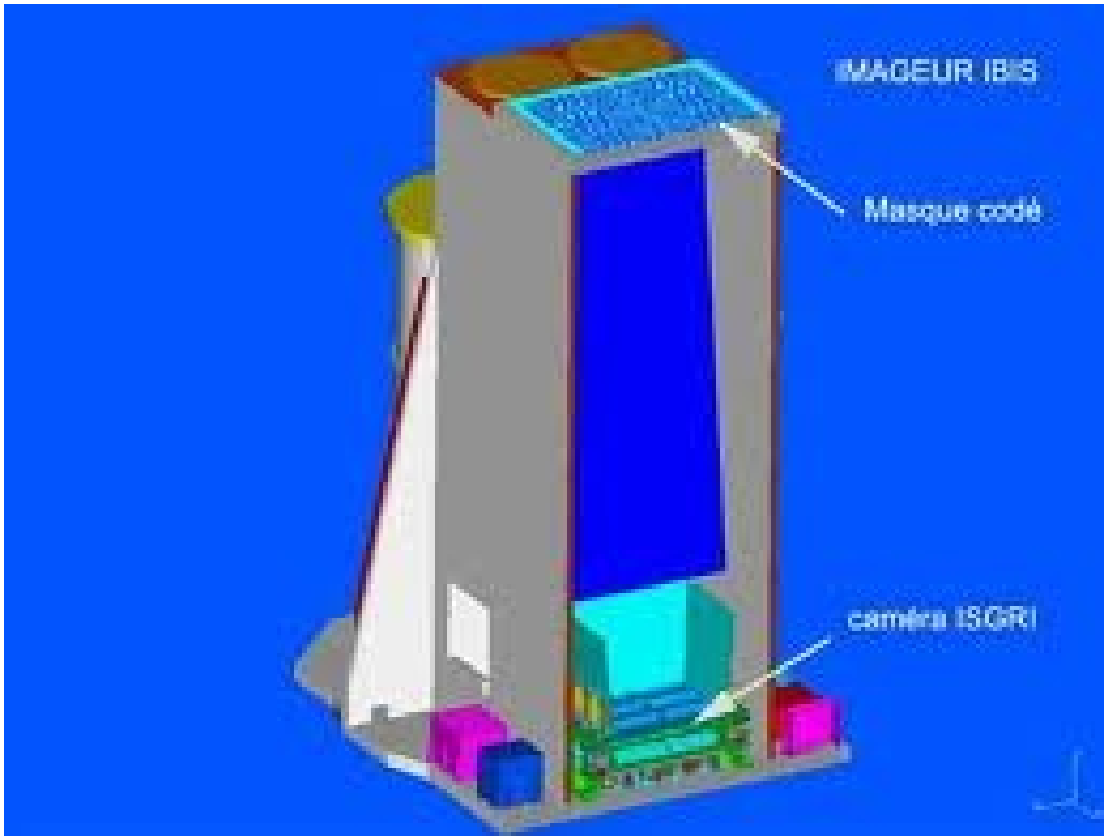


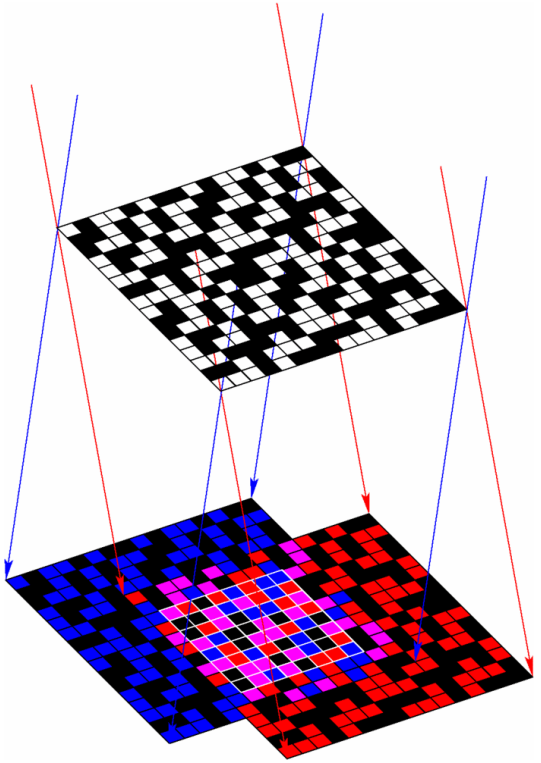


D. Gotz, Philipe Laurent et al in Paris

Precise satellite model is essential for these measurements

INTEGRAL IBIS: ISGRI and PICsIT

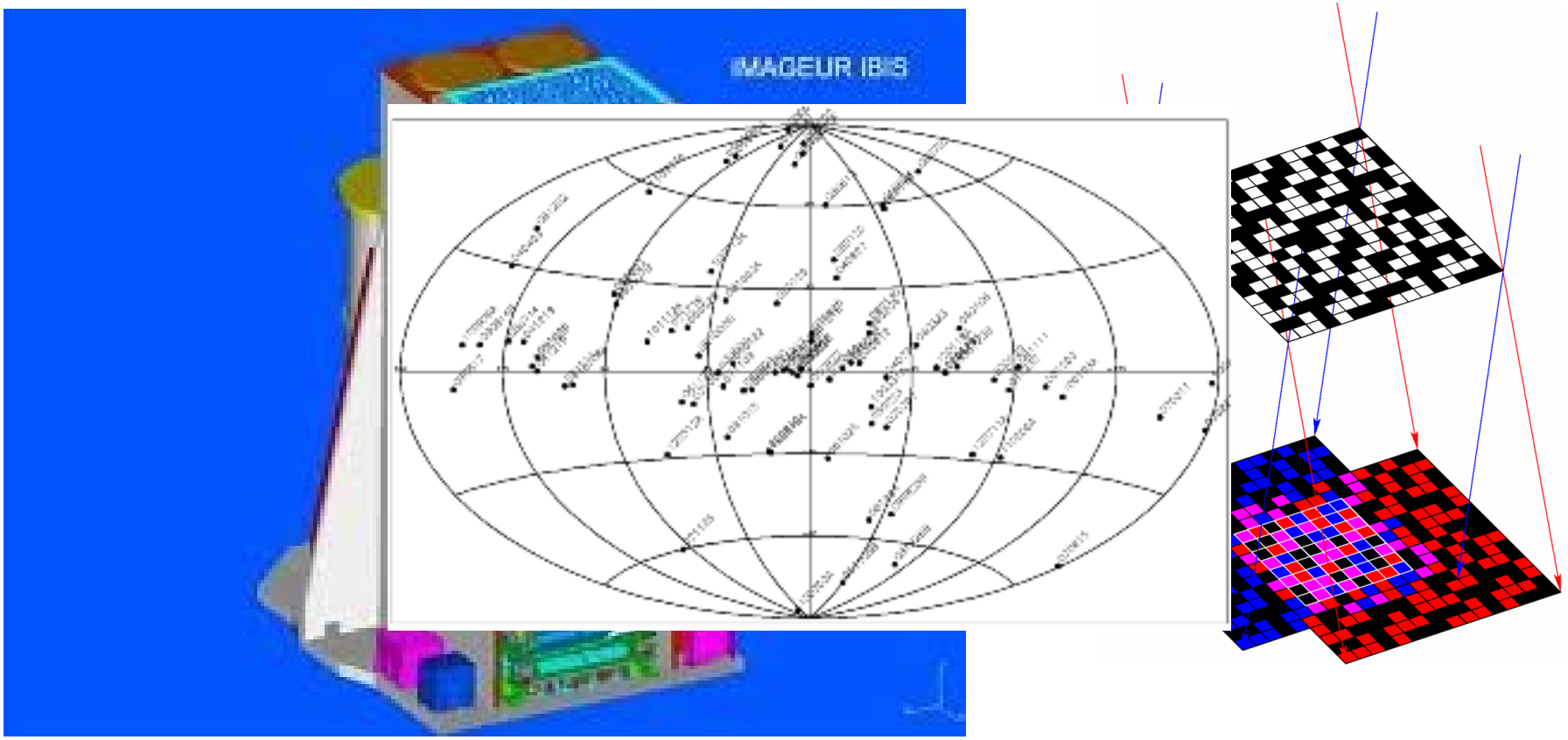




Instruments of INTEGRAL use coded mask for to project a shadow on the detector.

Provide high sensitivity in relatively large field of view (~15x15 deg)

INTEGRAL IBIS and SPI: GRBs

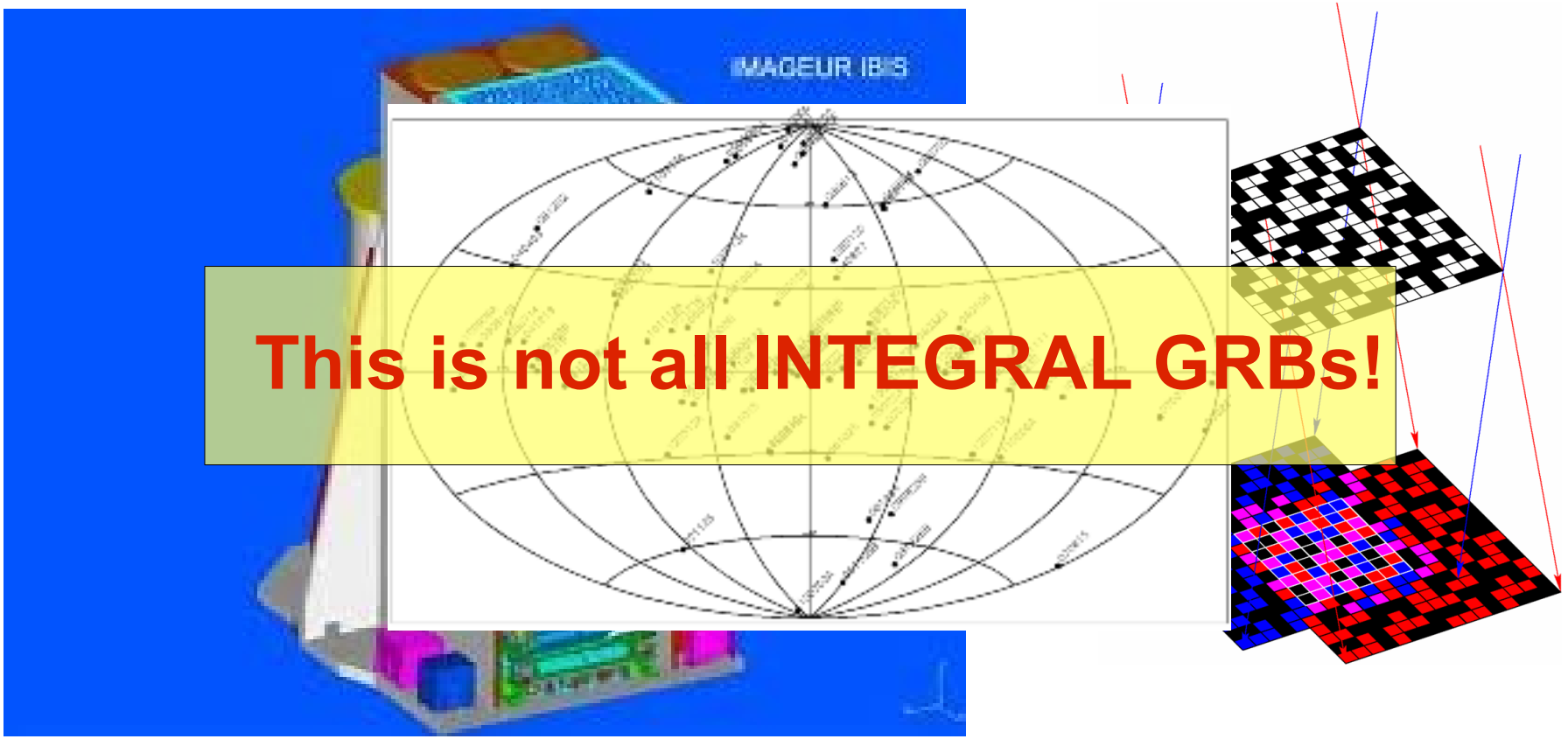


~100 GRBs in 10 years, follow galactic plane, as induced by the observational strategy (e.g. Bosnjak at el 2013), narrow FoV!

Not so wide energy band (for the purposes of GRB 20-500 keV).

There is no strategy to follow the bursts (why would it be important?.. see later)

INTEGRAL IBIS and SPI: GRBs



This is not all INTEGRAL GRBs!

~100 GRBs in 10 years, follow galactic plane, as induced by the observational strategy (e.g. Bosnjak at el 2013), narrow FoV!

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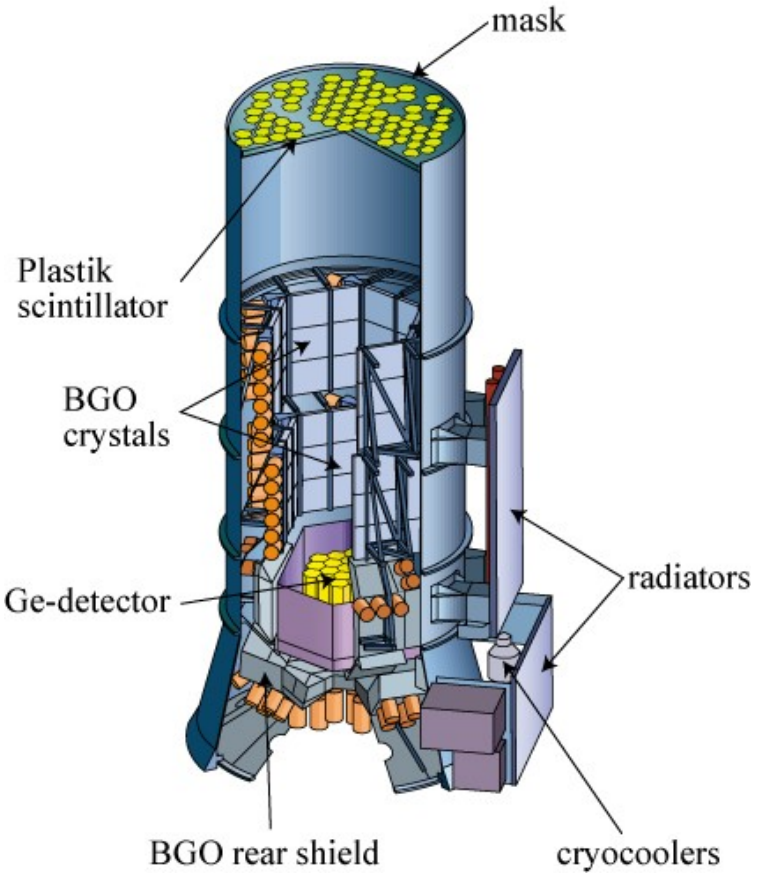
INTEGRAL SPI-ACS

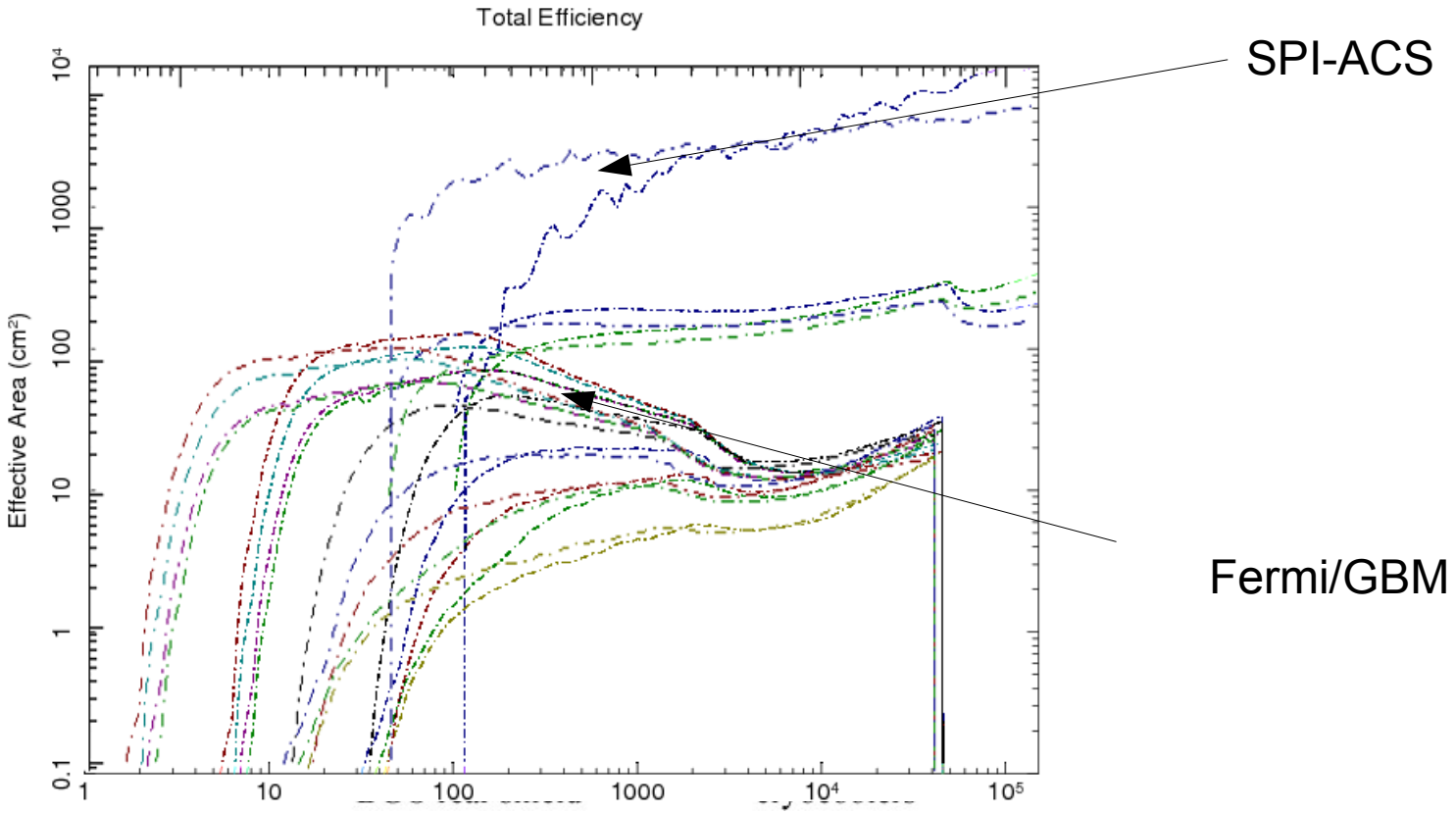


SPI-ACS is 512kg of BGO scintillator, viewed by 81 photomultipliers triggering on photons above ~100keV.
For some directions and energies it reaches effective area of $1m^2$

50 ms light curve from 100keV for (almost) continuously 11 years!

But nothing else...

INTEGRAL SPI-ACS



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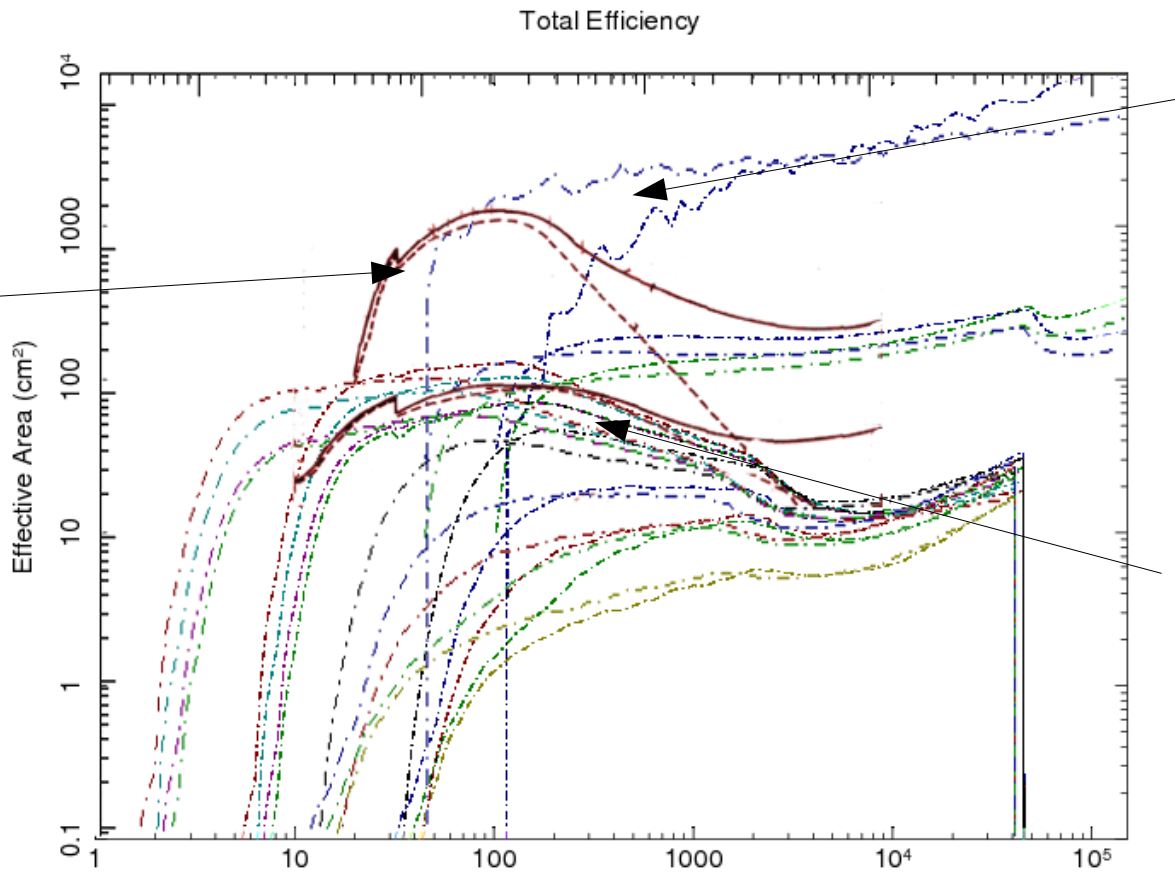

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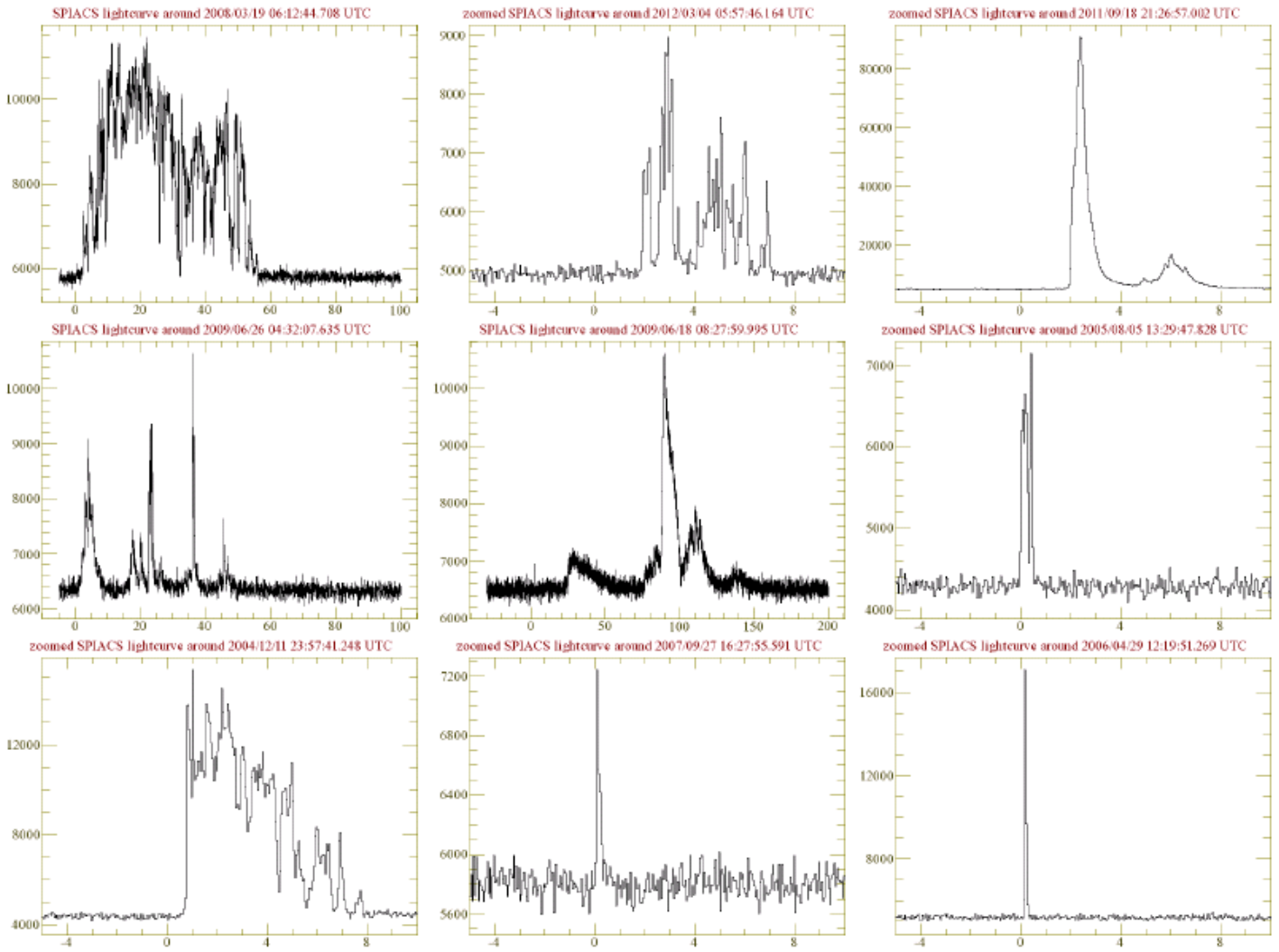


