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

Volodymyr Savchenko

Moscow 2013
~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, SPI, JEM-X: GRBs

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This is not all INTEGRAL GRBs!
SPI-ACS is 512kg of BGO scintillator, viewed by 91 photomultiplier triggering on photons above ~100keV. For some directions and energies it reaches effective area of 1m² 50 ms light curve from 100keV for (almost) continuously 11 years! But nothing else...
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50 ms light curve from 100keV for (almost) continuously 11 years!
SPI-ACS is 512kg of BGO scintillator, viewed by 81 photomultiplier. For some directions and energies the effective area approaching $1m^2$.

50 ms light curve from 100keV for (almost) continuously 11 years!
Large effective area, stable background and unbiased data taking makes it suitable for studying timing properties from 50ms to 10,000s.

(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.
The 1\textsuperscript{st} SPI-ACS GRB catalogue

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

At least large part of these excess short events could be real.
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

![Graph showing data points and trend line](chart.png)

**Previous catalogue**
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.

Are a subject of study on their own see talk of (Rodríguez-Gasén et al 2013)
But constitute non-trivial background for GRBs
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.
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.
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.
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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.

<table>
<thead>
<tr>
<th>GRB</th>
<th>Konus Wind</th>
<th>Suzaku WAM</th>
<th>Fermi GBM</th>
<th>RHESSI</th>
<th>Swift/BAT</th>
<th>IPN</th>
<th>Fermi LAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>461</td>
<td>452</td>
<td>292</td>
<td>145</td>
<td>127</td>
<td>21</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

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.
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How is the duration distribution divided in two (or more) populations depends on physical assumptions.
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Bromberg et al 2013
GRB candidate sample

Qin et al 2013
GRB candidate sample

But there is no good enough reason to use two Gaussian

This simple separation is known to fail in some individual GRBs
Ultra-long GRBs

Stable background and continuous observations make the SPI-ACS suitable for ultra-long GRBs.

GRB 130925A

Major episode missed by Swift and Fermi
Ultra-long GRBs

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

GRB 130925A

Large effective area allows to observe variability down to 1s, $T/dT \sim 5000$
Numerous attempts to characterise variability time scale in the GRBs were made, usually exploiting stacked PSD or autocorrelation function. (e.g. Beloborodov 2000). 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.
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The range of the time scales is also large, although the clustering near 1 second is apparent.
SGR/AXP outbursts

SPI-ACS was in unique position to study these bursts since suffers less from the saturation effects

For example, Giant outburst of SGR 1806-20 (Mereghetti et al 2005).
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 cm^{-2} s) were observed by a number of instruments (Swift/BAT, Fermi).

SPI-ACS was in unique position to study these bursts since it did not suffer from the saturation effects (VS et al 2009, Mereghetti et al 2009).
April 19-22 and May 5-11

25 bursts were detected by SPI-ACS April 19-22 and 7 May 5-6, this episode was factor of 100 fainter.

Chance of random clustering is negligible
The brightest bursts reached $10^{-6}\text{erg/cm}^2\text{s}$ (first estimate).

Atel 4101, VS et al 2012

http://www.isdc.unige.ch/integral/ibas/magnetar/
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Not one of them is seen by any other instrument!

Atel 4101, VS et al 2012

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Why are they not seen?

- Unlucky observational conditions?
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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 than any other instrument.
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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 than 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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- 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

SPI-ACS spectrum

OTTB usual case
Joint analysis of GBM and SPI-ACS

![Data and folded model](image)

Square root of chi-squared for each channel

![Current Theoretical Model](image)

OTTB extreme
Joint analysis of GBM and SPI-ACS

1 MeV black body
Joint analysis of GBM and SPI-ACS

Usual case extremely hard black body
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)
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Fermi-LAT

LAT covers small fraction of the sky, sensitive to about $10^{-5}$ erg/cm² in one second (for example coverage for one of the burst is shown)
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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 off-axis GRB?

IBIS shield starts to become transparent above ~100 keV, where the ACS also starts to be sensitive.
INTEGRAL/IBIS off-axis GRB?

What can be done with these extra ISGRI GRBs?

IBIS shield starts to become transparent above ~100 keV, where the ACS also starts to be sensitive.
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, P. 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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20keV to 10GeV : same universal spectrum from prompt to late afterglow
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Hard X-ray afterglow with SPI-ACS?

Much larger sample: off-axis events

Minaev et al, in preparation
Prospects

- SPI-ACS is sensitive to bursts about $10^{-8}$ erg/cm$^2$ from 100 keV
- Larger sample of out-of-FoV 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

Near real-time 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.
Online resources

- Near realtime data interface for prompt reaction on the astrophysical events
- Data for the HEAVENS, to be explored within the frame of the rich data base

- Near realtime data server (ISDC)
  - NRT catalogue collection
  - And data analysis (Cloud, APC/CCLyon)

- Public web interface (google appengine cloud)

- New alerts

- 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 et al 2004** studied temporal properties.
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
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.
<table>
<thead>
<tr>
<th>Crystal</th>
<th>Suzaku/HXD-II WAM</th>
<th>CGRO/BATSE LAD</th>
<th>Beppo-SAX/PDS GRBM</th>
<th>INTEGRAL/SPI-ACS</th>
<th>Fermi GBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGO</td>
<td>NaI(Tl)</td>
<td>CsI(Na)</td>
<td>BGO</td>
<td>BGO</td>
<td>BGO</td>
</tr>
<tr>
<td>Energy range (keV)</td>
<td>50-5000</td>
<td>20-2000</td>
<td>40-700</td>
<td>&gt; 75</td>
<td>150-30000</td>
</tr>
<tr>
<td>Effective area (cm²)</td>
<td>800@100 keV</td>
<td>2000@100 keV</td>
<td>700@200 keV</td>
<td>3000@100keV</td>
<td>120@200 keV</td>
</tr>
<tr>
<td>400@1 MeV</td>
<td>150@1 MeV</td>
<td>100@1 MeV</td>
<td></td>
<td>≤ 8000@1MeV</td>
<td>120@1 MeV</td>
</tr>
<tr>
<td>Time resolution</td>
<td>31.25 ms</td>
<td>2 ms</td>
<td>7.8 ms</td>
<td>50 ms</td>
<td>5 µs</td>
</tr>
</tbody>
</table>