SPI-ACS

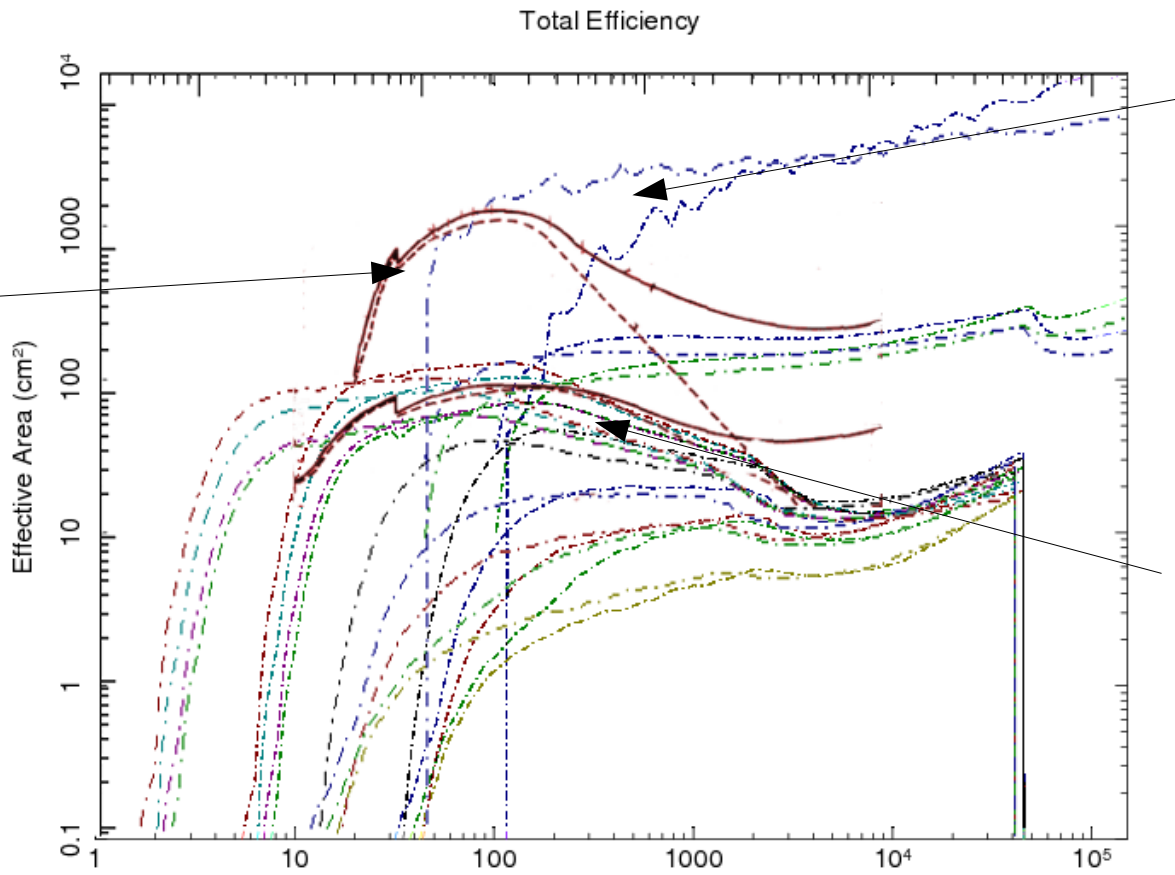
BATSE

ermi/GBM

For some directions and energies the effective area approaching ...m^2

50 ms light curve from 100keV for (almost) continuously 11 years!

INTEGRAL SPI-ACS



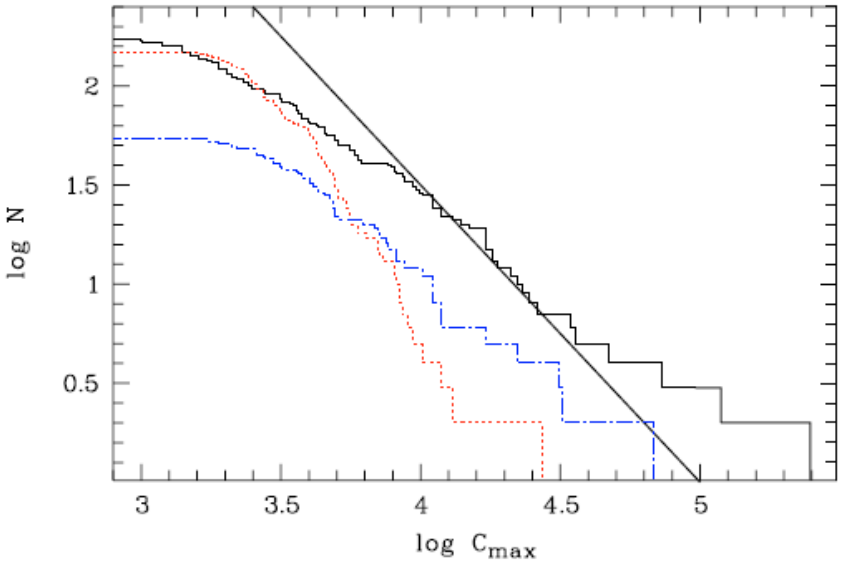
Large effective area, stable background and unbiased data taking makes it suitable for studying timing properties from 50ms to 10000s.

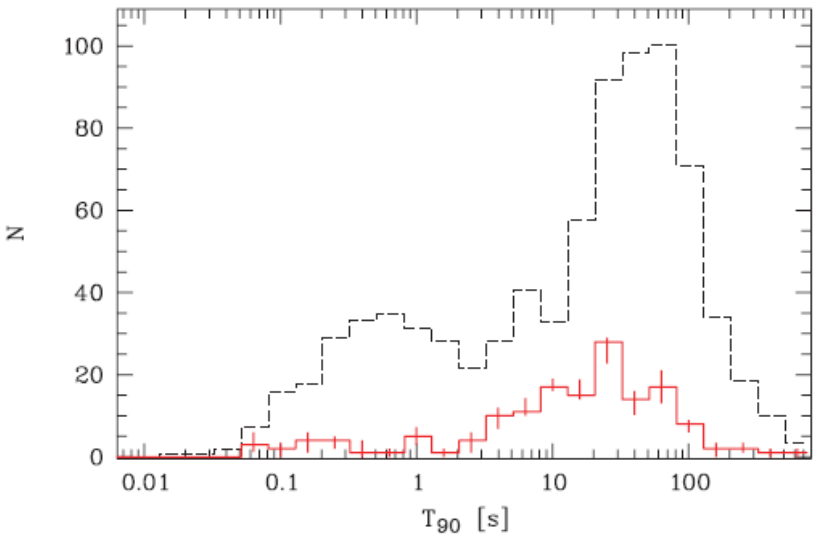
(but not much else)

The 1st SPI-ACS GRB catalogue

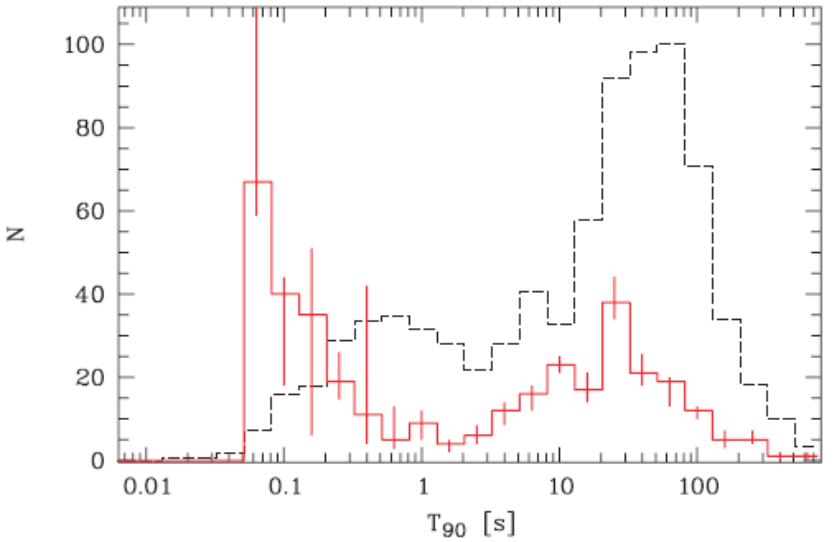
Rau et al 2005 made the first catalogue of confirmed and candidate bursts in the 22 months of SPI-ACS data.

Large number (30/day) of very short events - “the short spikes” was attributed to the high-energy cosmic ray interaction effects.





Red: confirmed GRBs

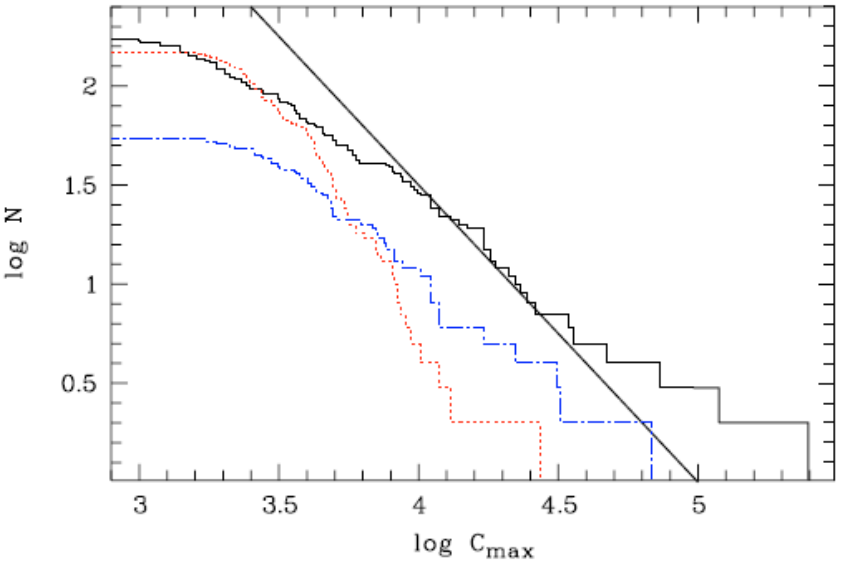


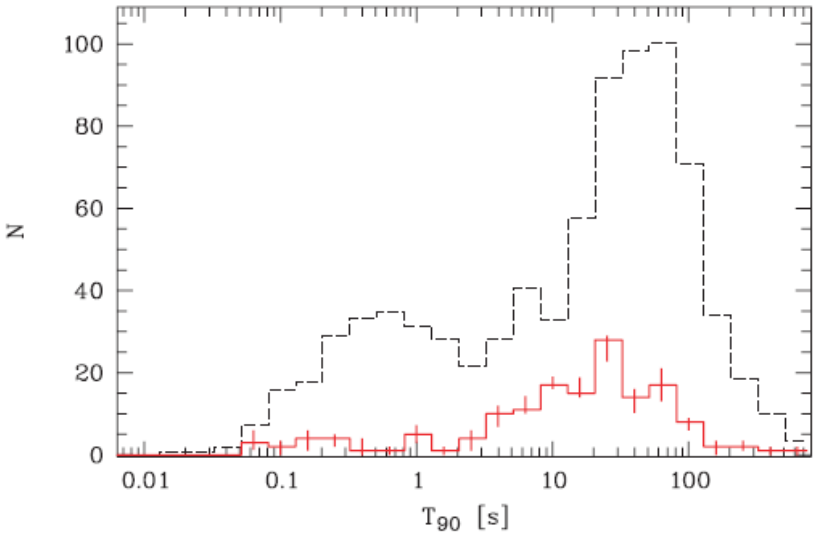
Red: candidate GRBs

The 1st SPI-ACS GRB catalogue

There may be a bias against low duration GRBs in many instruments, including BATSE (Norris et al 1984).

Large part of these events could be real





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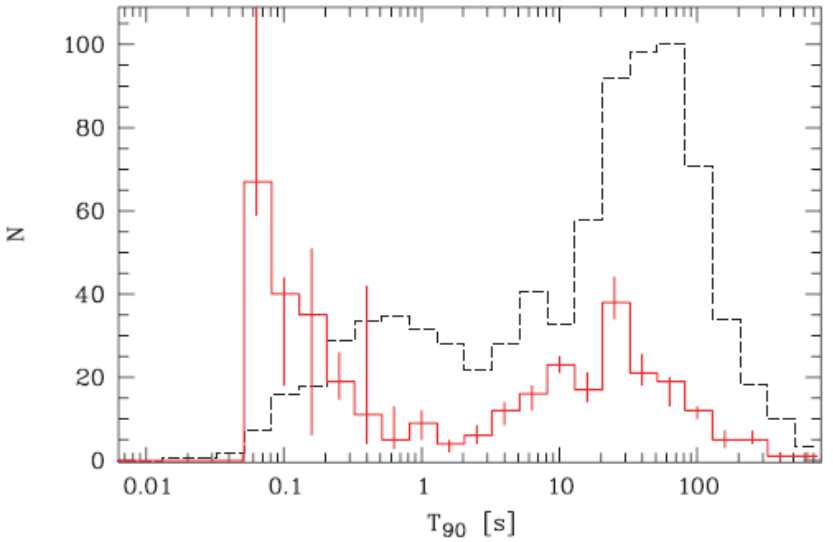
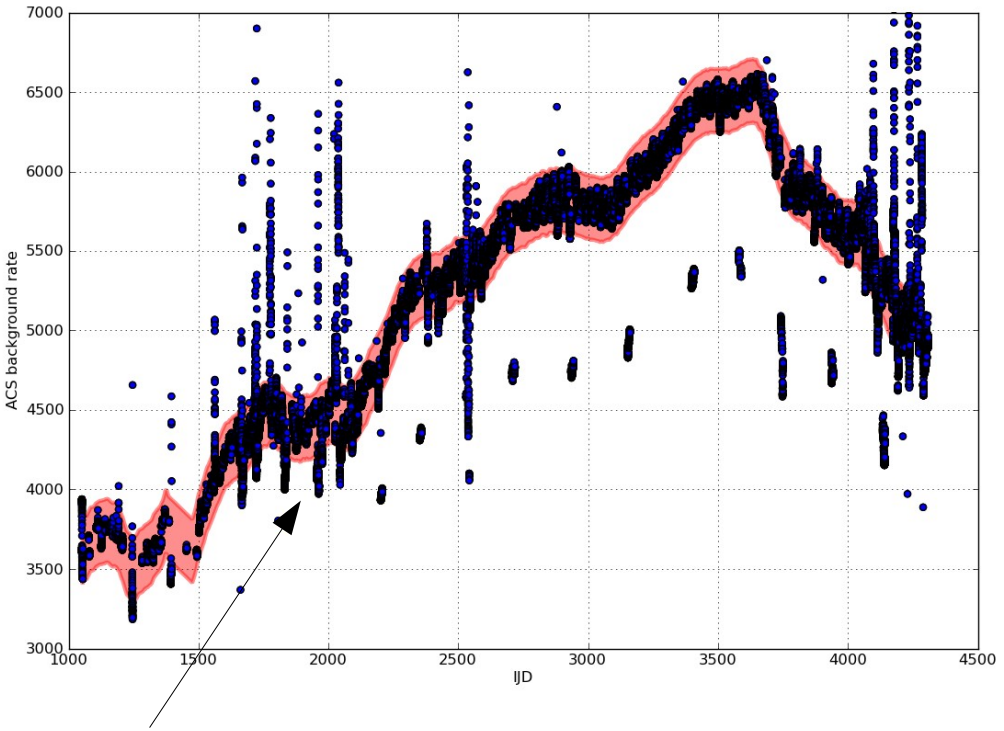


Red: candidate GRBs

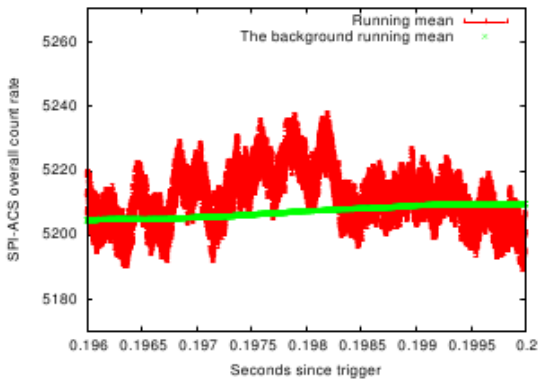
New SPI-ACS trigger catalogue

- New catalogue exploits data collected in nearly 10 years
- We gave a closer look to the systematic effects and developed ways to exclude them

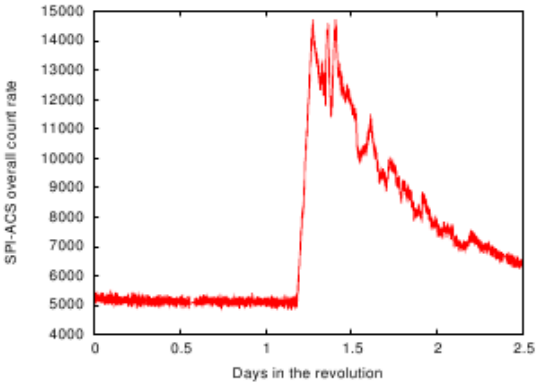


Previous catalogue

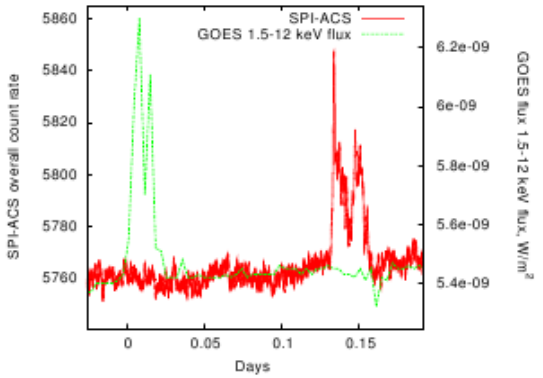
Solar flares



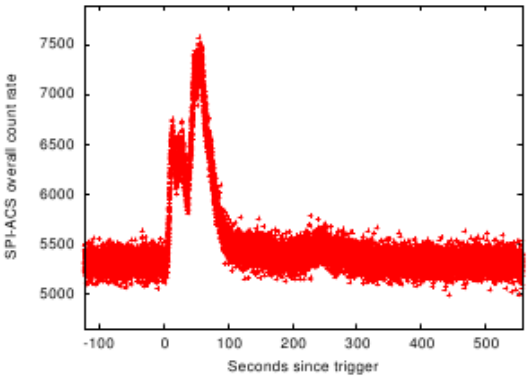
(a) Weak solar activity



(b) Very bright flare



(c) Isolated proton flare and the GOES data



(d) Similar to a GRB

Solar flares introduce various kinds of effects in the SPI-ACS data, contributing to the background for GRB searches.

Short isolated flares can not be independently distinguished from the cosmic bursts.

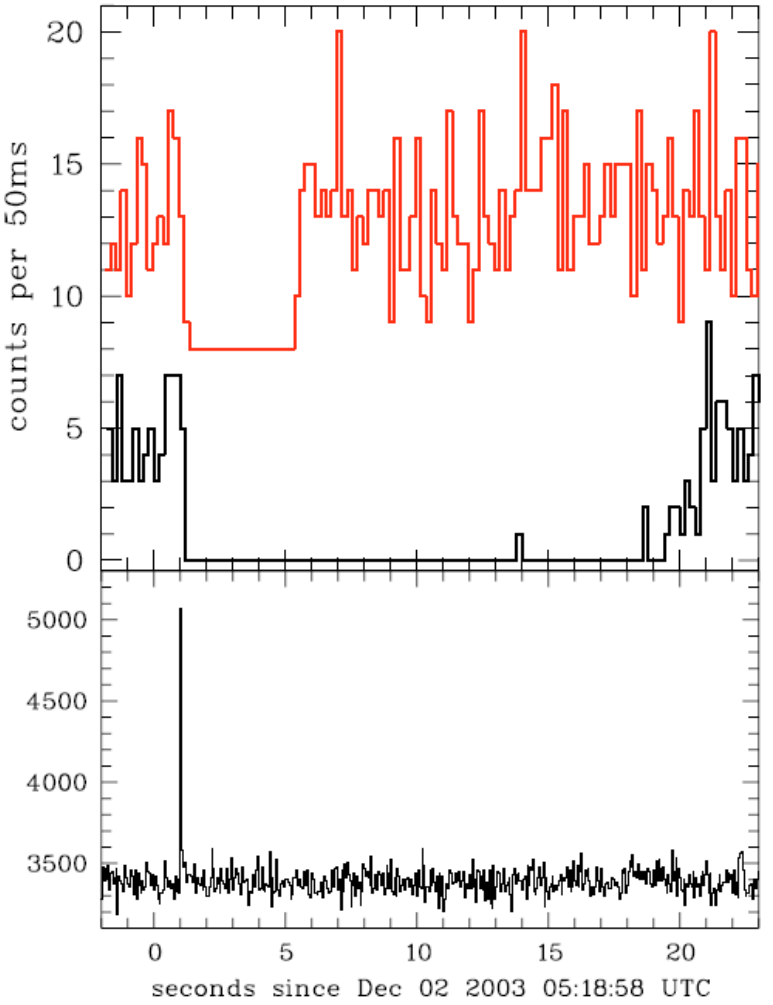
Usually stability of the background around the GRB can be used to exclude affected regions.

“Short spikes”

SPI-ACS is not a calorimeter: number of counts produced with the CR interaction with the SPI-ACS is determined by the time the phosphorescence is above the threshold.

Undoped BGO features very low long-term phosphorescence – 0.005% at 1ms – not even measured by other means. Still, it seems to be enough to produce expected number of counts.

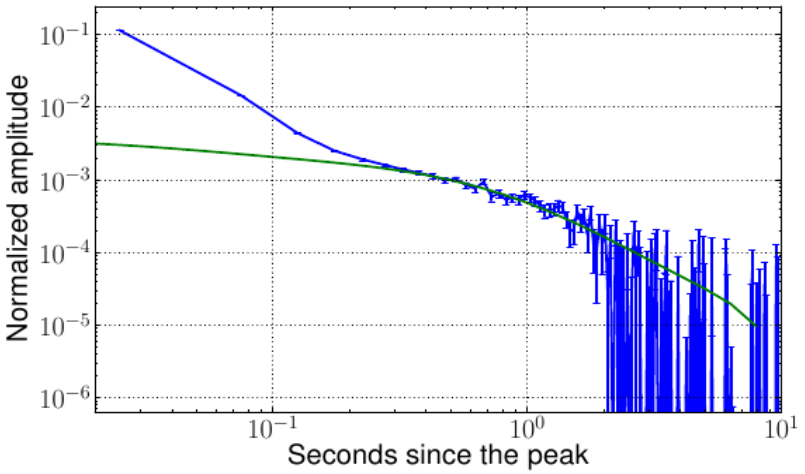
Correlation of the spikes with SPI saturation effects supports the cosmic ray origin.

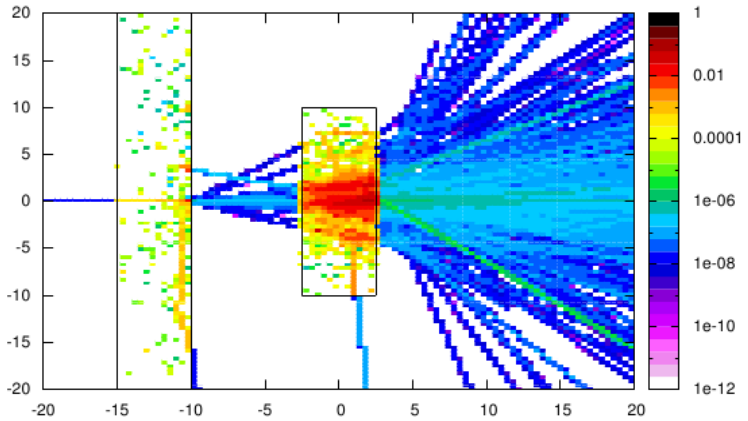


The short spikes can be easily confused with the SGRB.

Rau et al 2005.

Short spikes





Stacking of different samples of the spikes reveal long (up to 10 s) very weak extended emission

While this work was in progress, Minaev, Pozanenko et al 2011 reported similar finding, and first considered this an indication that the bursts are real.

To produce a count in the ACS 100keV has to be released – BGO afterglow can not be responsible.

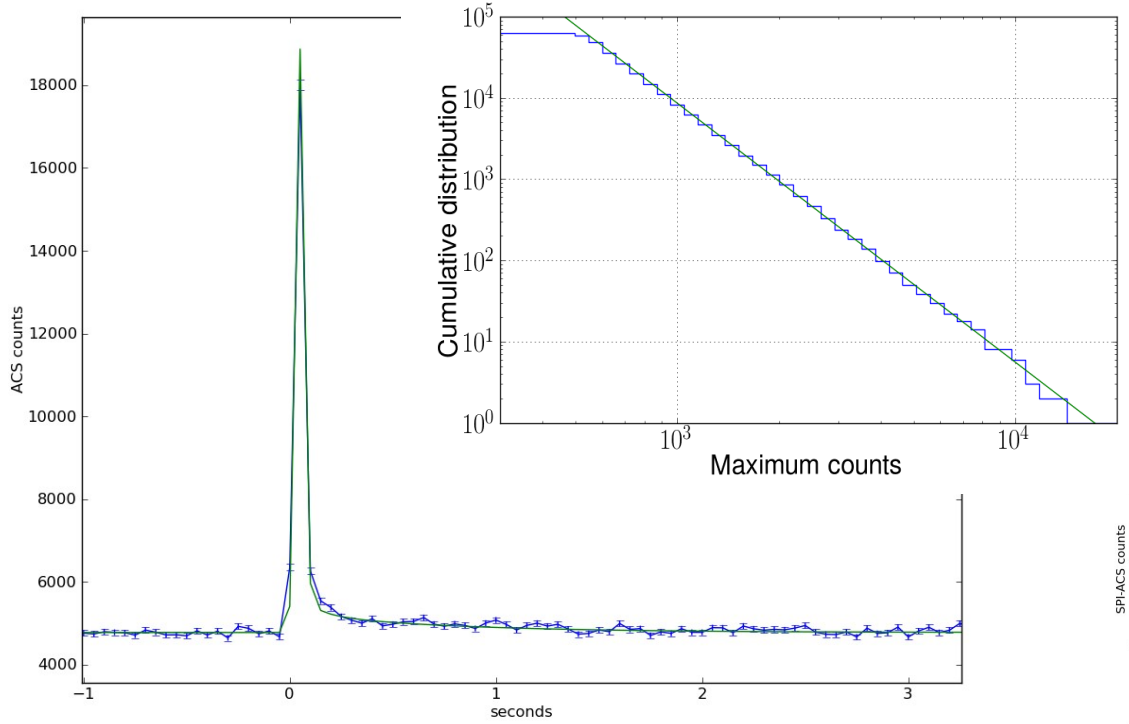
Short-term Induced radioactivity can be responsible It predicts the shape of the afterglow, well fitting the observation.

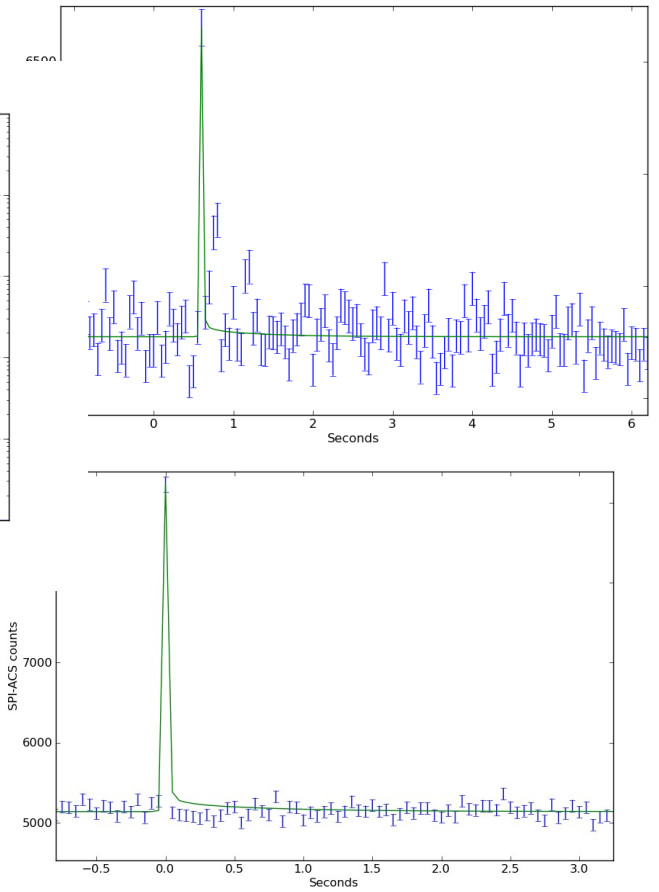
It seems that nether ms-scale BGO phosphorescence nor the second-scale activation are not normally measured in the ground-based experiments. It can be, however, seen in the SPI Ge detectors (A. Pozanenko, private communication)

Filtering-out Short Spikes

The expected shape is universal: all the spikes are renormalized template.
This can be used to filter them using the Bayesian approach.

100 000 short spikes rejected with this method



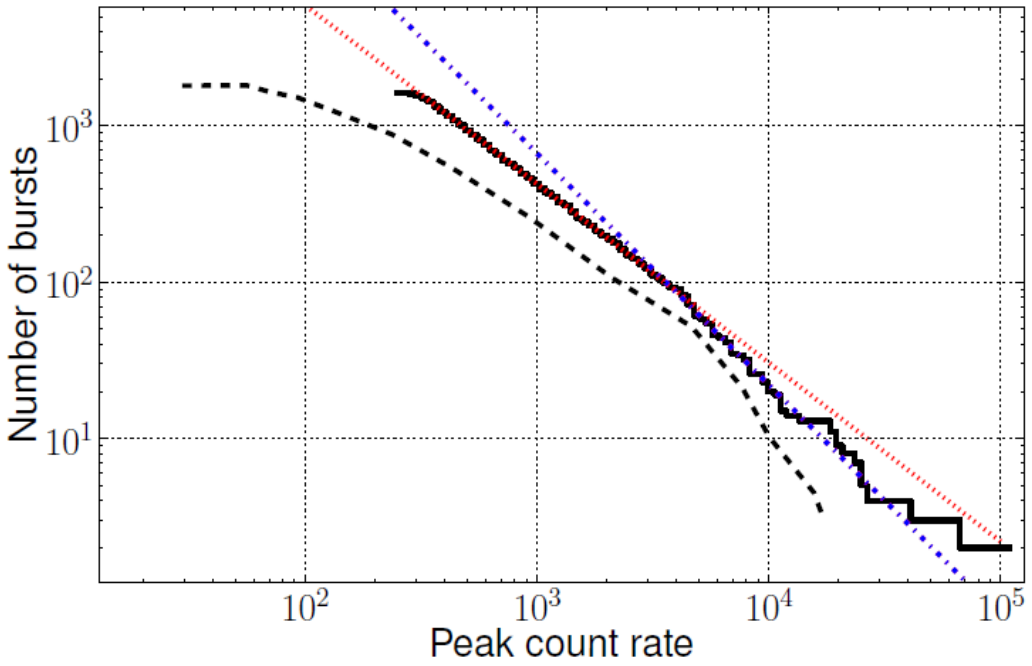


Even very bright events may fit the template.
The distribution of the peak count rates is very regular.

Even rather weak real bursts may not be rejected.

GRB candidate sample

1614 (2500 in looser selection) candidate events identified in 2412 days of exposure

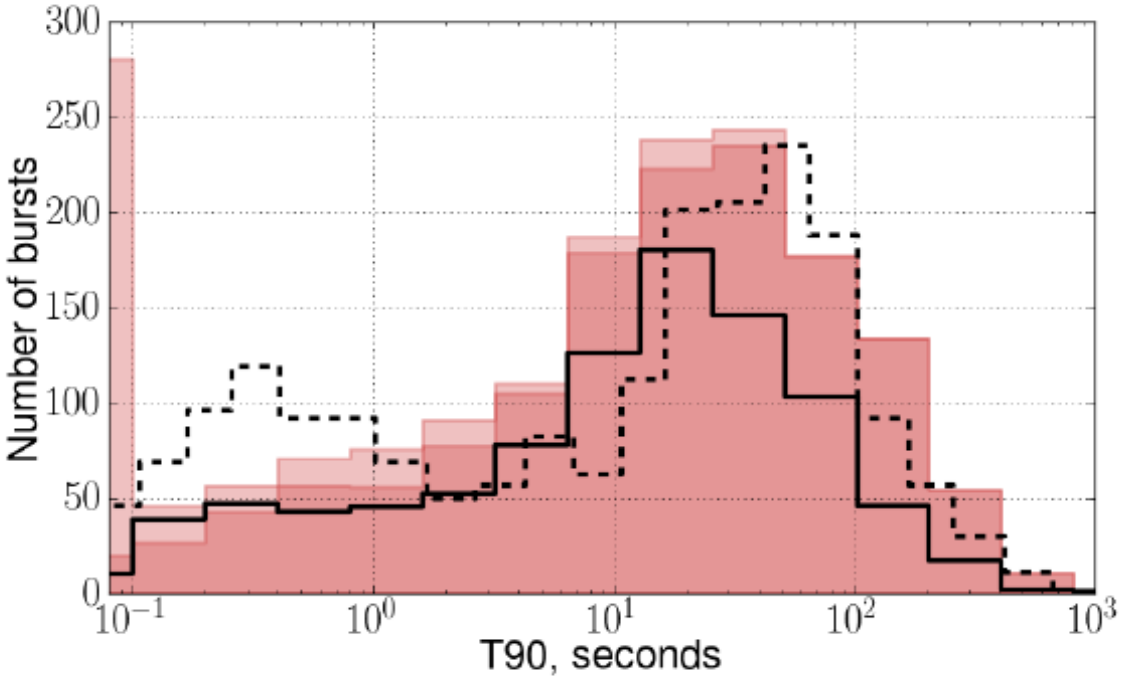


Peak count rate distribution is similar to the one observed by BATSE.

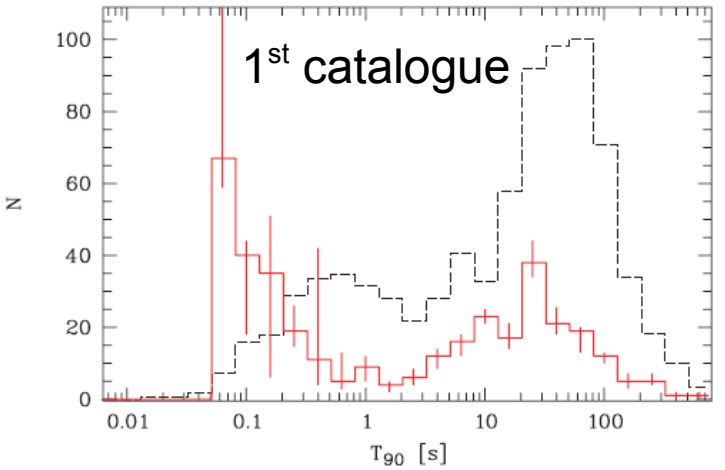
	Konus Wind	Suzaku WAM	Fermi GBM	RHESSI	Swift/BAT	IPN	Fermi LAT
GRB	461	452	292	145	127	21	16

These includes only reported bursts. In fact, e.g. Swift/BAT sees a lot of bursts out of FoV. ~15 SPI-ACS unconfirmed bursts were detected in offline analysis of BAT.

GRB candidate sample



The duration distribution does not reveal a characteristic time scale for the short burst duration. This is more similar to the observation of other instruments but BATSE.



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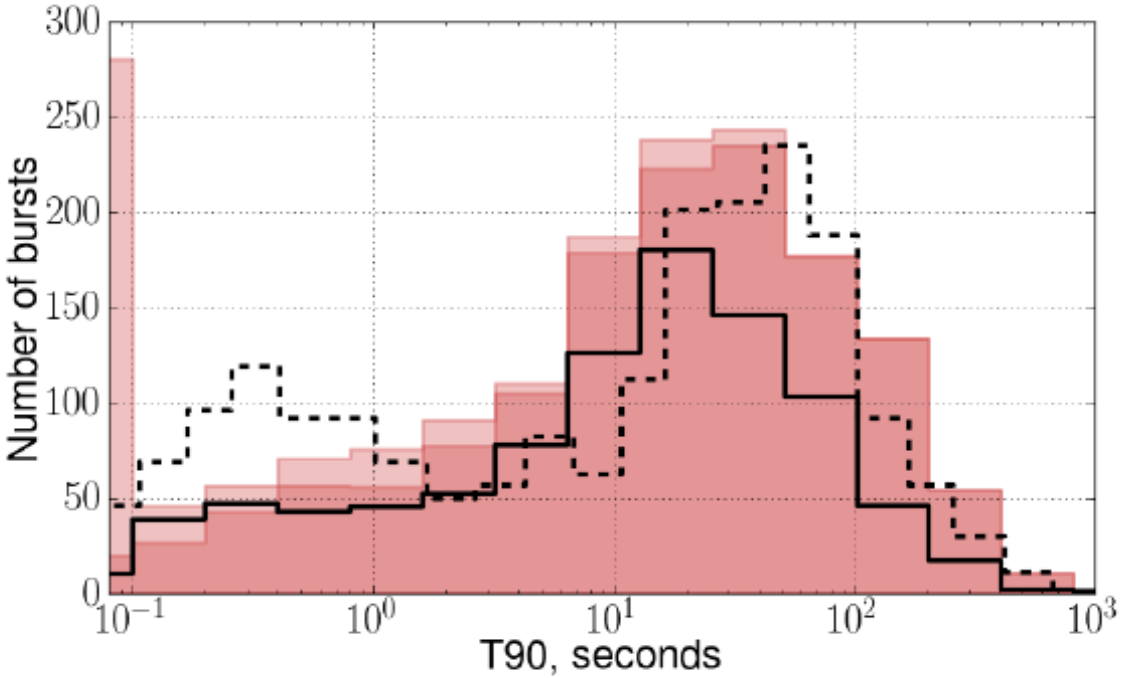

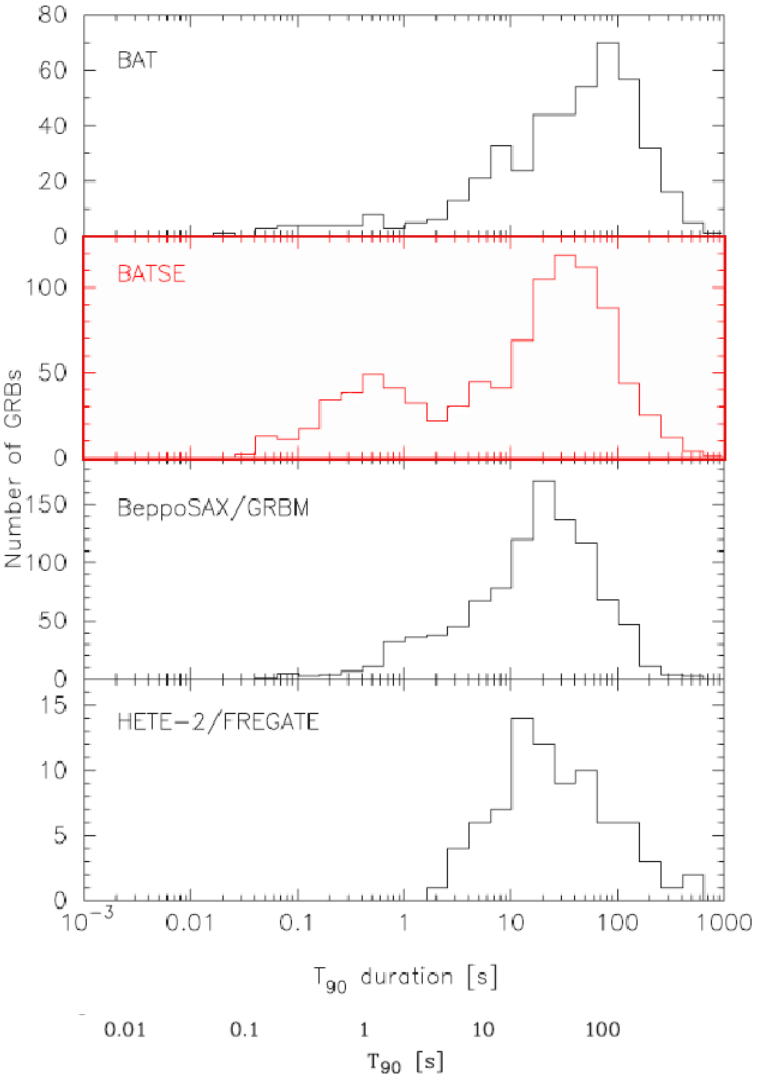

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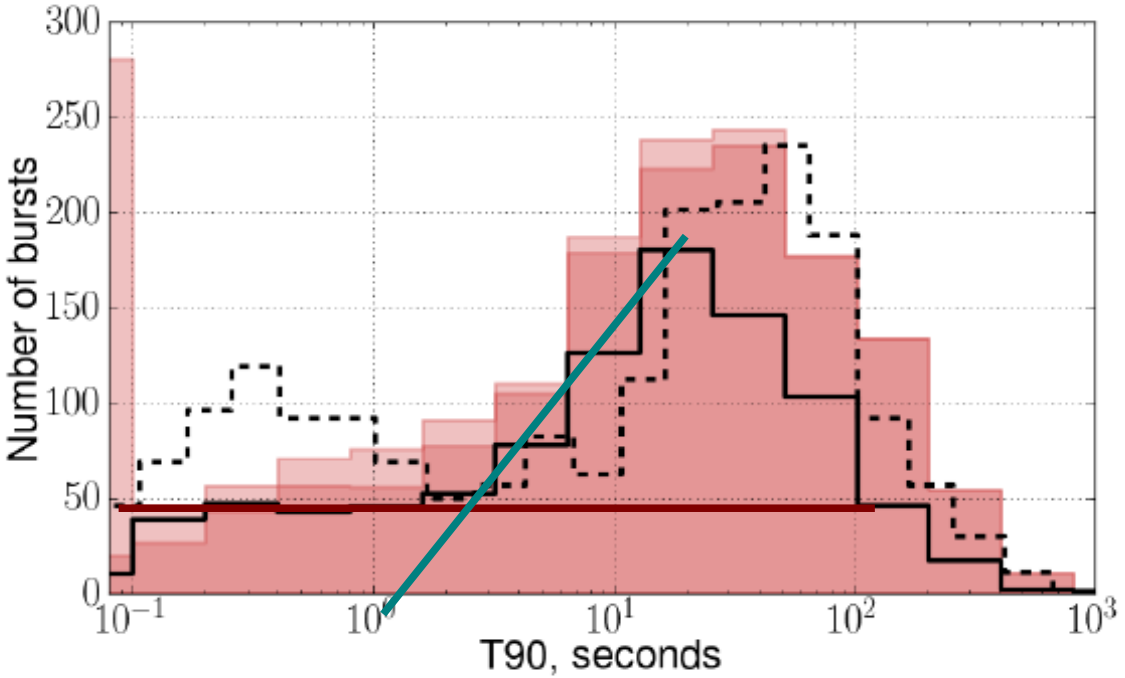

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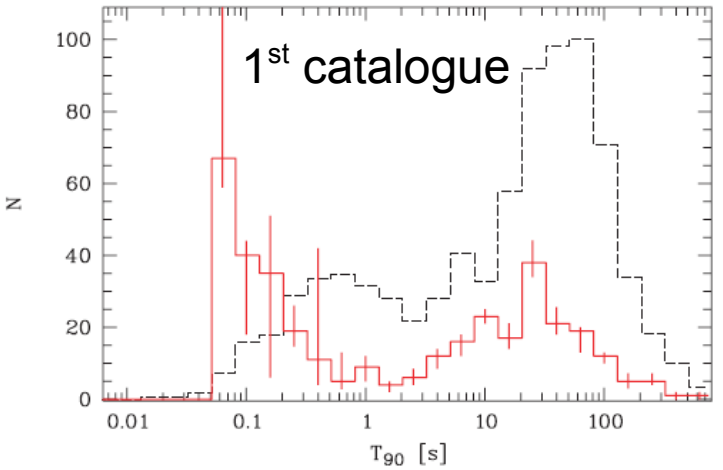
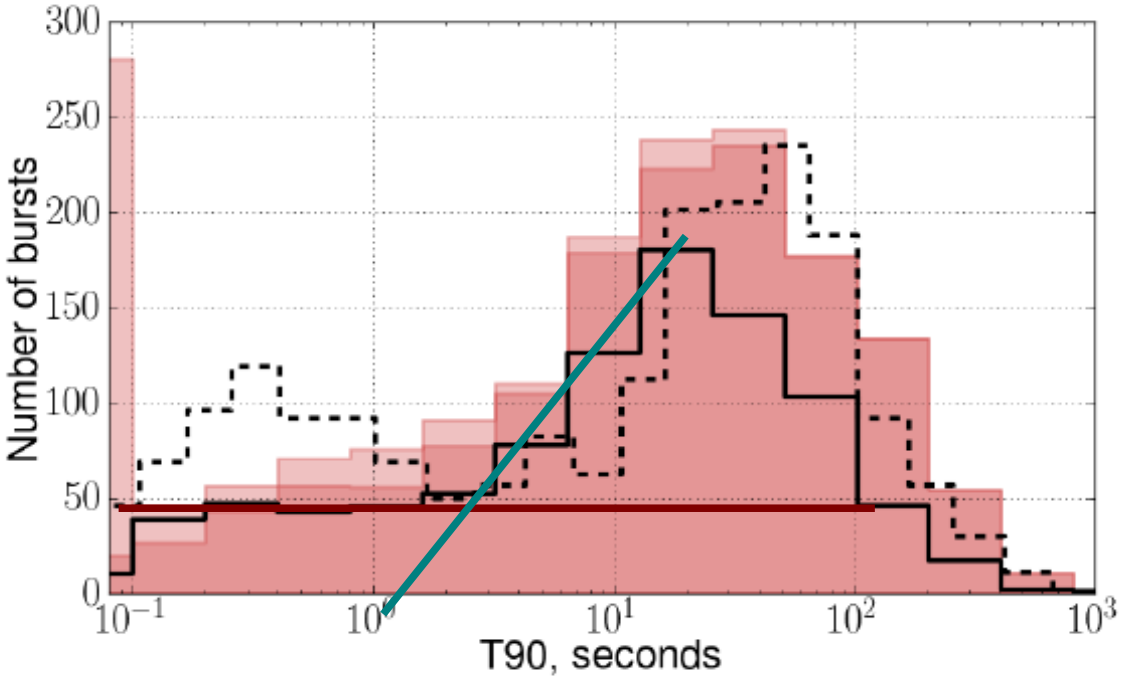


How is the duration distribution divided in two (or more) populations depends on physical assumptions

GRB candidate sample



Spectral information from another instrument is required... But bias in duration can be investigated

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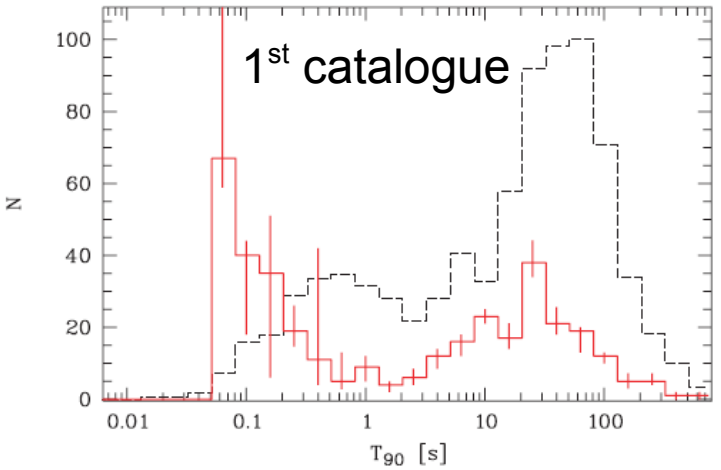

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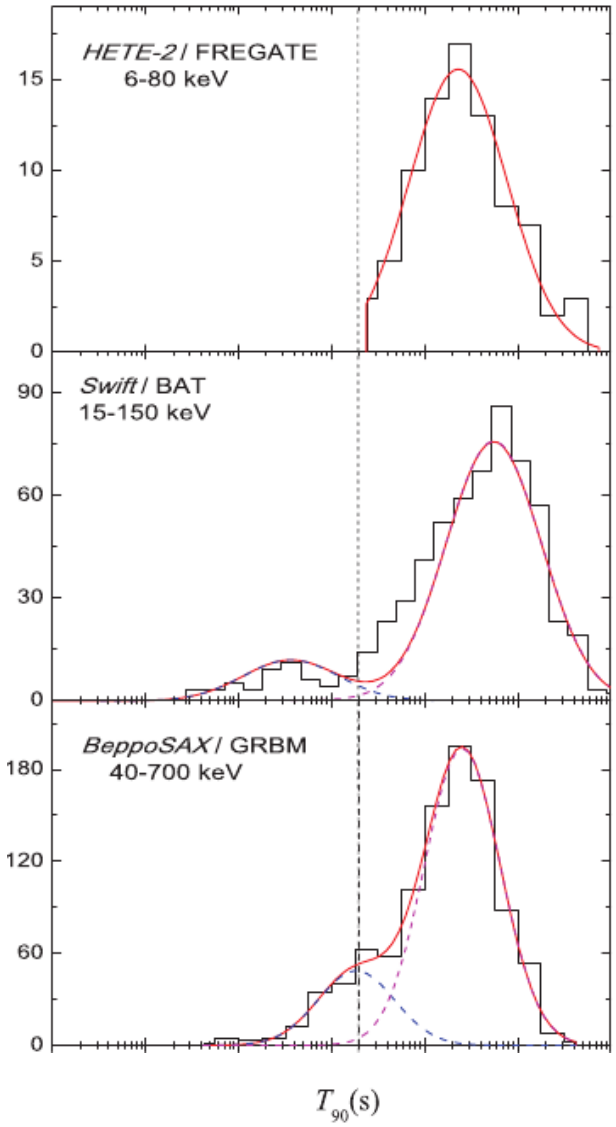
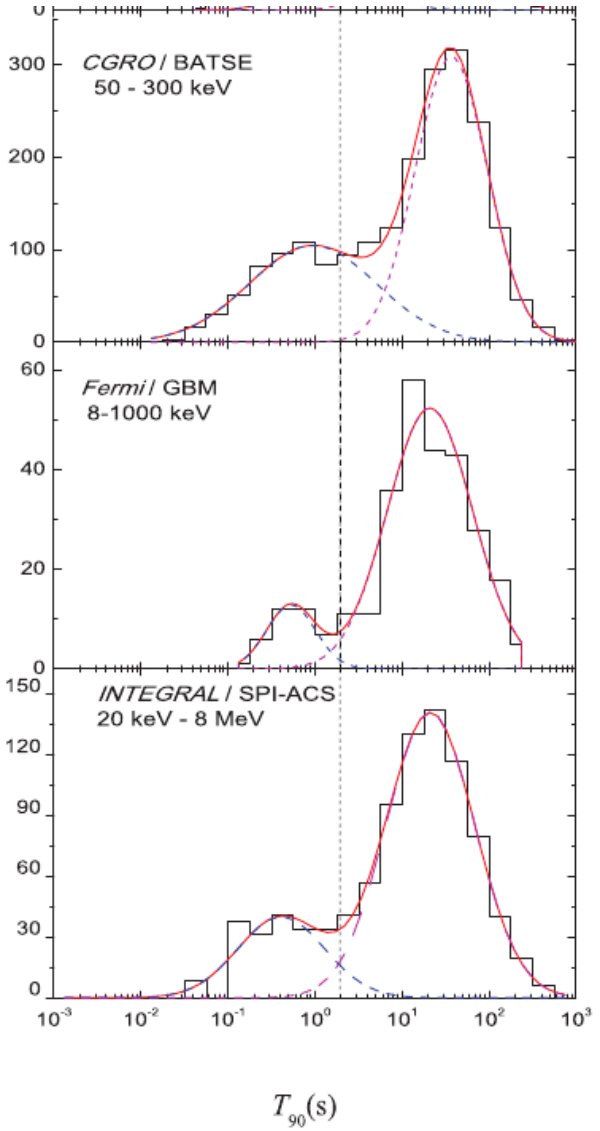


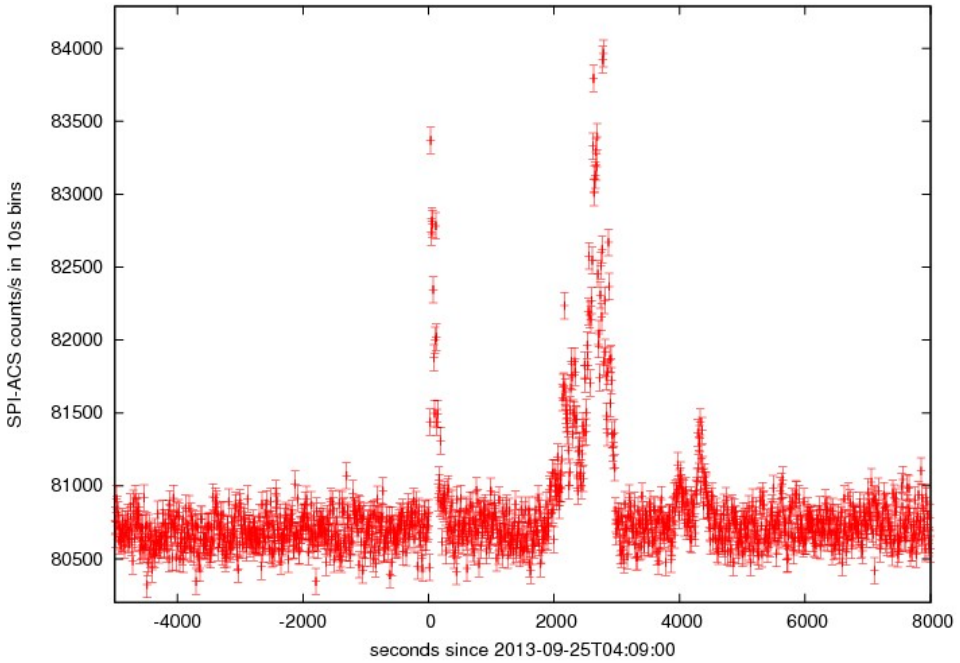


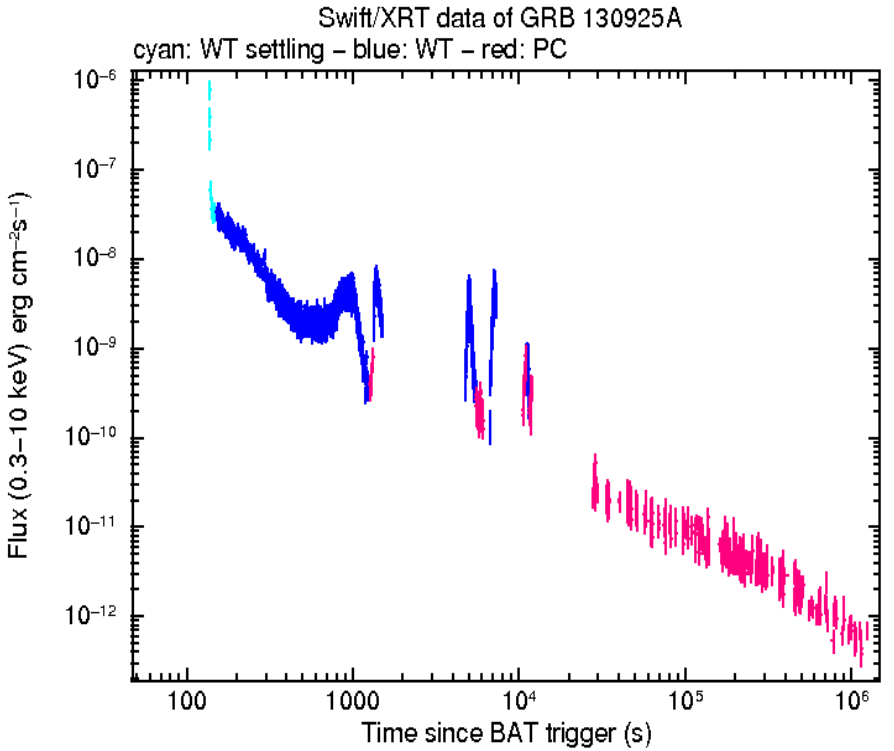
Qin et al 2013

Ultra-long GRBs

Stable background and continuous observations make the instrument suitable for for ultra-long GRBs

GRB 130925A



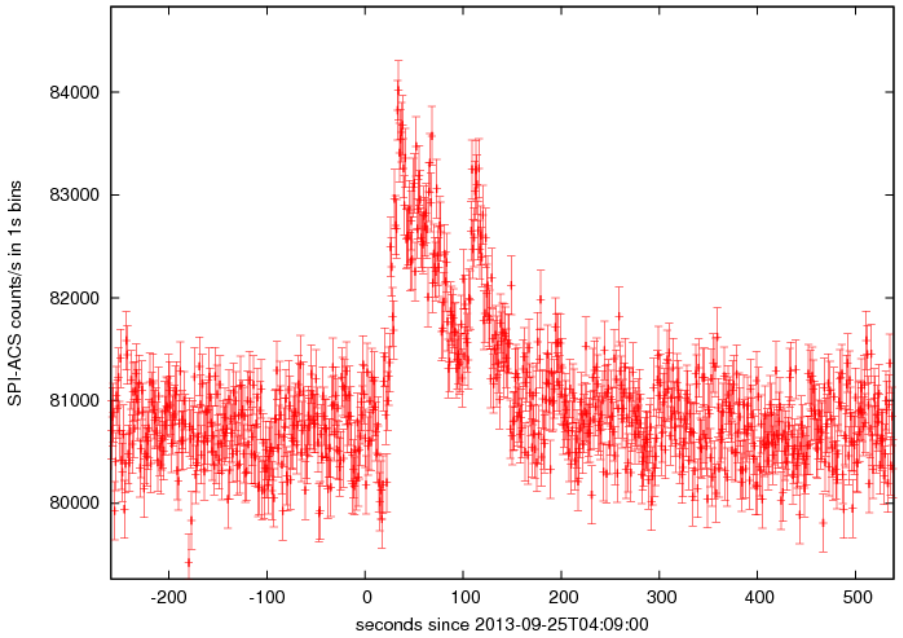


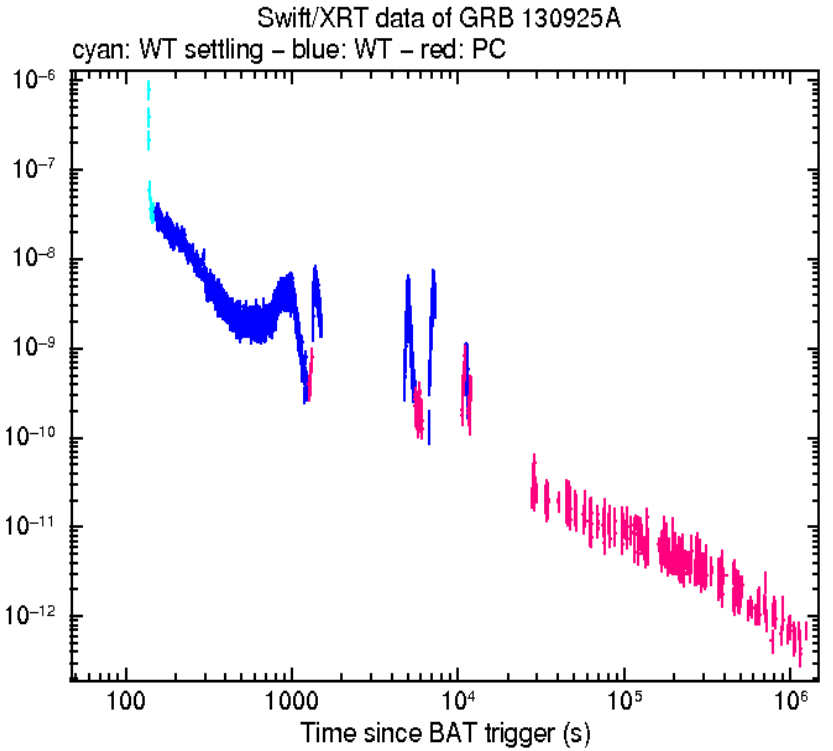
Major episode missed by Swift and Fermi

Ultra-long GRBs

Stable background and continuous observations make it good for for ultra-long GRBs

GRB 130925A

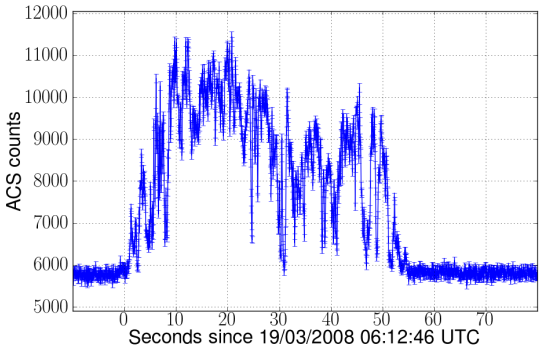


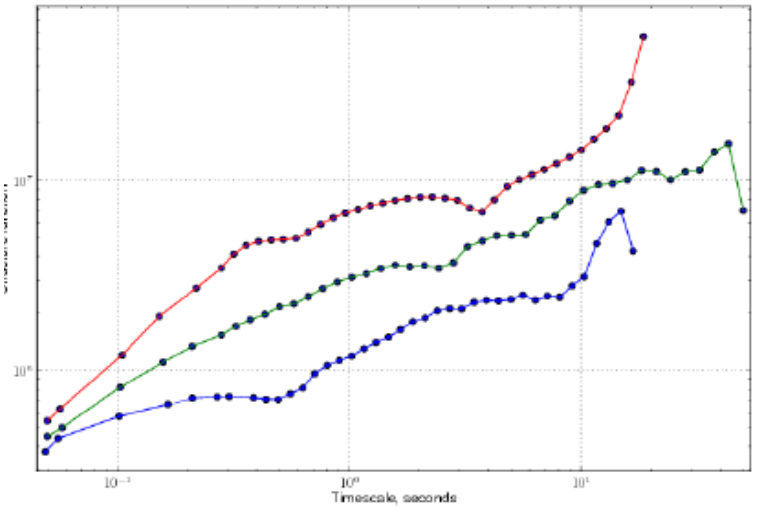


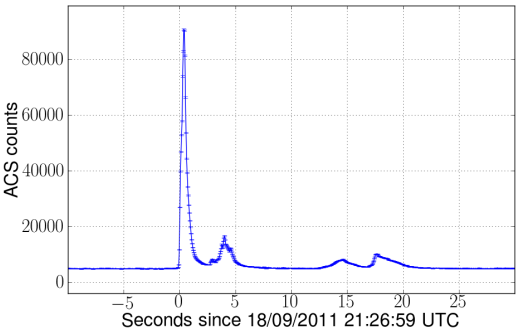
Large effective area allows to observe variability down to 1s, T/dT~5000

Characterising variability

Numerous attempts to characterise variability time scale in the GRBs were made, usually exploiting stacked PSD or autocorrelation function. (e.g. *Beloborodov 2000, Pozanenko 2008*). A time scale of one second was identified.







We studied instead structure functions of the individual bursts, identifying slopes and breaks.

We did not find the previously reported bimodality in slopes, although the range of the values is large

Nature of the variability should be investigated taking into account spectral information

Characteristic time scale

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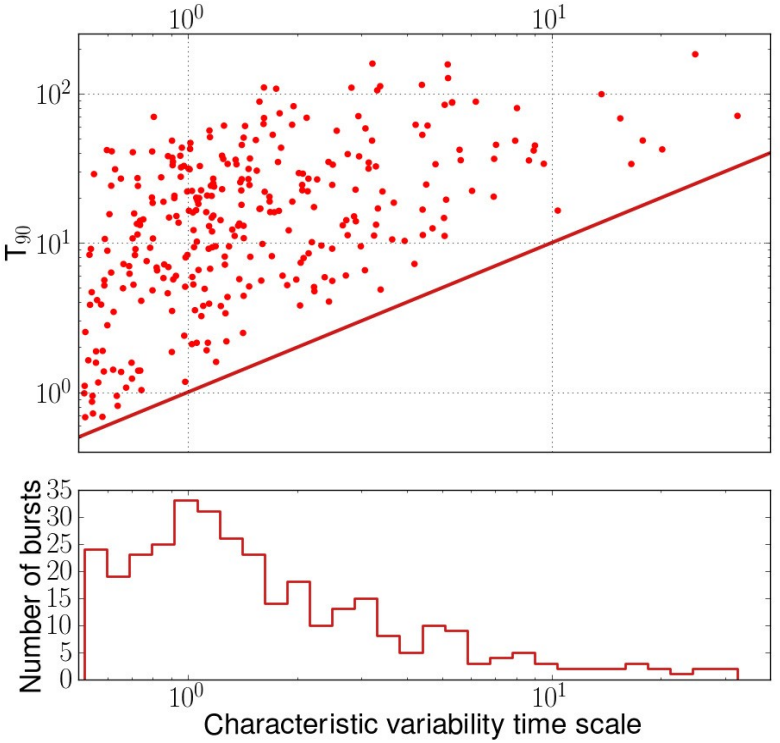


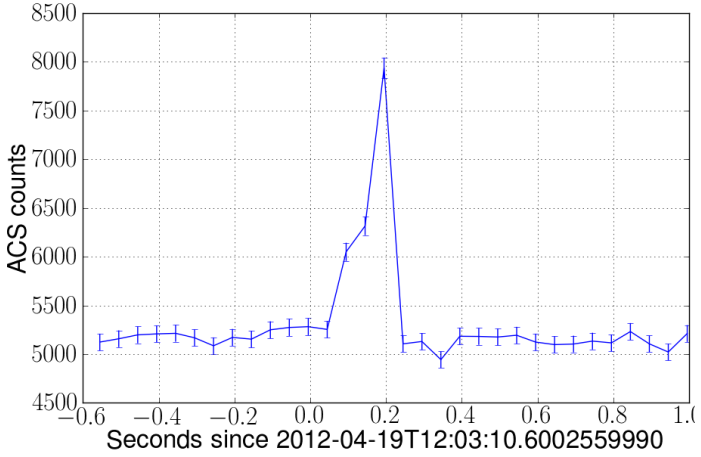
The range of the time scales is also large, although the clustering near 1 second is apparent

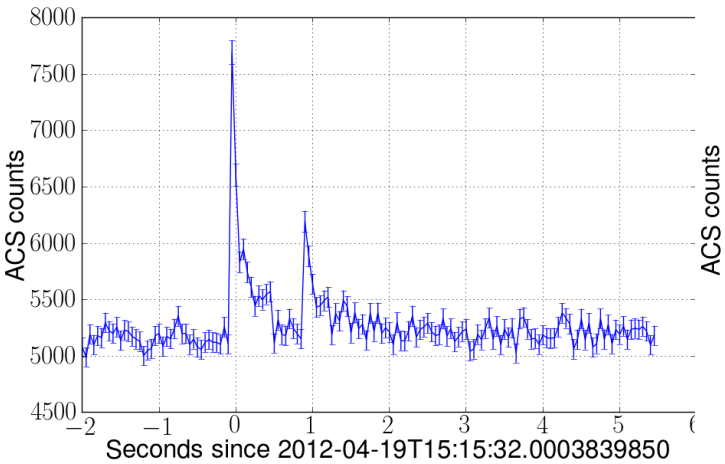
GRBs,
Magnetar bursts,
Solar flares,
Short spikes (HE particles),
solar particles and radiation belts,

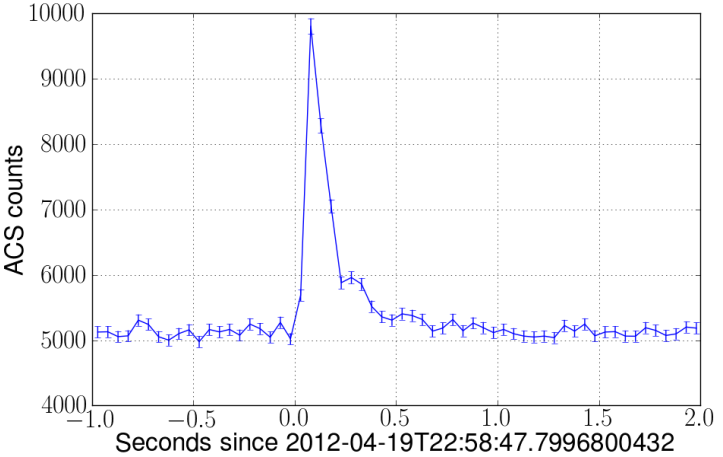
other events?..

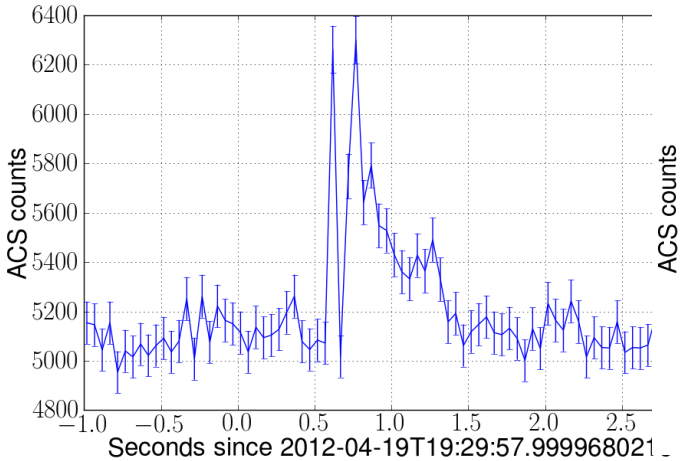
April 19-22 and May 5-11

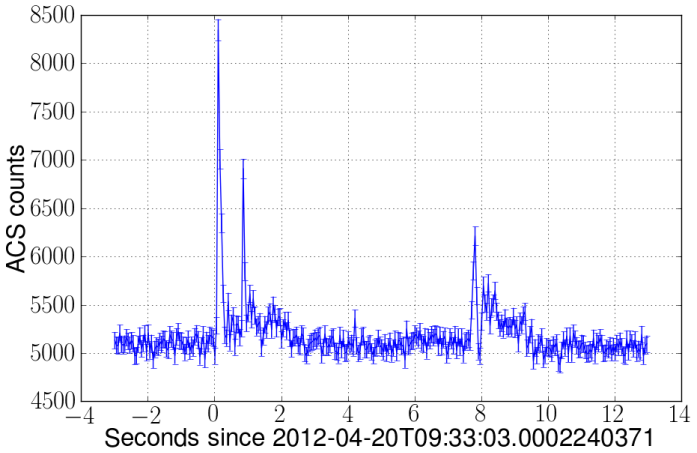
25 bursts were detected by SPI-ACS April 19-22 and 7 May 5-6.

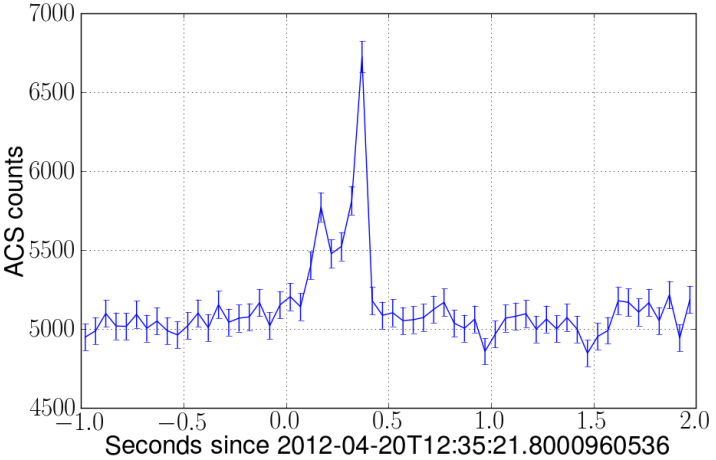












Chance of random clustering is negligible

The brightest bursts reached 10^{-6}erg/cm^2/s (first estimate).

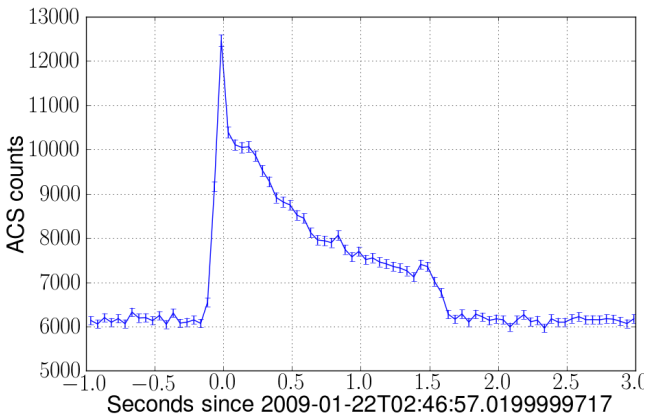
Atel 4101, Savchenko et al 2012

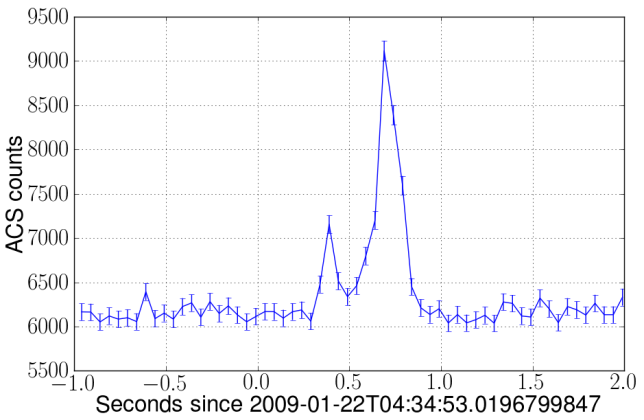
http://www.isdc.unige.ch/integral/ibas/magnetar/

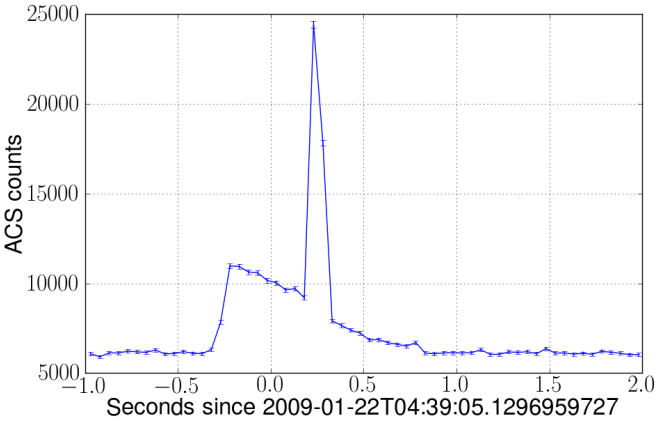
SGR/AXP outburst

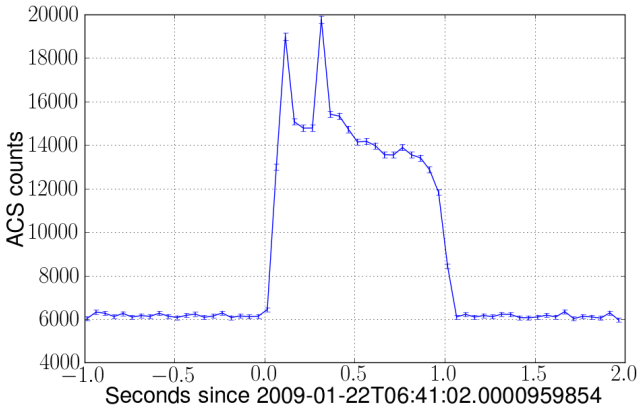
On January 2009 outburst of an AXP 1547.0-5408 happened (Gronwall et al 2009) Hundreds of strong bursts (>10^{-4} erg cm2 s) were observed by a number of instruments (Swift/BAT, Fermi), this episode was factor of 100 stronger.

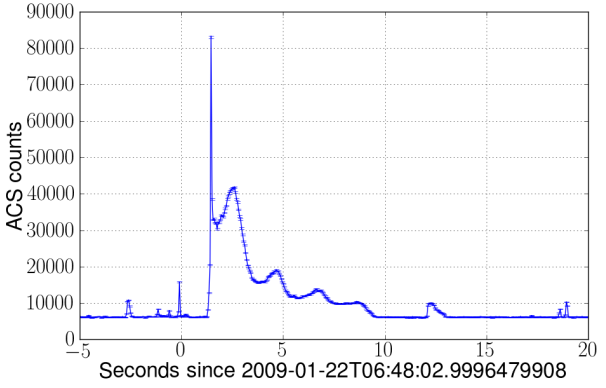
SPI-ACS was in unique position to study these bursts since it did not suffer from the saturation effects (Savchenko et al 2009, Mereghetti et al 2009).

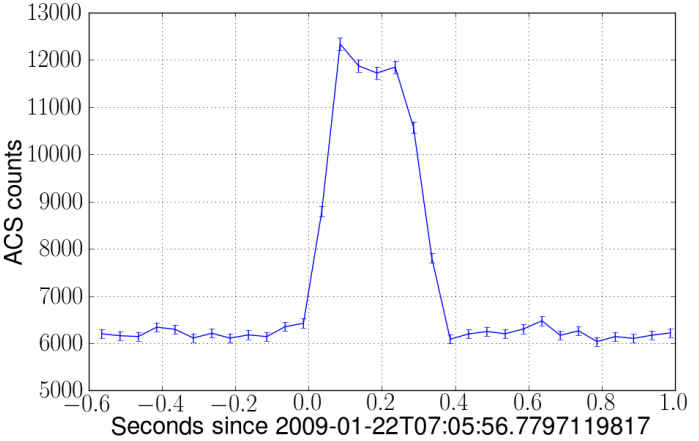












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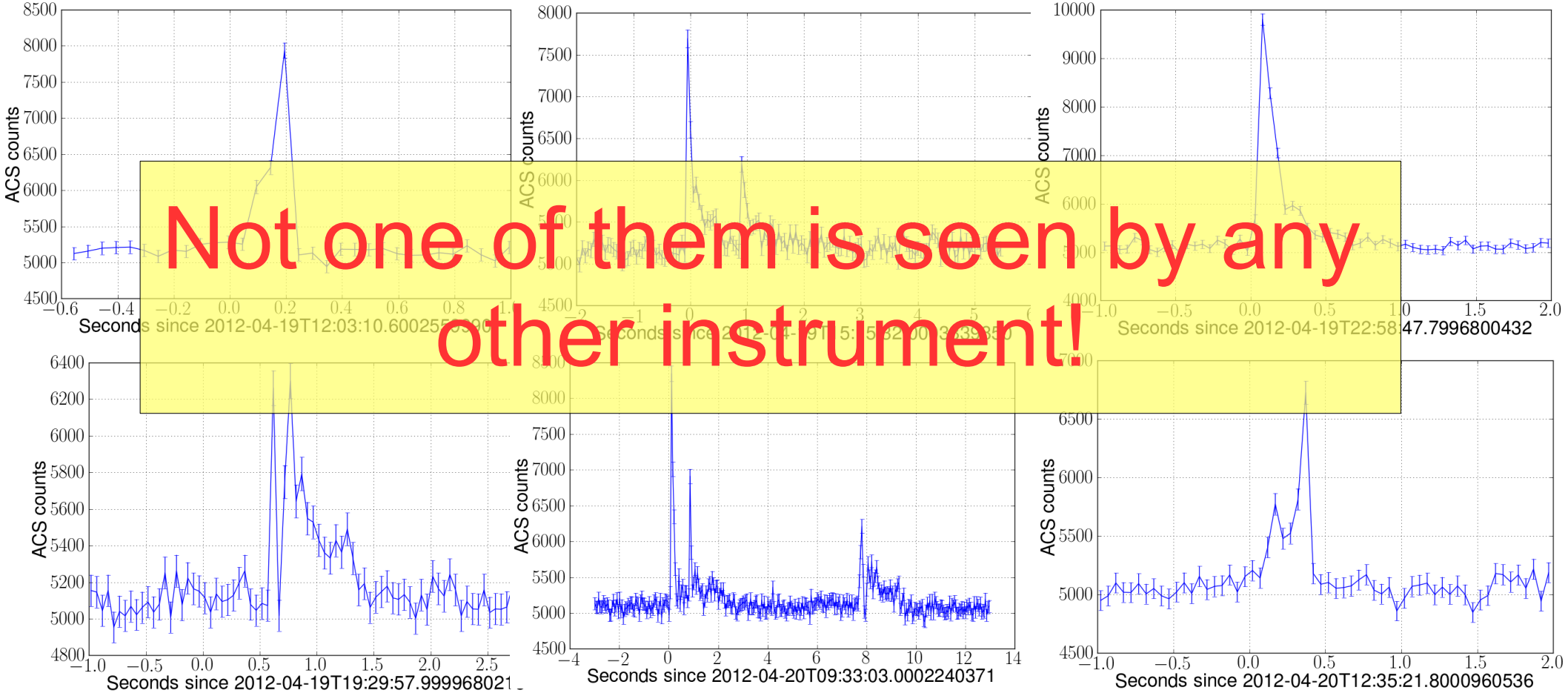
25 bursts were detected by SPI-ACS April 19-22 and 7 May 5-6.



Not one of them is seen by any other instrument!

Chance of random clustering is negligible

The brightest bursts reached 10^{-6}erg/cm^2/s (estimate).

Atel 4101, Savchenko et al 2012

http://www.isdc.unige.ch/integral/ibas/magnetar/

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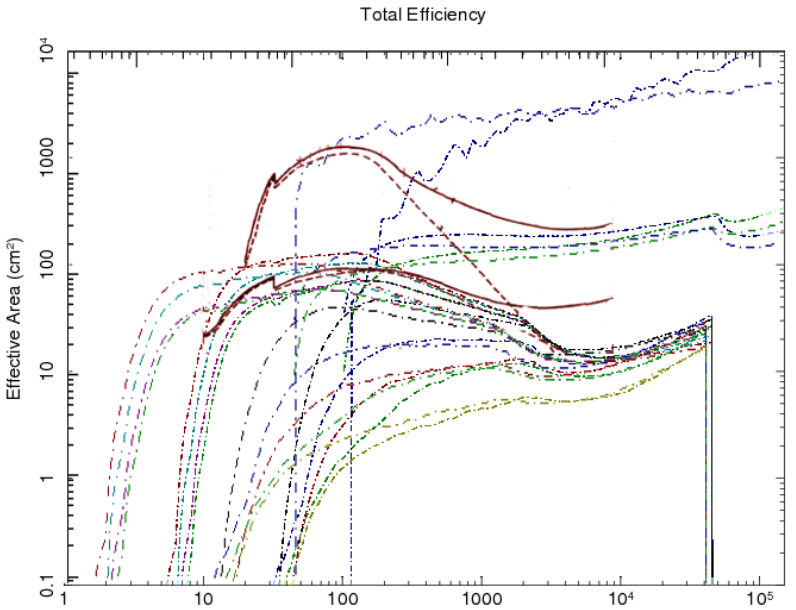
- It is indeed on the detection limit, then forcing sensitivity (e.g. doing stacking analysis) one should get a marginal detection: SPI-ACS sensitivity to hard events is larger then any other instrument.



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- Unlucky observational conditions?
- It is indeed on the detection limit, then forcing sensitivity (e.g. doing stacking analysis) one should get a marginal detection: SPI-ACS sensitivity to hard events is larger then any other instrument.
- Or there is an essential reason SPI-ACS sees something others do not: something unique about the instrument or INTEGRAL itself.

Usual means of confirming

- Swift/BAT – very small effective area, very soft band, hardly at all overlapping with SPI-ACS, Earth occultations.
- Fermi/GBM – very small effective area, occultations, 0.08-80 MeV.
- Suzaku/WAM – smaller effective area, limited by trigger, occultations.
- Konus-Wind – much smaller effective area.

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- Konus-Wind – much smaller effective area.

- ISGRI, SPI, JEMX detector data – sensitive to soft particles.
- IBIS Veto, and rest of the INTEGRAL housekeeping.

Confirmed events

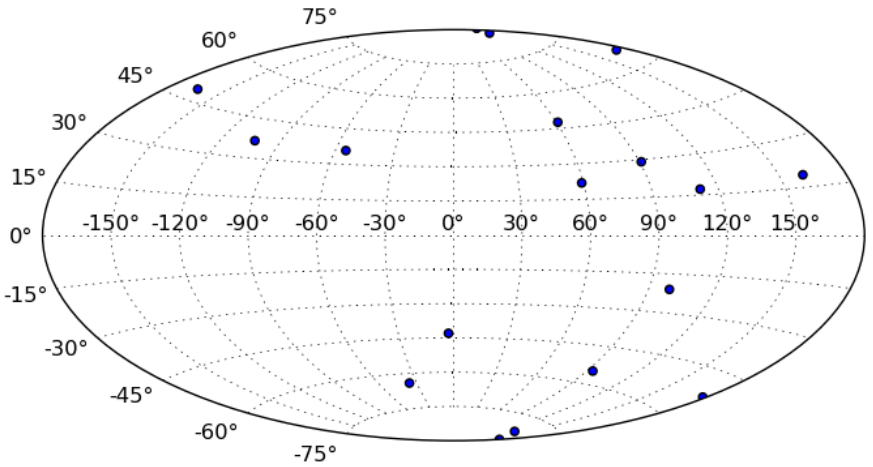
- 2012-04-20 07:26:18 (ACS, Konus, BAT)
- 2012-04-21 08:17:43 (GBM, GCN 13280, possibly SGR)
- 2012-05-06 11:39:45 (ACS, Suzaku, GBM)
- 2012-05-09 14:52:03 (ACS, GBM)
- 2012-05-10 20:22:09 (GBM, BAT)

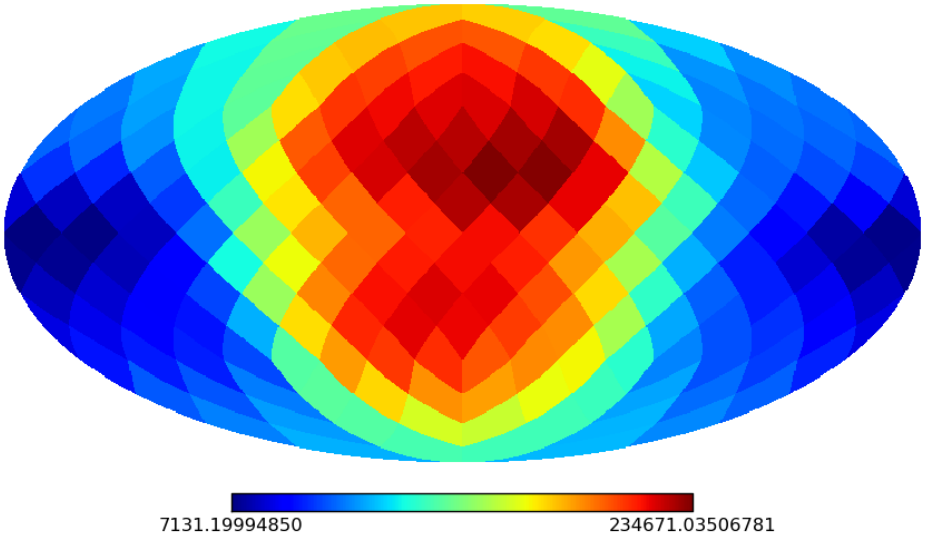
Several burst were confirmed during the activity episodes.

In all likelihood they are normal real GRB/SGR.

Fermi GBM

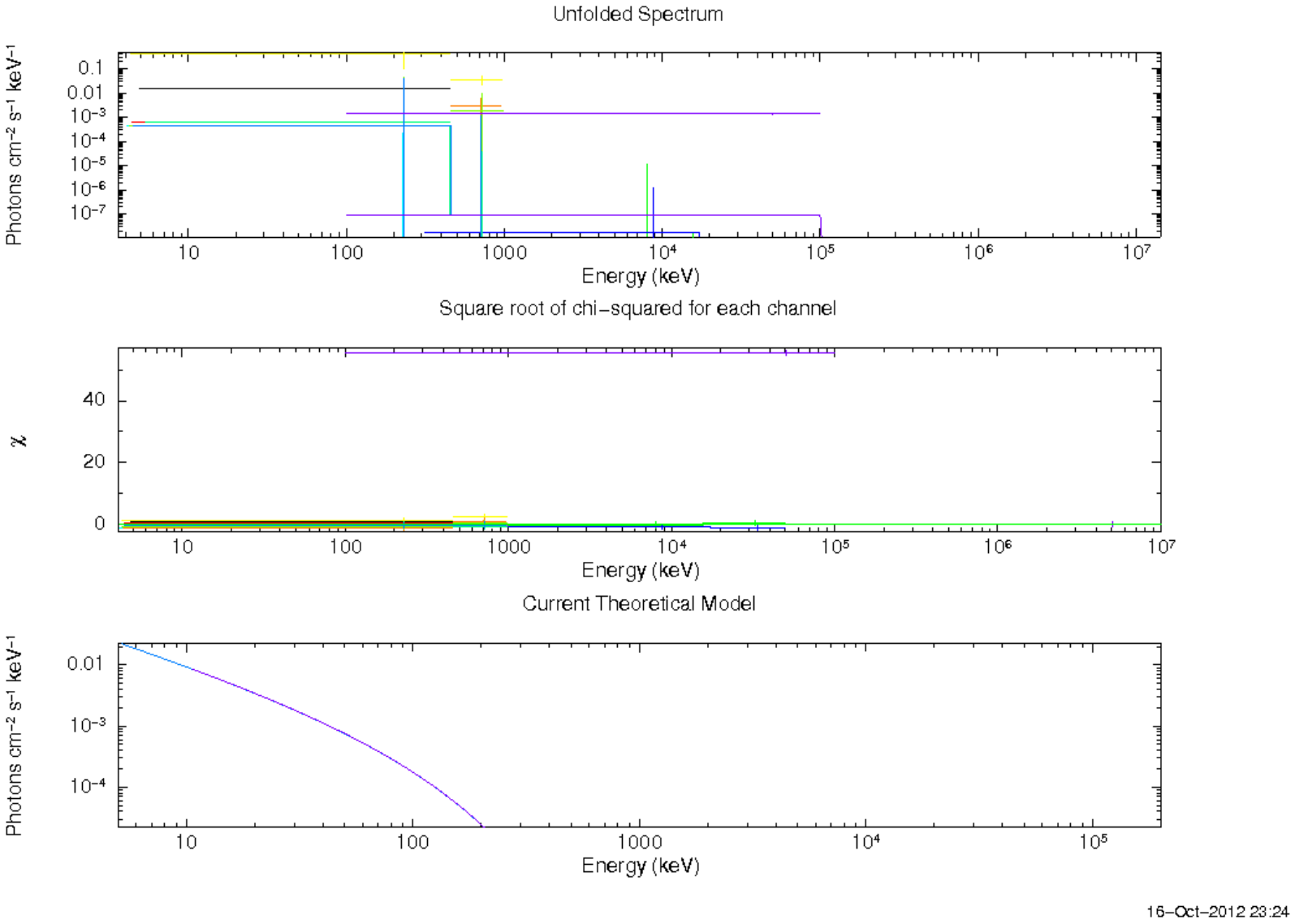
One has to explore which regions of the sky were accessible to the Fermi/GBM during the SPI-ACS bursts





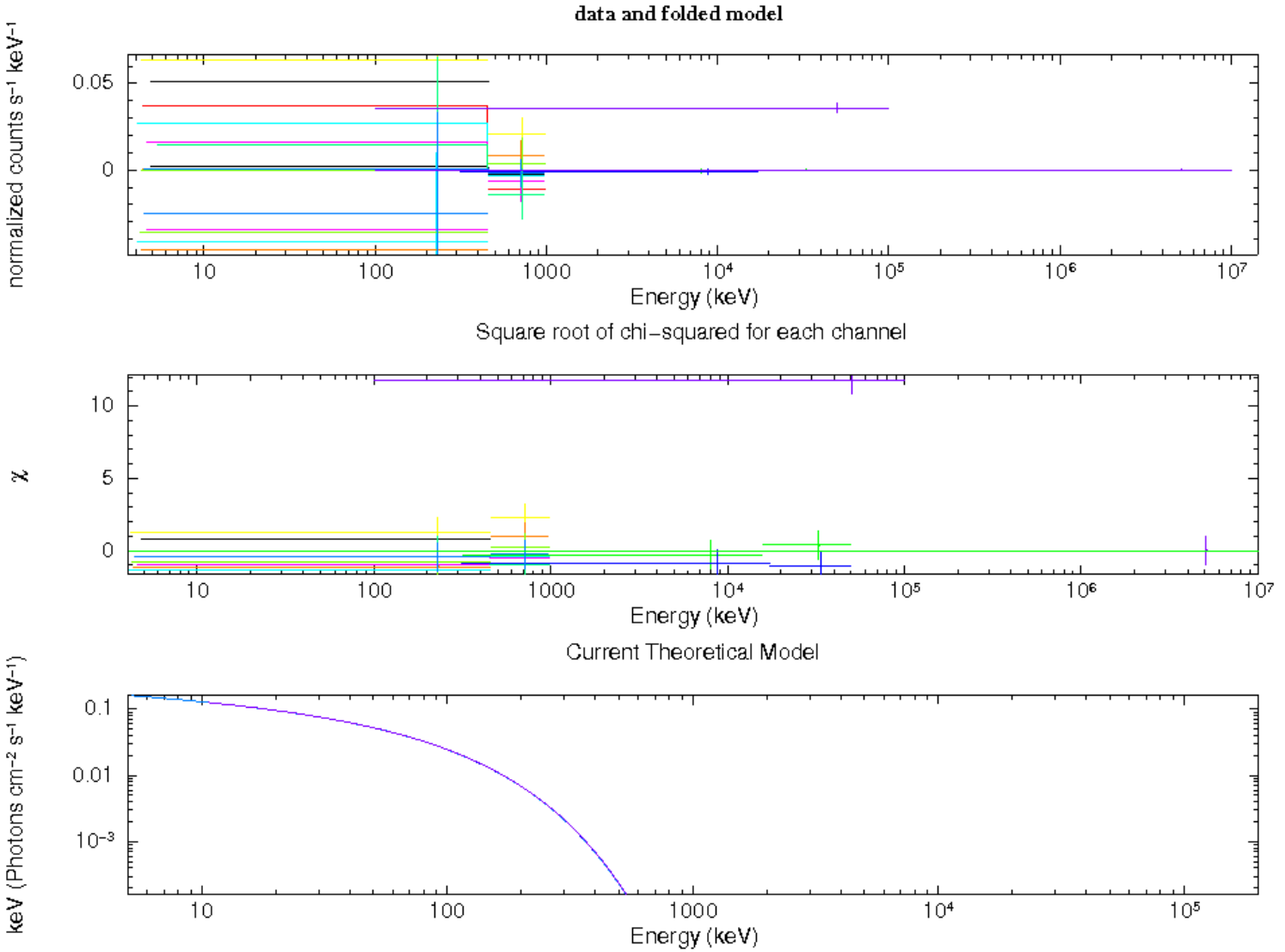
ACS counts in the GBM for different source positions

Joint analysis of GBM and SPI-ACS



OTTB usual case

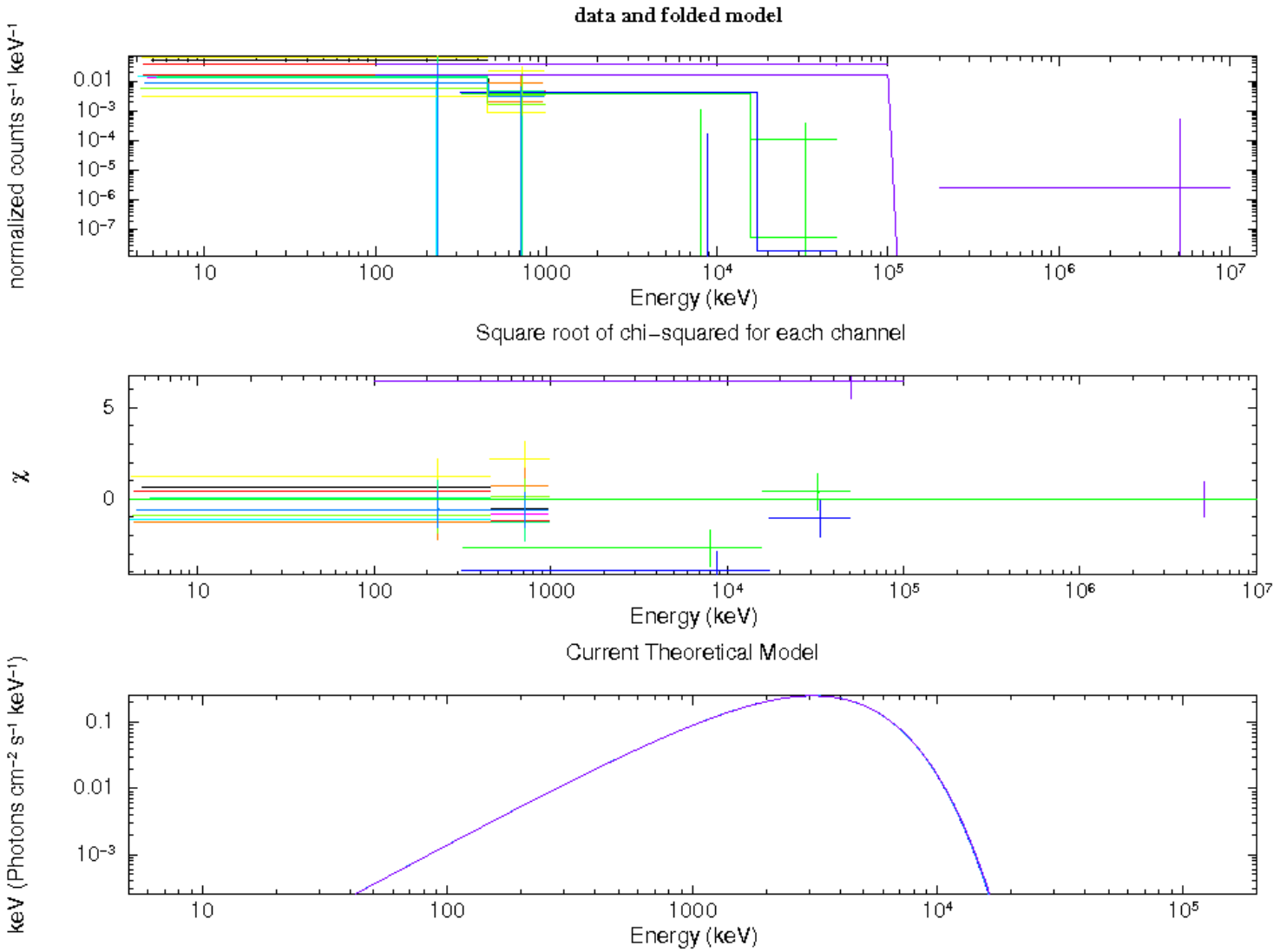
Joint analysis of GBM and SPI-ACS



OTTB extreme

19−Oct−2012 00:38

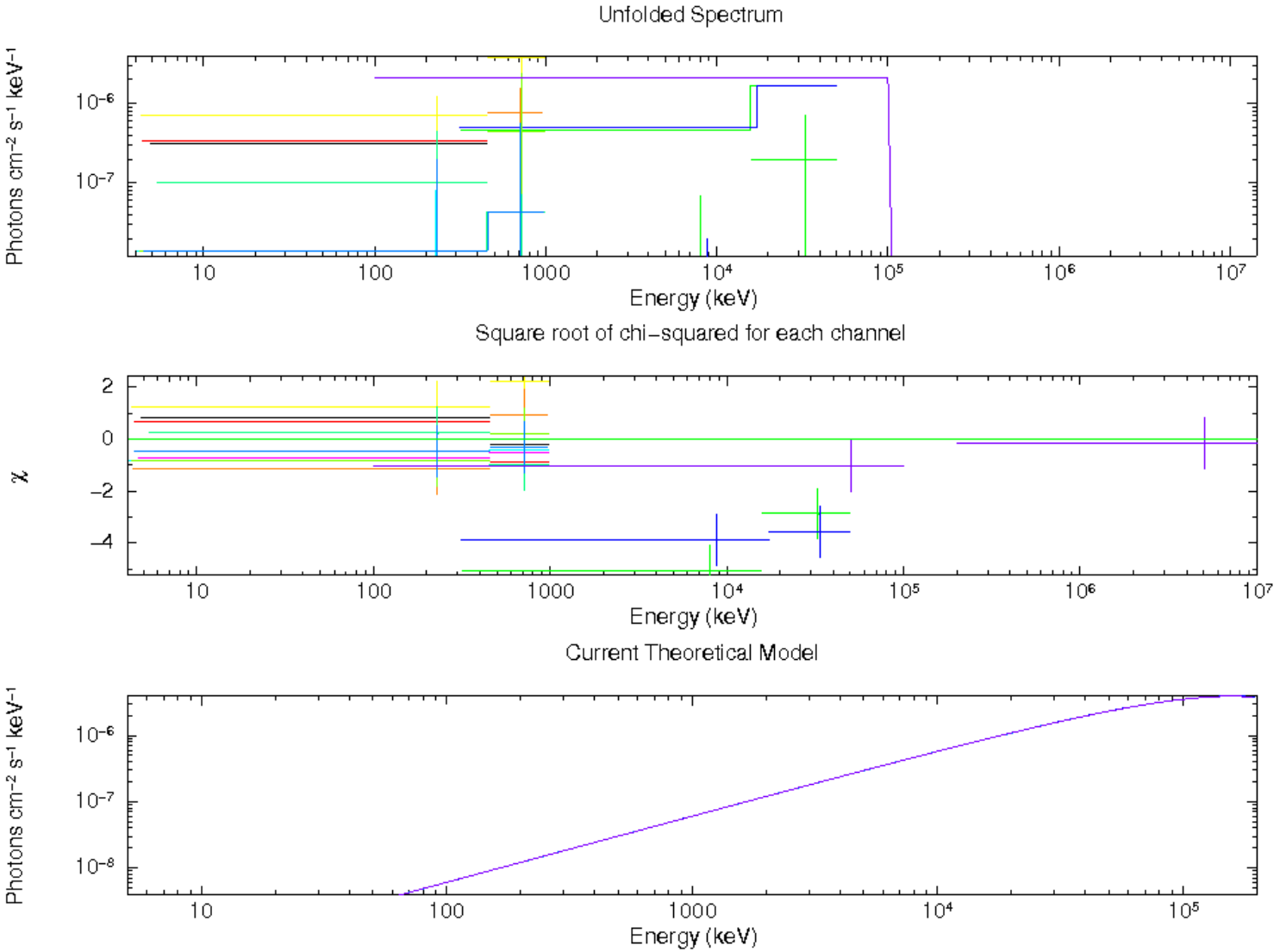
Joint analysis of GBM and SPI-ACS



1 MeV black body

19−Oct−2012 00:17

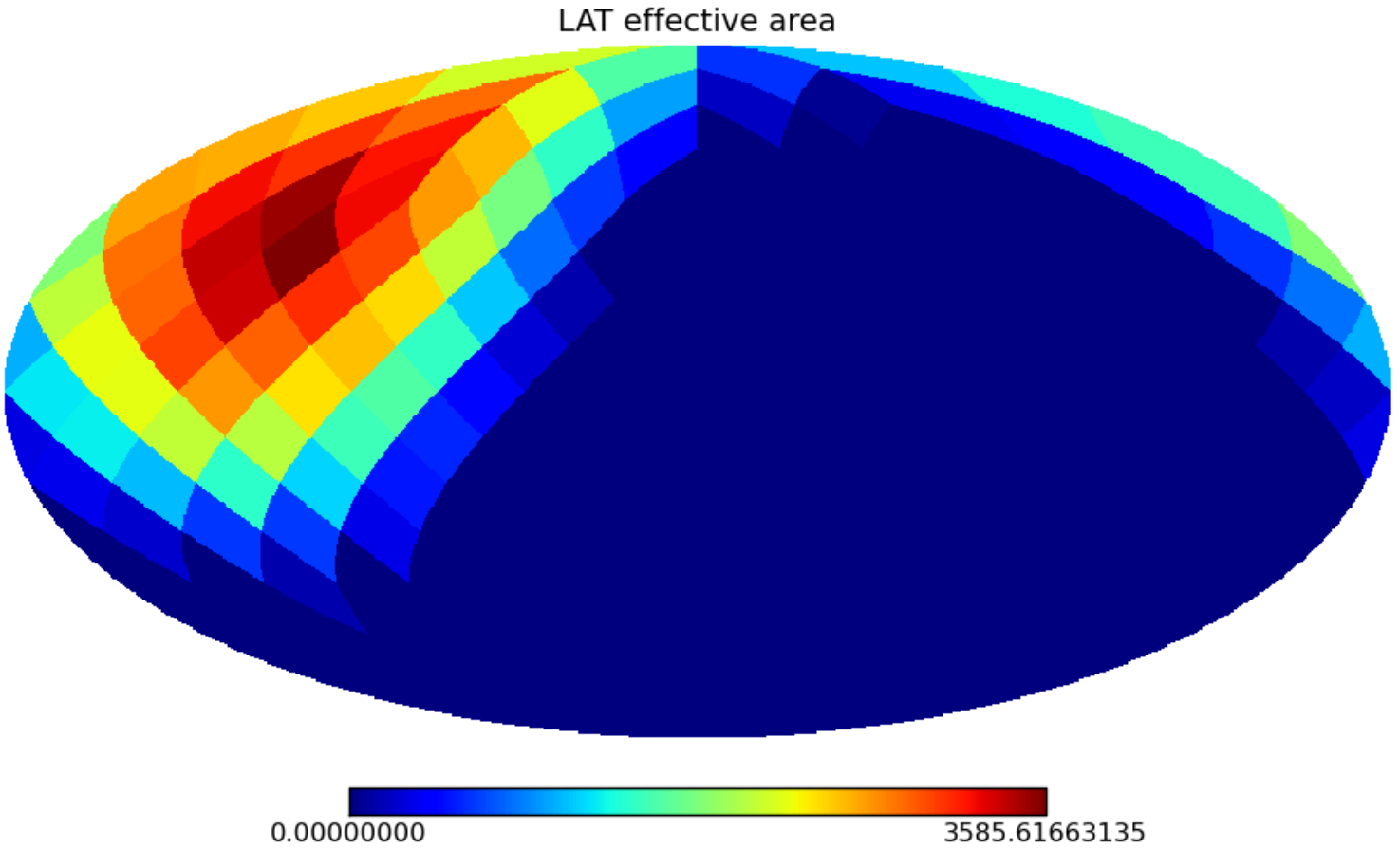
Joint analysis of GBM and SPI-ACS



Usual case extremely hard black body

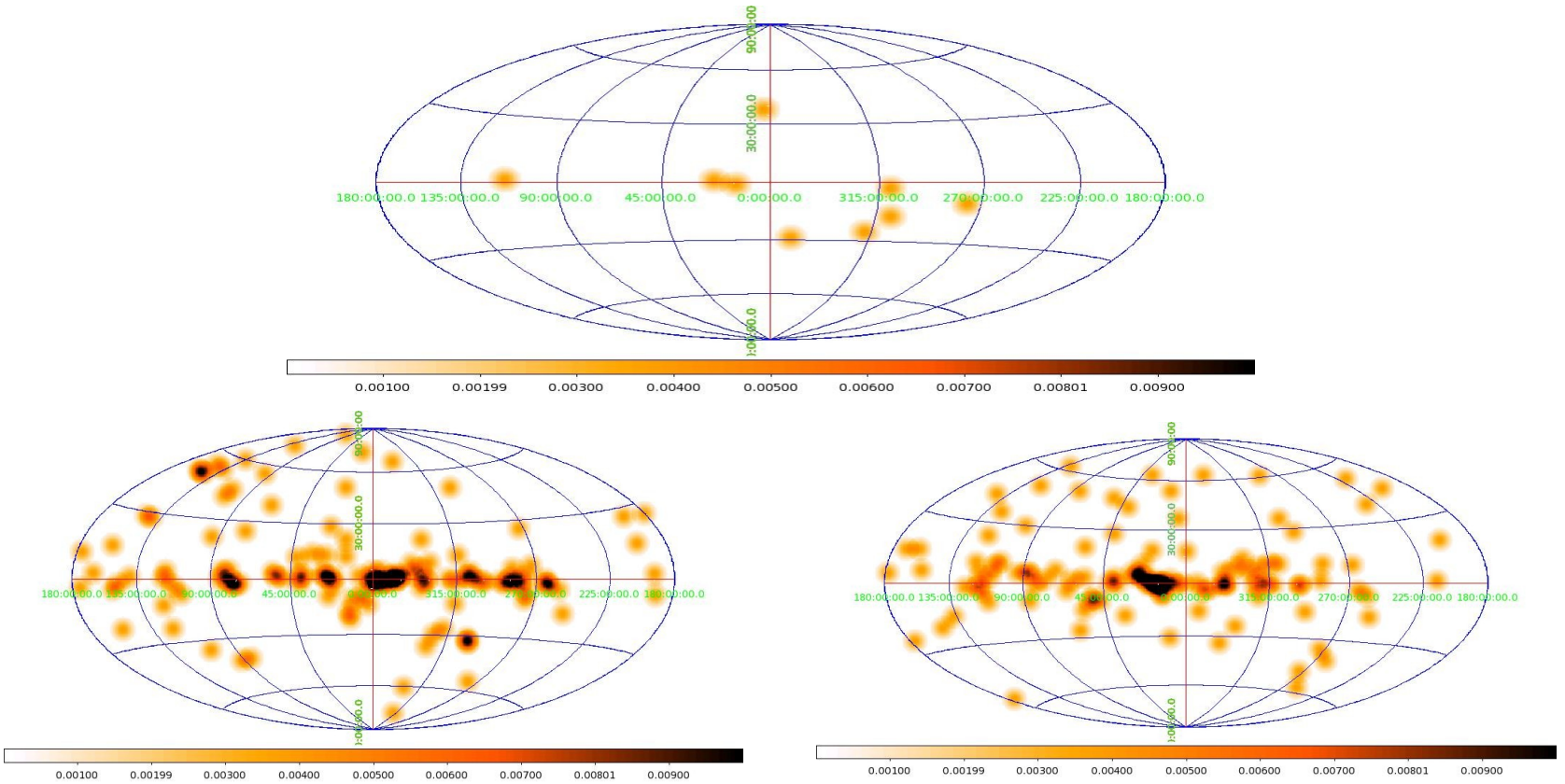
16−Oct−2012 23:33

Fermi-LAT



LAT covers small fraction of the sky, sensitive to about 10^{-5} erg/cm^2 in one second (for example coverage for one of the burst is shown)

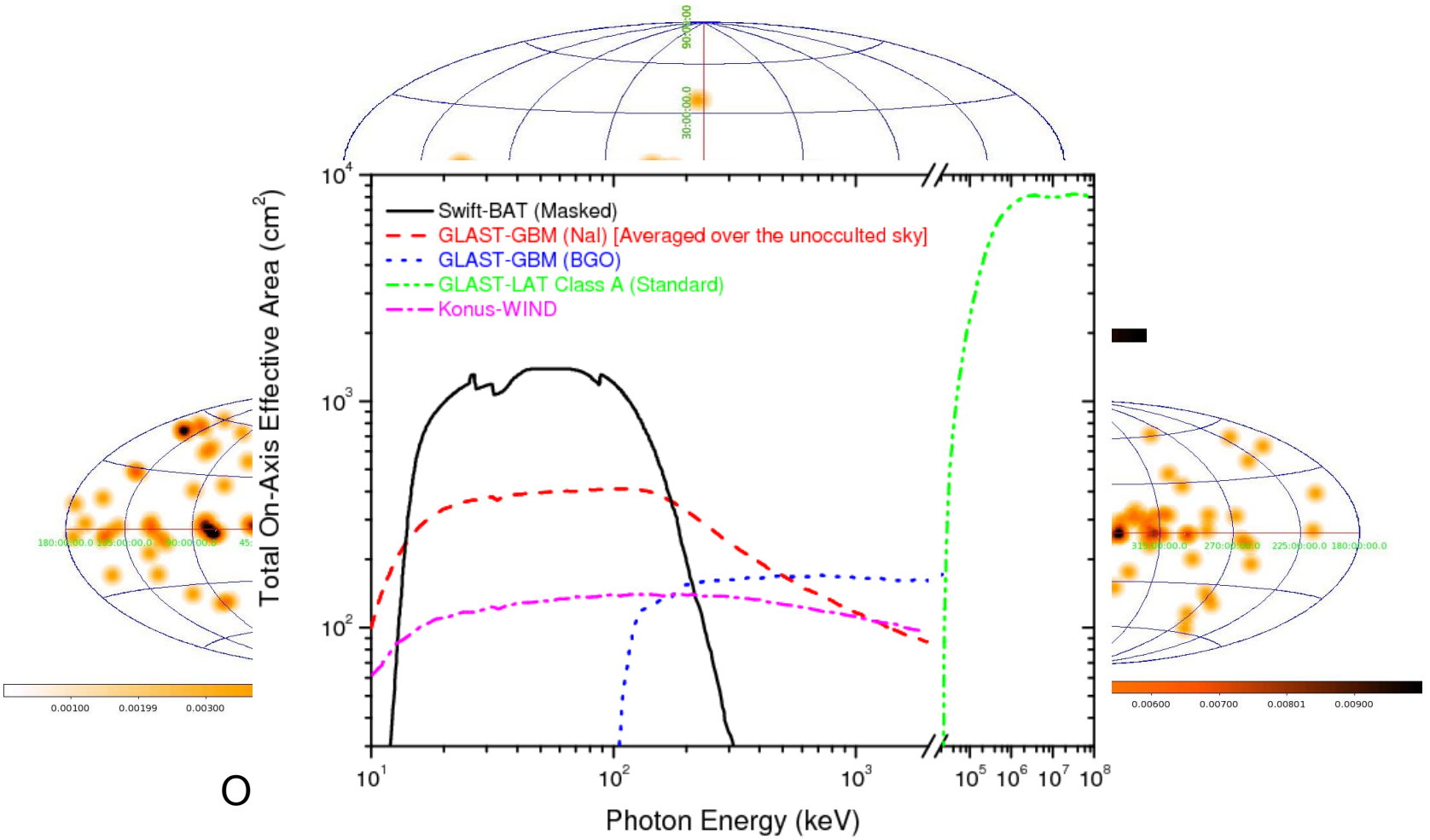
Fermi-LAT



On-bursts an off-bursts (x10 exposure) images

LAT covers small fraction of the sky, sensitive to about 10^{-5} erg/cm^2 in one second (for example coverage for one of the burst is shown)

Fermi-LAT



O

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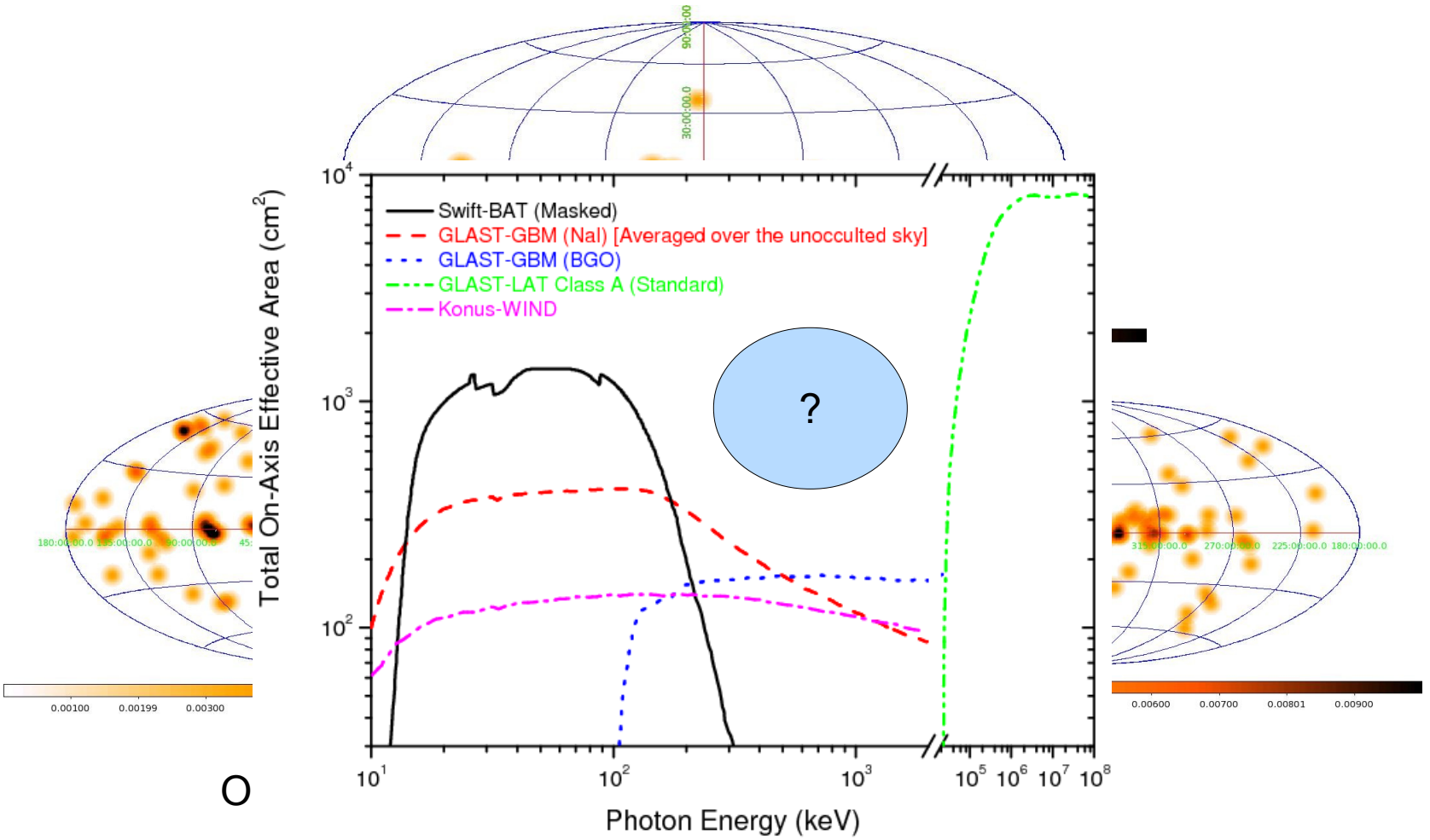
Fermi-LAT



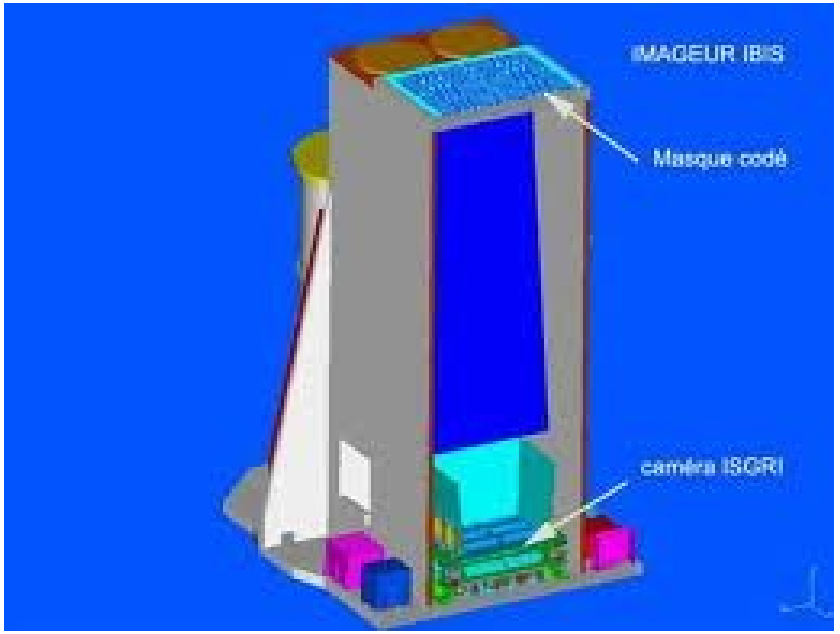
O

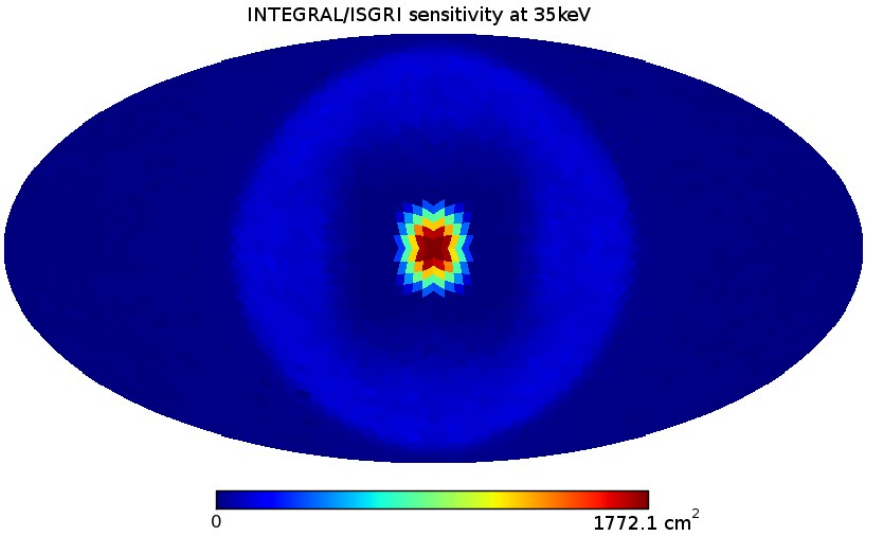
LAT covers small fraction of the sky, sensitive to about 10^{-5} erg/cm^2 in one second (for example coverage for one of the burst is shown)

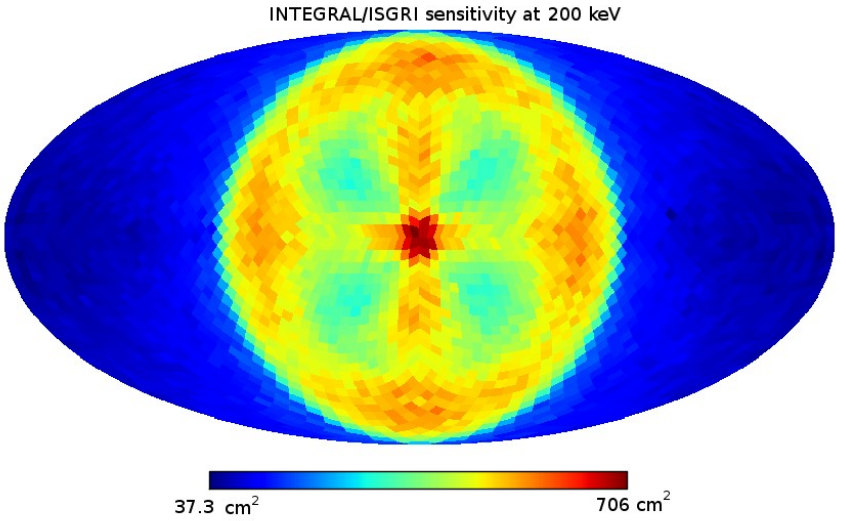
Possible origin of the events

- Rare (<1/10 years) outburst of an astrophysical source. E.g. SGR-like but with unusually hard spectrum.
- Bunches of particles: 30000 of >MeV particles. Seems to be excluded by non-observation of other INTEGRAL instruments
- Earth origin: but no dependency on the distance from the Earth
- Failure of electronics: but two counters (SPI VETO and SPI-ACS) are consistent
- Failure of PMT/crystals: but DFEEs behave consistently
- Unknown instrumental effect...

INTEGRAL/IBIS shield?



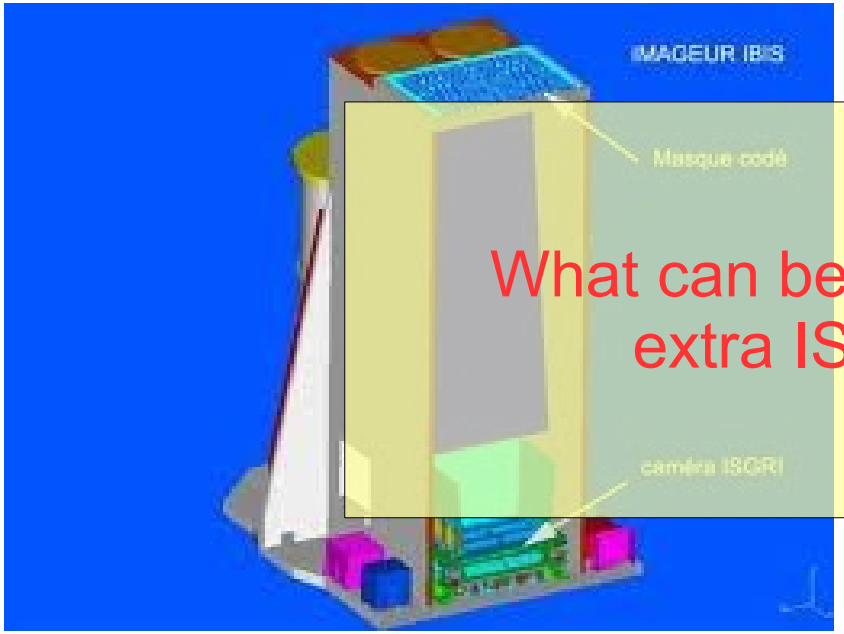


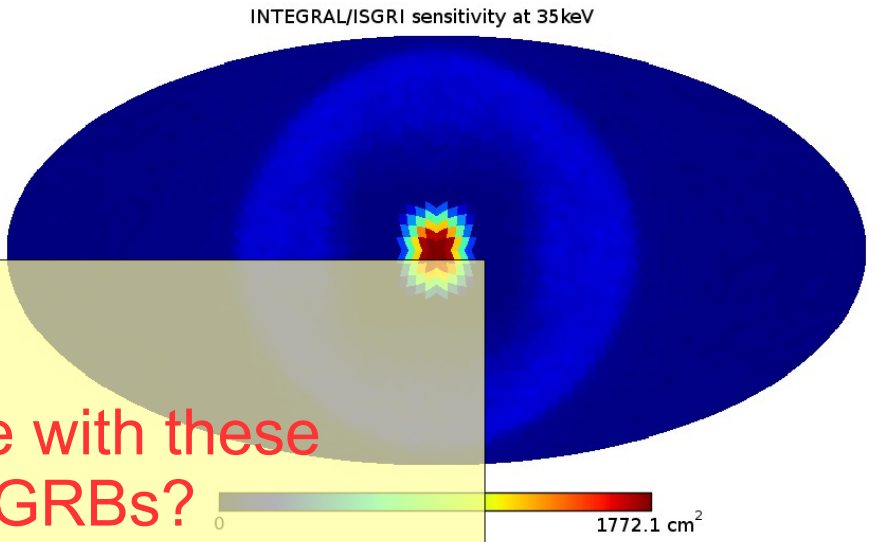


IBIS shield becomes transparent above ~100 keV

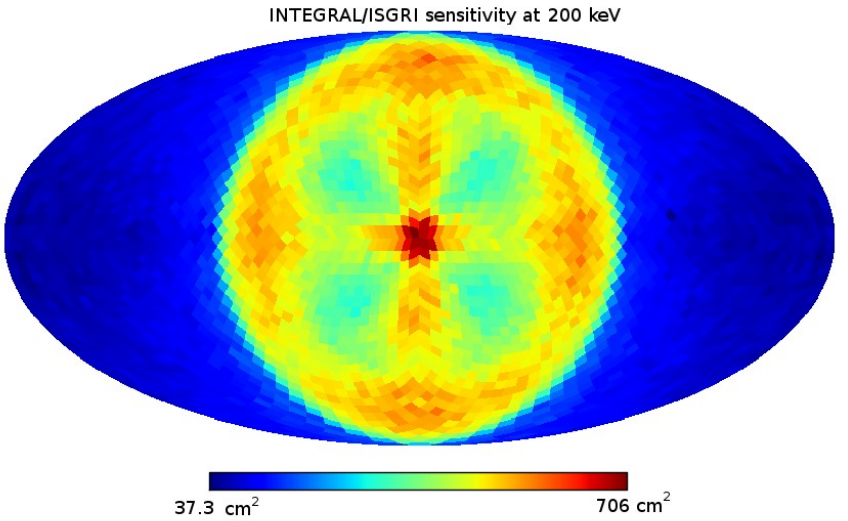
Under investigation..

INTEGRAL/IBIS shield?





What can be done with these extra ISGRI GRBs?



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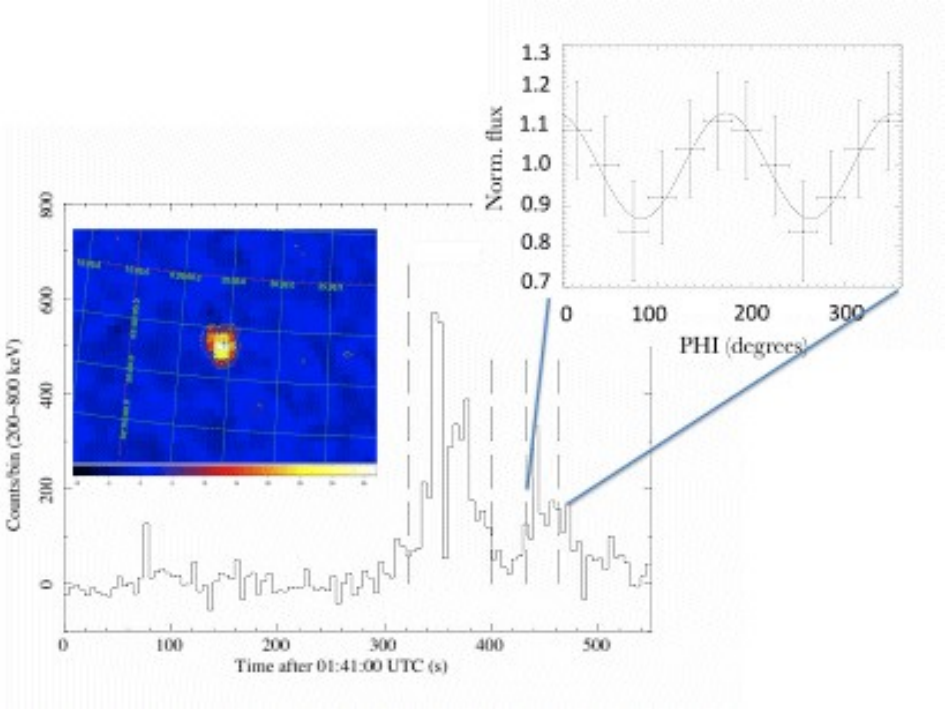
Under investigation..

Gamma-ray polarization measurements

Both SPI and IBIS can be used to measure gamma-ray polarization by measuring direction of of Compton electron

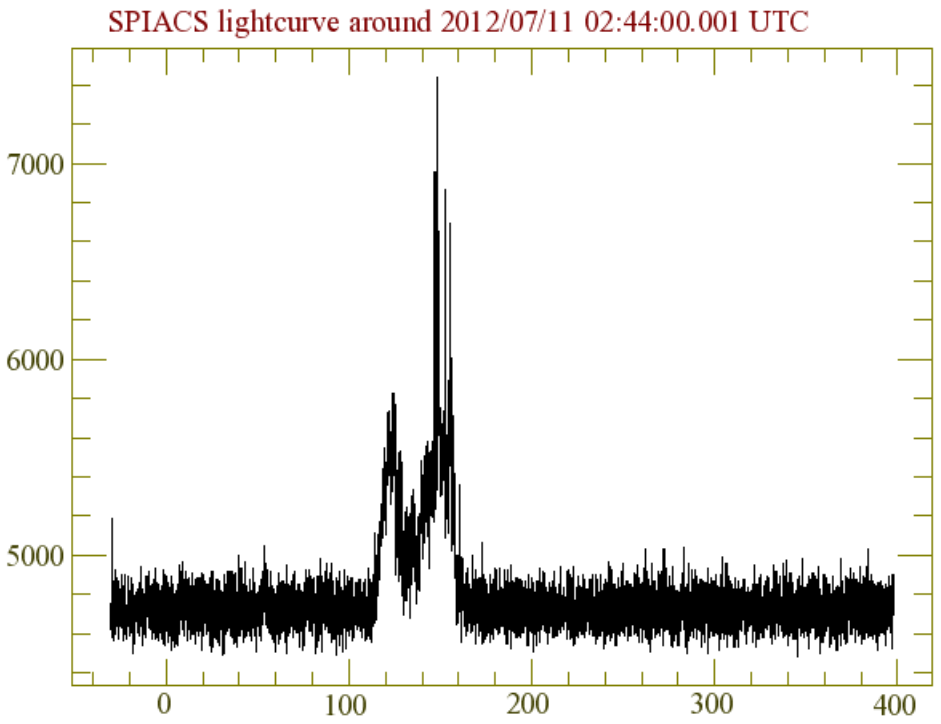


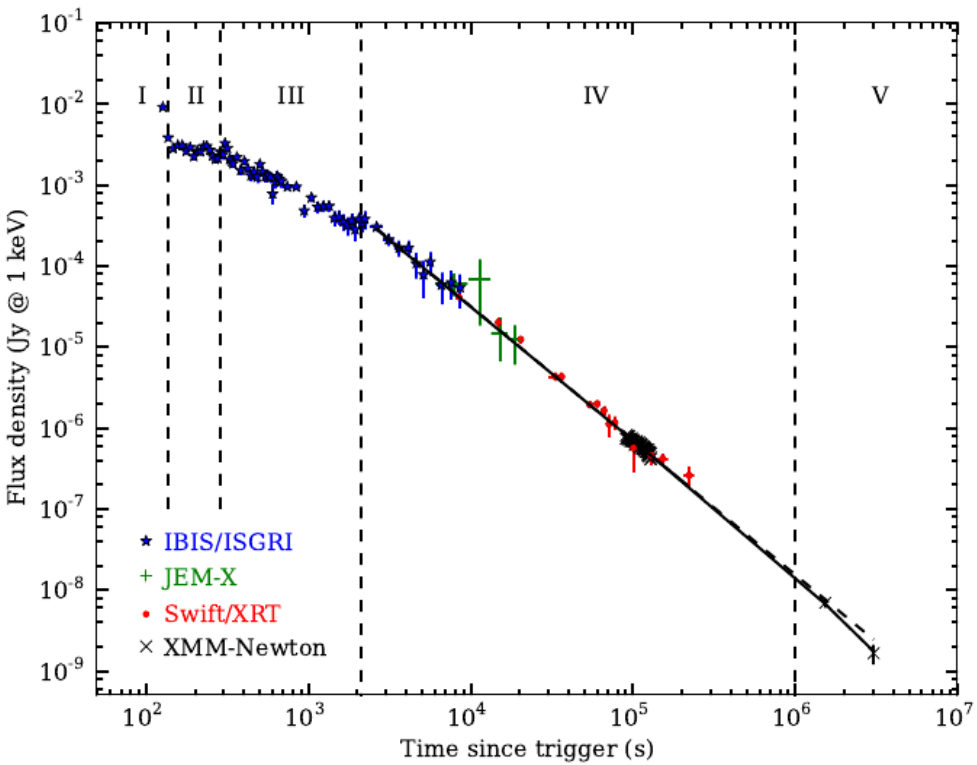
D. Gotz, Philipe Laurent et al in Paris

Mass model is essential for these measurements

INTEGRAL/ISGRI GRB120711A

- Luminous GeV-loud GRB happened in ISGRI FoV (1 in 10 years chance)





Emission has been observed above 20 keV for 10000 seconds

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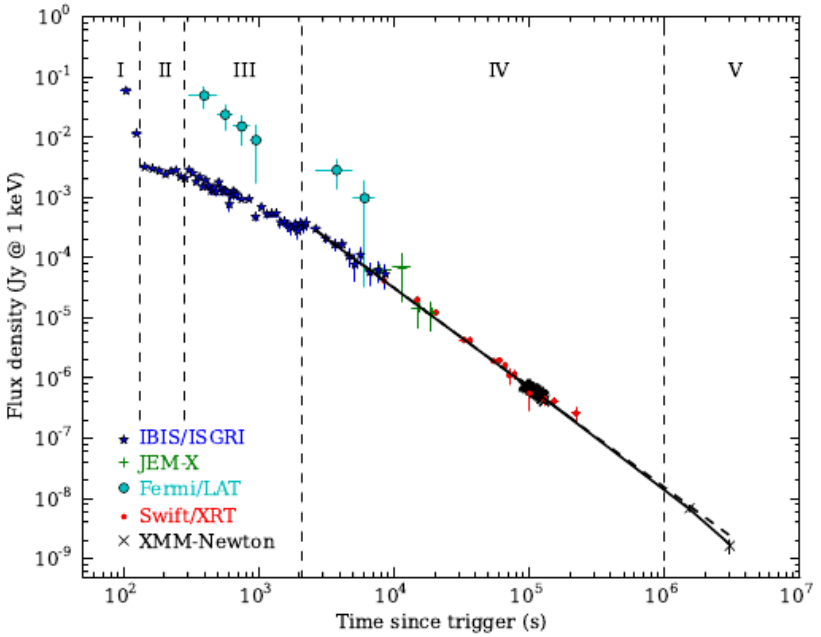

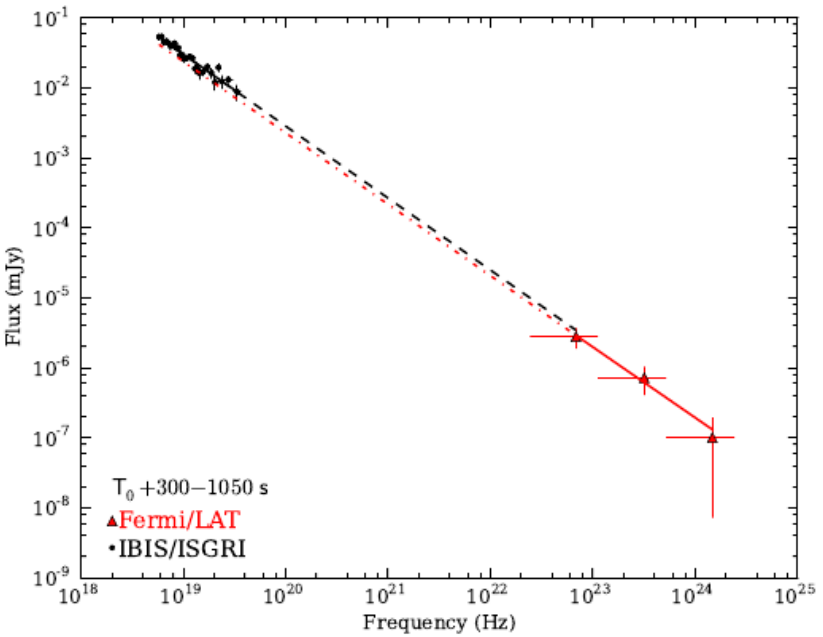

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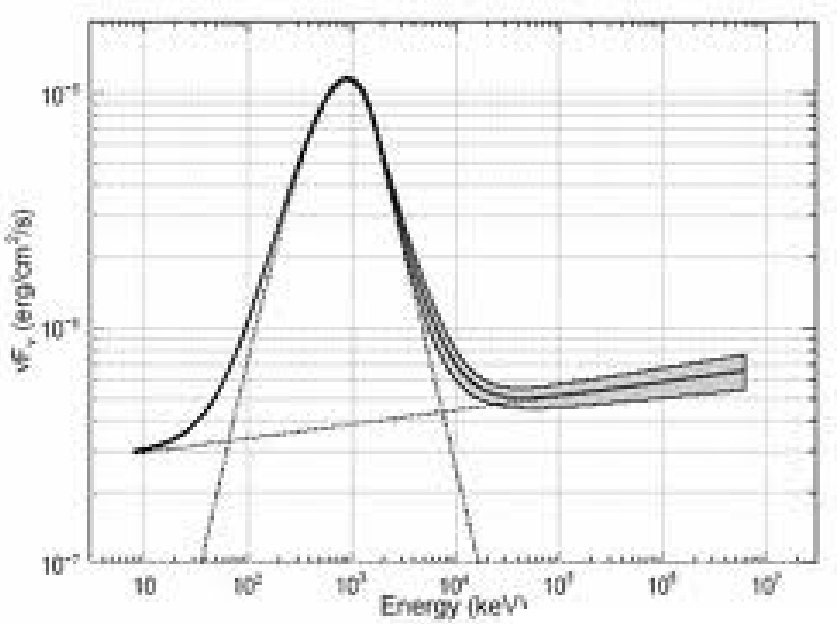
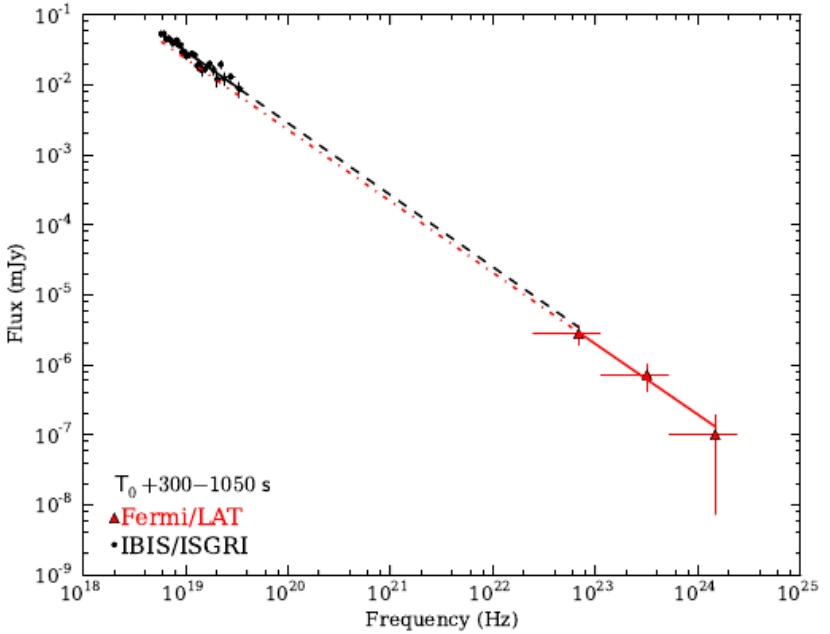
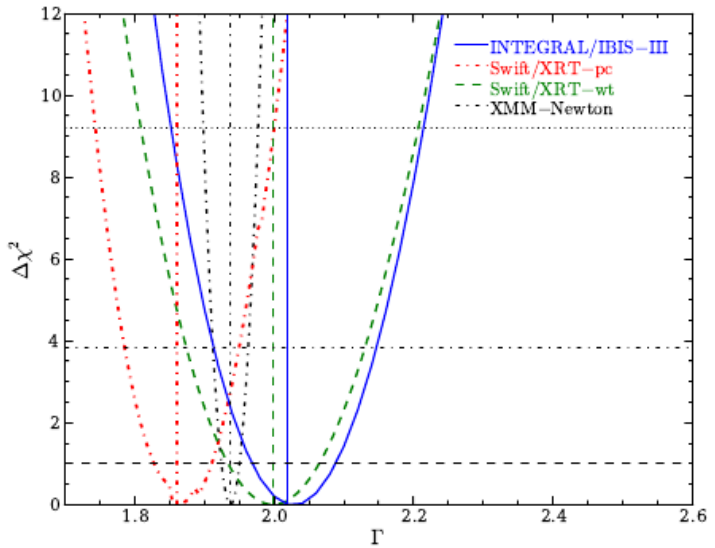
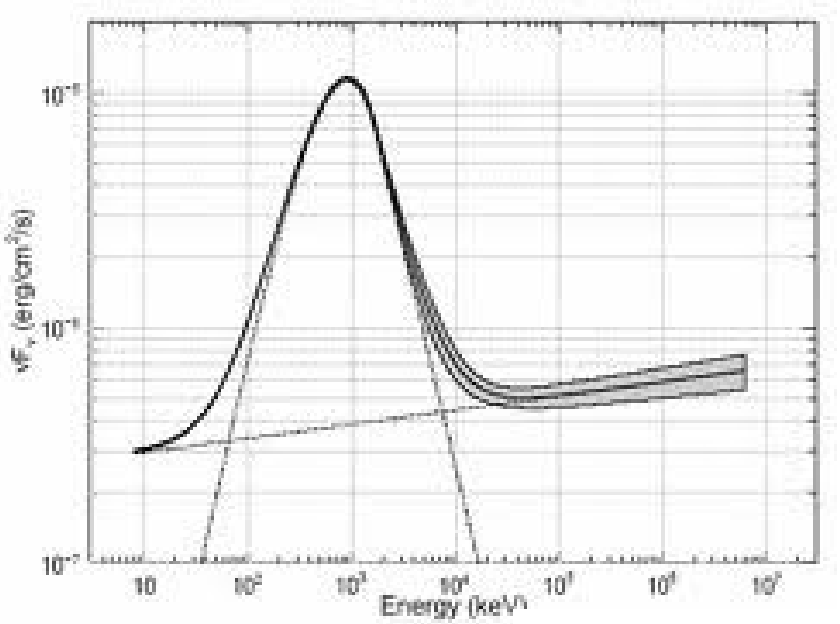


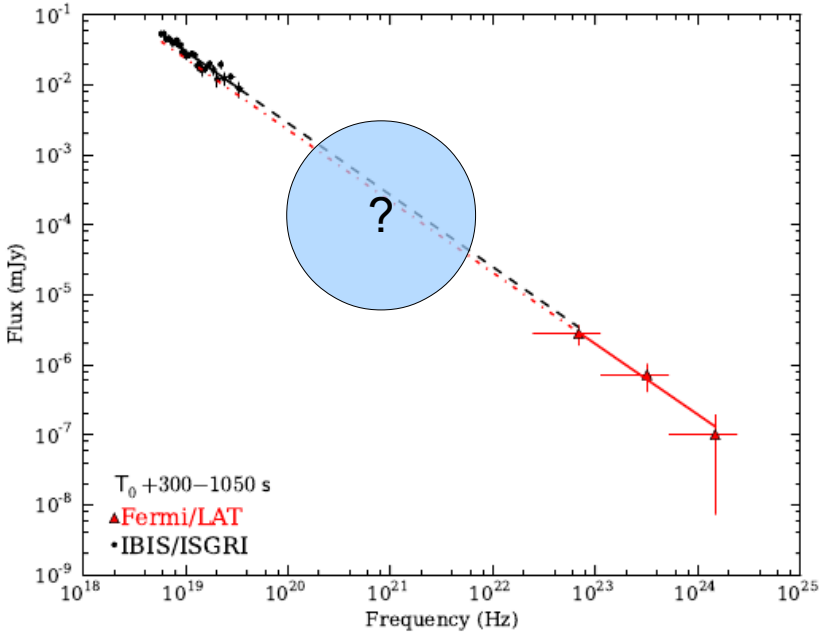


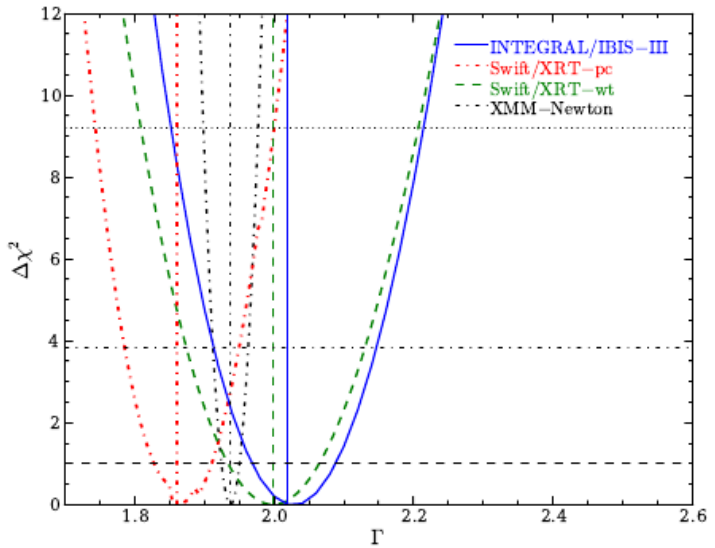


20keV to 10GeV : same universal spectrum from prompt to late afterglow

INTEGRAL/ISGRI GRB120711A





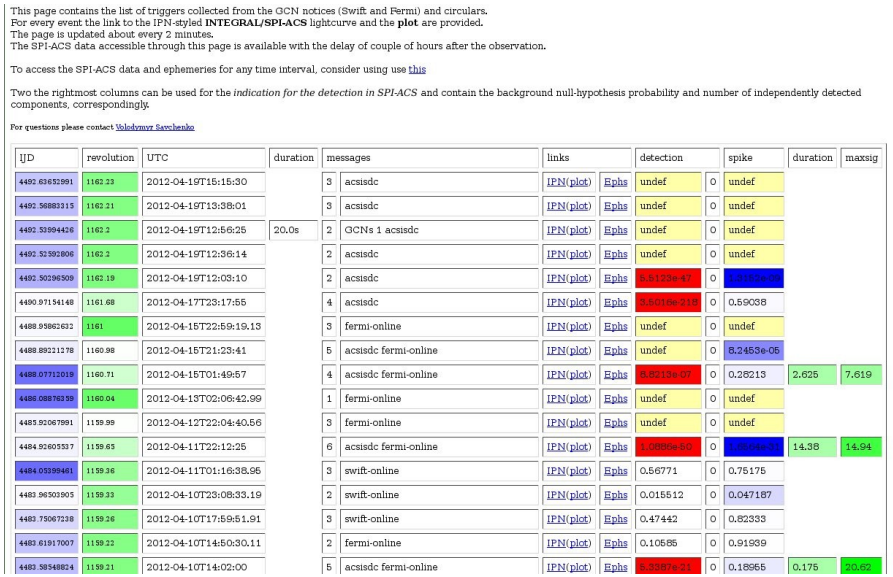


20keV to 10GeV : same universal spectrum from prompt to late afterglow

Prospects

- SPI-ACS is sensitive to bursts about 10^{-8} erg/cm^2 from 100 keV
- Larger sample of GRBs can be studied with INTEGRAL
- Instrument calibration work, understanding the satellite model, is required to better exploit potential of INTEGRAL
- New large effective area instrument at ~1MeV capable of studying GRBs on the variability scale would be able to test measurements of the SPI-ACS

Online resources



This page contains the list of triggers collected from the GCN notices (Swift and Fermi) and circulars.
For every event the link to the IPN-styled **INTEGRAL/SPI-ACS** lightcurve and the **plot** are provided.
The page is updated about every 2 minutes.
The SPI-ACS data accessible through this page is available with the delay of couple of hours after the observation.

To access the SPI-ACS data and ephemeries for any time interval, consider using use this

Two the rightmost columns can be used for the *indication for the detection in SPI-ACS* and contain the background null-hypothesis probability and number of independently detected components, correspondingly.

For questions please contact Volodymyr Savchenko

IJD	revolution	UTC	duration	messages		links		detection		spike	duration	maxsig
4492.63652991	1162.23	2012-04-19T15:15:30		3	acsisdc	IPN(plot)	Ephs	undef	0	undef		
4492.58883315	1162.21	2012-04-19T13:38:01		3	acsisdc	IPN(plot)	Ephs	undef	0	undef		
4492.53994426	1162.2	2012-04-19T12:56:25	20.0s	2	GCNs 1 acsisdc	IPN(plot)	Ephs	undef	0	undef		
4492.52592806	1162.2	2012-04-19T12:36:14		2	acsisdc	IPN(plot)	Ephs	undef	0	undef		
4492.50296509	1162.19	2012-04-19T12:03:10		2	acsisdc	IPN(plot)	Ephs	5.8123e-47	0	5.8123e-47		
4490.97154148	1161.68	2012-04-17T23:17:55		4	acsisdc	IPN(plot)	Ephs	5.5016e-218	0	0.59038		
4488.95862632	1161	2012-04-15T22:59:19.13		3	fermi-online	IPN(plot)	Ephs	undef	0	undef		
4488.89221178	1160.98	2012-04-15T21:23:41		5	acsisdc fermi-online	IPN(plot)	Ephs	undef	0	8.2453e-05		
4488.07712019	1160.71	2012-04-15T01:49:57		4	acsisdc fermi-online	IPN(plot)	Ephs	6.8213e-07	0	0.28213	2.625	7.619
4486.08876359	1160.04	2012-04-13T02:06:42.99		1	fermi-online	IPN(plot)	Ephs	undef	0	undef		
4485.92067991	1159.99	2012-04-12T22:04:40.56		3	fermi-online	IPN(plot)	Ephs	undef	0	undef		
4484.92605337	1159.65	2012-04-11T22:12:25		6	acsisdc fermi-online	IPN(plot)	Ephs	1.0889e-50	0	1.0889e-50	14.38	14.94
4484.05399461	1159.36	2012-04-11T01:16:38.96		3	swift-online	IPN(plot)	Ephs	0.56771	0	0.75175		
4483.96503905	1159.33	2012-04-10T23:08:33.19		2	swift-online	IPN(plot)	Ephs	0.015512	0	0.047187		
4483.75067238	1159.26	2012-04-10T17:59:51.91		3	swift-online	IPN(plot)	Ephs	0.47442	0	0.82333		
4483.61917007	1159.22	2012-04-10T14:50:30.11		2	fermi-online	IPN(plot)	Ephs	0.10585	0	0.91939		
4483.58548824	1159.21	2012-04-10T14:02:00		5	acsisdc fermi-online	IPN(plot)	Ephs	5.3387e-21	0	0.18965	0.175	20.62

SPI-ACS direct access to the data

Light curves	both NRT and Archived, available with a delay of few hours. *Now in the IPN format*
Ephemeries	INTEGRAL ephemeries
Attitude	and Ecliptic to satellite coordinates convertion
Triggers	Links to the ACS lightcurves for a list of external triggers

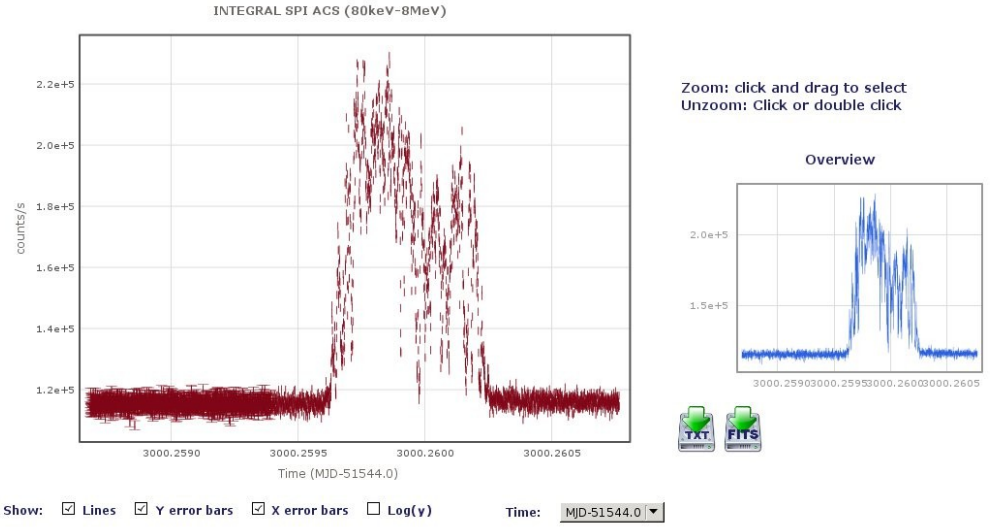
Try using the script to access the lightcurves

For the realtime triggers and overall list of the triggers give a look to ACS triggers page at ISDC

For a nice online graphical interface to SPI-ACS light curves (and much more) check out the HEAVENS (though, do not search there for the most recent ones)

If in doubt contact me

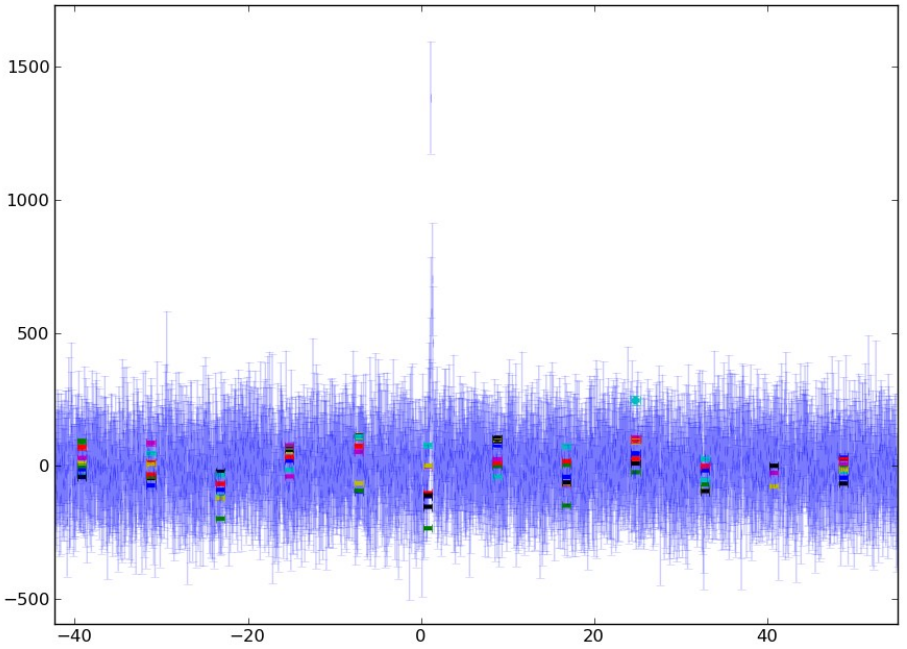
Near realtime data interface, for prompt reaction on the astrophysical events



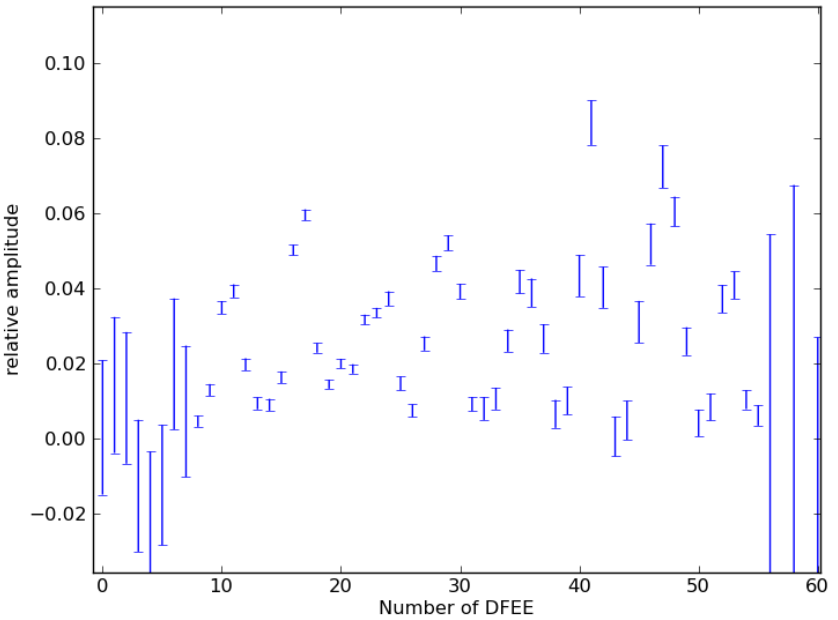
Data for the HEAVENS, to be explored with in the frame of the rich data base

Individual DFEE

Sometimes, burst happens to be observed in individual FEEs.
No signal is observed in the case of these bursts.

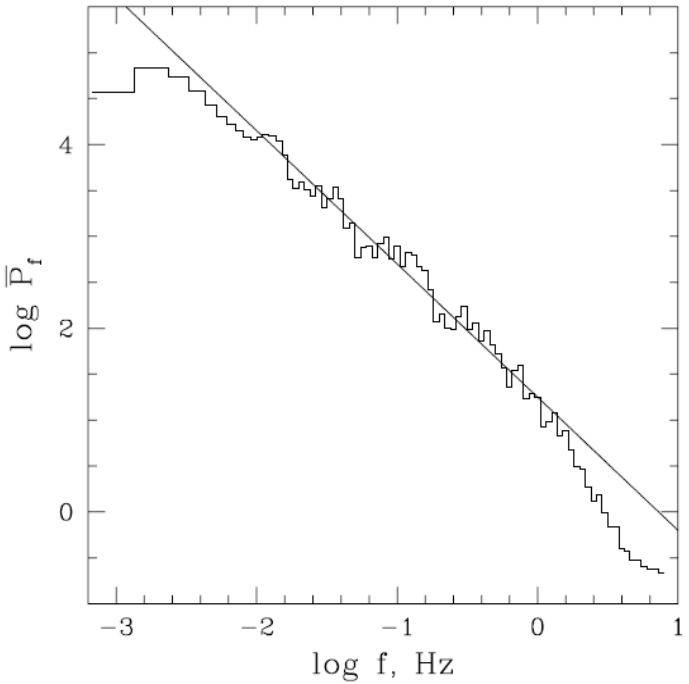


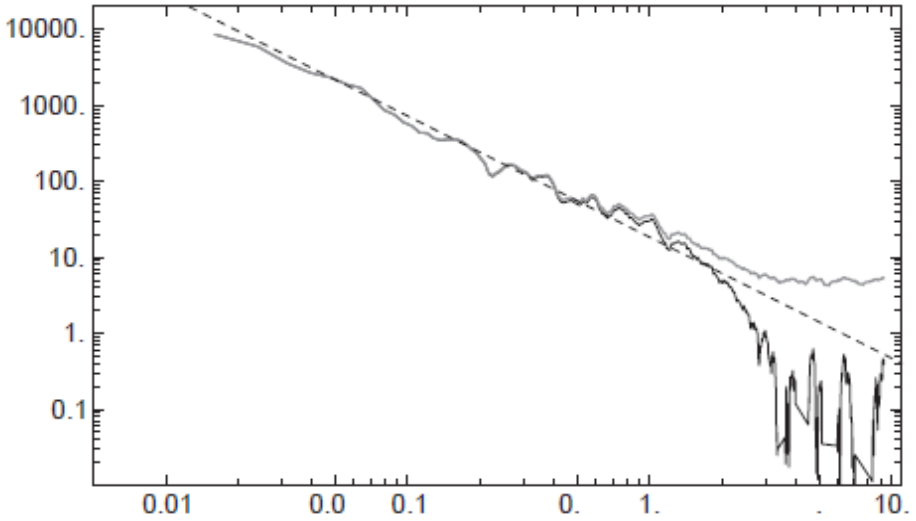
For comparison: relative contribution of different FEE in GRB 080319B



Timing properties

- *Beloborodov et al 2000* first performed extensive studies of averaged GRB power density spectra

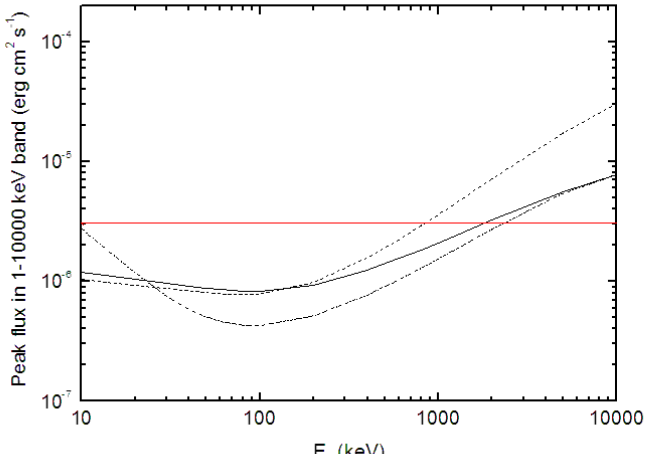


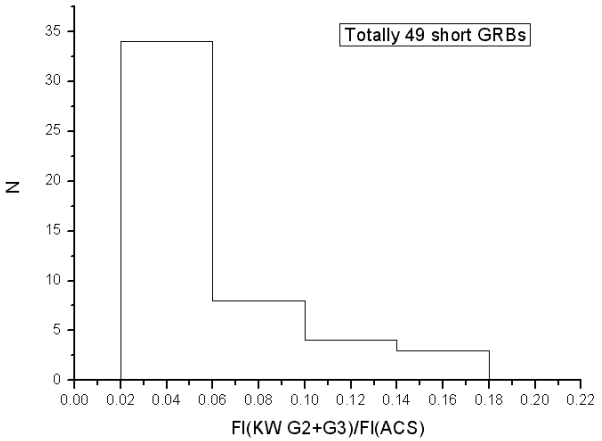


- *Ryde at al 2004* studied temporal properties

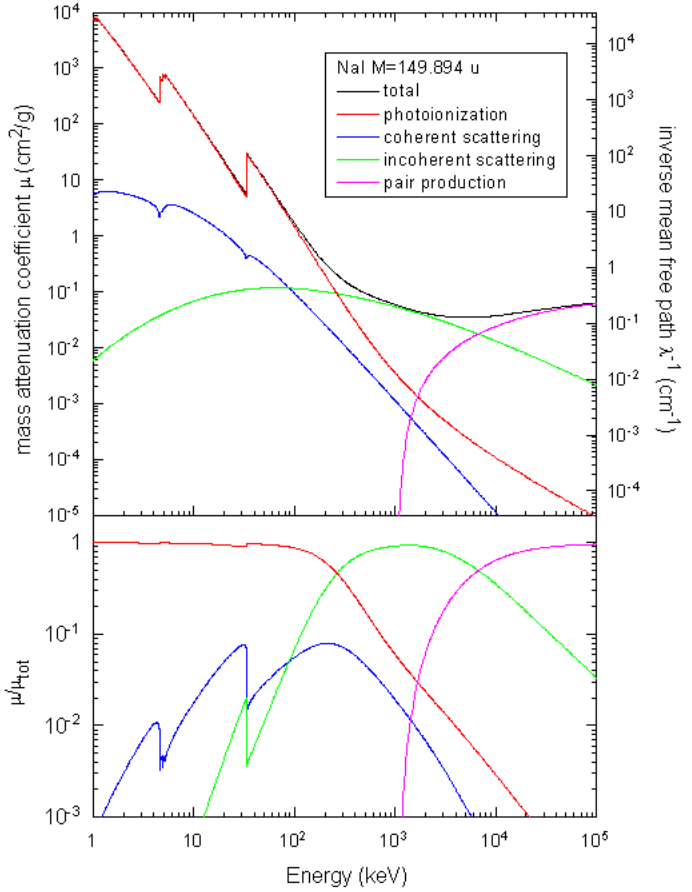
Konus-Wind

Sensitivity to the Band spectrum:





Thick detectors (7.5cm) – sensitive to high energy photons



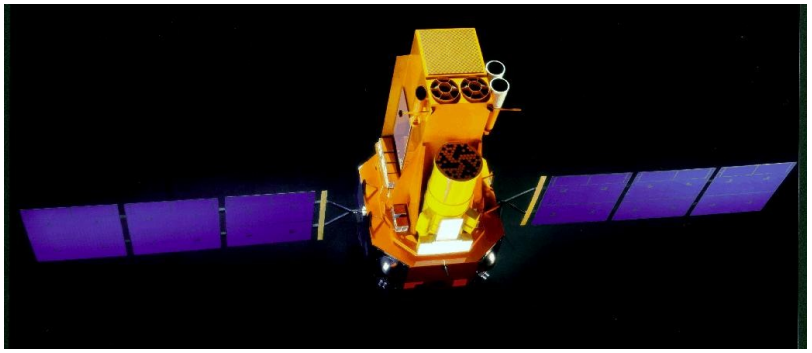
Assuming GRB-like spectrum, the brightest bursts should be visible in the Konus-Wind, but not necessarily all the rest of them.

What to do next?

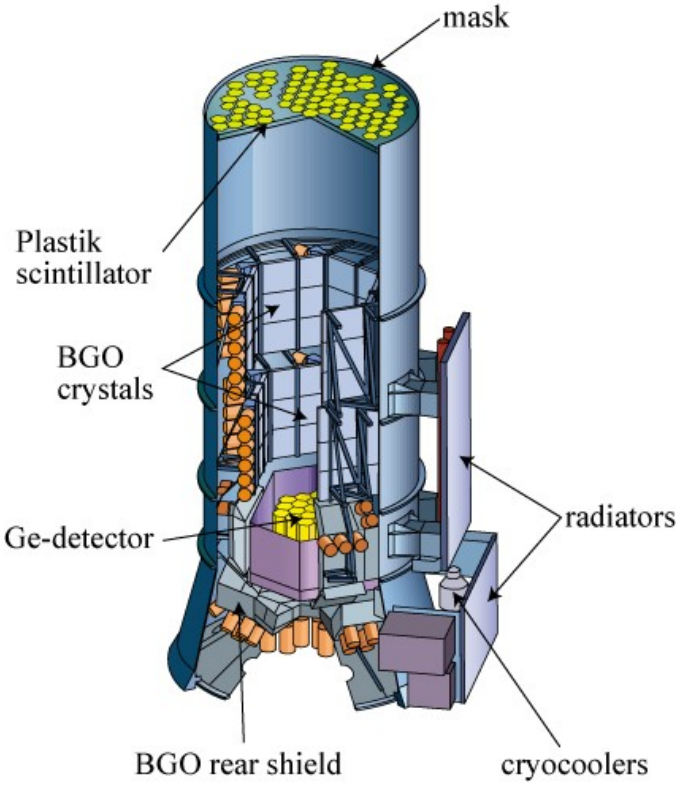
- Figure out if instrumental effects may be responsible
- Get proper upper limits using responses
- Stacking bursts in GBM, LAT, Konus

INTEGRAL SPI-ACS

Launched in 2002, INTEGRAL covers broad range of energies from optical to 10 MeV



The high-energy spectrometer SPI is wrapped in the active anti-coincidence shield - ACS

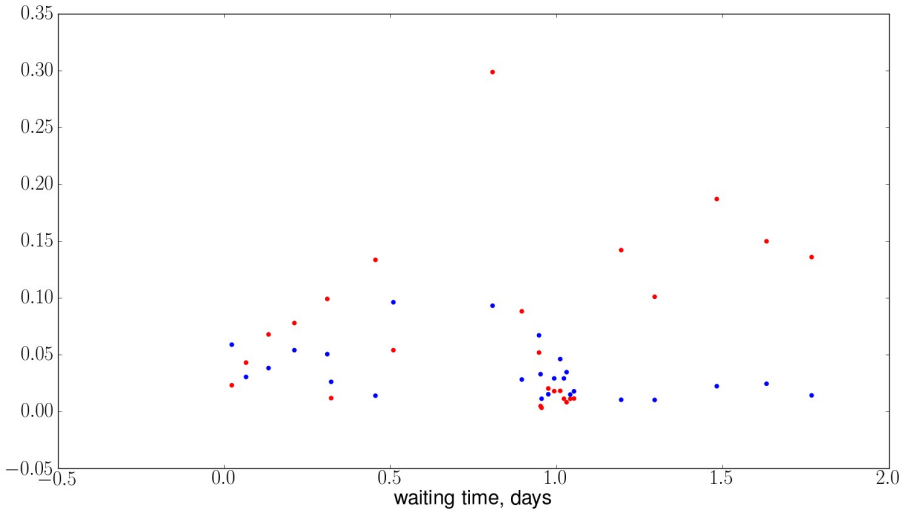


SPI-ACS is 512kg of BGO scintillator, viewed by 81 photomultiplier.
For some directions and energies it reaches effective area of 0.8m2

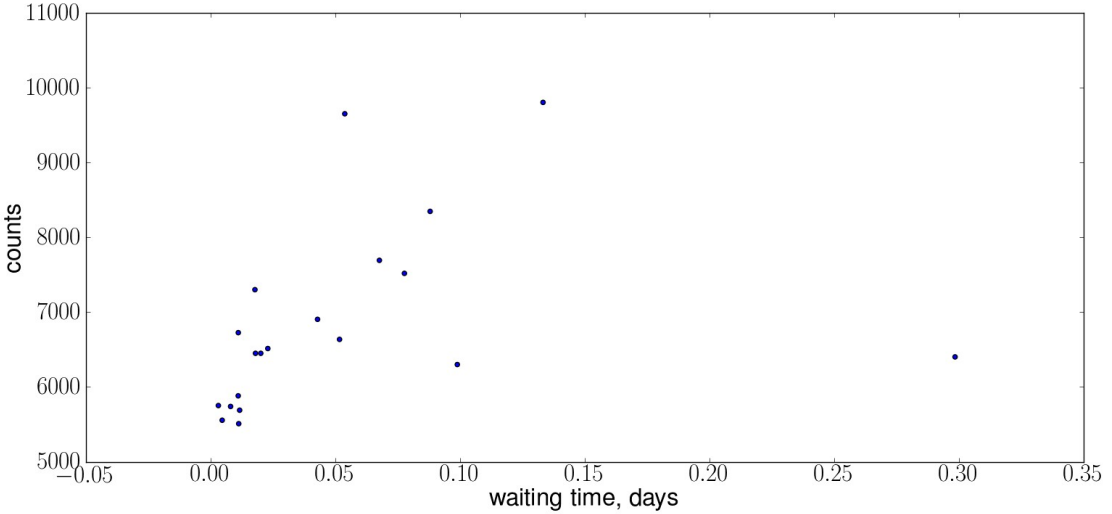
However, it records virtually no information but single 100 keV-80 MeV continuous 50ms rate

The detection is not affected by on-board trigger biases!

April 19-22 and May 5-6



Burst count rate seems to be correlated with the waiting time before the burst: indication of discharge mechanism.



	Suzaku/HXD-II WAM	CGRO/BATSE LAD	Beppo-SAX/PDS GRBM	INTEGRAL/SPI-ACS	Fermi GBM
Crystal	BGO	NaI(T1)	CsI(Na)	BGO	BGO
Energy range (keV)	50-5000	20-2000	40-700	> 75	150-30000
Effective area (cm2)	800@100 keV 400@1 MeV	2000@100 keV 150@1 MeV	700@200 keV 100@1 MeV	3000@100keV $\lesssim$ 8000@1MeV	120@200 keV 120@1MeV
Time resolution	31.25 ms	2 ms	7.8 ms	50 ms	5 μs