Expected and unexpected gamma-ray emission from GRBs in light of AGILE and Fermi

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Outline

• The EGRET heritage;

• Description of the AGILE detectors for GRB;

• The AGILE HE GRBs sample:
  • GRB 080514B (extended emission, same spectrum at keV – GeV);
  • GRB 090401B (complete coverage by Swift)
  • GRB 090510 (short with delayed component and spectral evolution);
  • GRB 100724B (simultaneous emission at MeV and GeV);
  • GRB 130327B (confirmation by LAT, no Swift Detection)
  • GRB 130427A (First with detection in Likelihood analysis by AGILE/GRID)

• Upper limits in gamma-rays of the undetected GRBs;

• The AGILE MCAL GRB sample & the AGILE contribution to IPN

• Conclusions
EGRET

- 1991-2000
- 30 MeV - 30 GeV
- AGN, GRB, Unidentified Sources, Diffuse Bkg
Five GRBs coincident in time with BATSE triggers were detected by EGRET above 100 MeV;

They showed both simultaneous and extended emission of gamma rays, until a few hundreds of seconds after trigger (with GRB 940217 until more than 5000 s);

In some GRBs (e.g. GRB 930131) the spectrum in 1 MeV – 1 GeV is described by the same model, others (e.g. GRB 941017) show additional components;
The EGRET heritage on GRBs


The EGRET heritage on GRBs

prompt gamma rays, $E > 50$ MeV

deadtime limited

"delayed" gamma-ray emission

The EGRET heritage

- Need fast timing for gamma-ray detection (improving EGRET deadtime, 100 msec → 100 microsec or less).

**Prompt Emission** (GRB 930131)  
**Delayed Emission** (GRB 940217)
The AGILE Payload: the most compact instrument for high-energy astrophysics

It combines for the first time a gamma-ray imager (30 MeV - 30 GeV) with a hard X-ray imager (18-60 keV) with large FOVs (1-2.5 sr) and optimal angular resolution.
AGILE: inside the cube…

HARD X-RAY IMAGER (SUPER-AGILE)

GAMMA-RAY IMAGER
SILICON TRACKER

ANTICOINCIDENCE

(MINI) CALORIMETER
AGILE GRB ON-BOARD SEARCH PROCEDURE

Super-A & MCAL EVENTS

8 (SA) + 12 (MCAL) DETECTOR RATEMETERS (1 ms)

NORMAL BURST SEARCH

1 ms 16 ms 64 ms 256 ms 1.024 s 8.192 s

HARDWARE

HARDWARE by dedicated state-machine

SOFTWARE

ultra-short GRBs, TGFs

sub-ms search

HARDWARE

by dedicated state-machine
Gamma-ray sky on-line with the APP AGILEScience (iPhone and Android)
AGILE gamma-ray sky, Sept. 20, 2014
(counts map, E > 100 MeV)
AGILE gamma-ray sky, Sept. 20, 2014
(counts map, E > 100 MeV)

blazar PKS 0502+049
ATEL and GCNs very fast notification with the APP AGILEScience (iPhone and Android)
expectations on GRBs above 100 MeV…

• EGRET detected ALL bright GRBs in its FOV (0.5 sr), 5 GRBs in 6 years.

• for a FOV ~2.5 sr naively expect AGILE detection 4-5 times more than EGRET: a few / year.

• not true.
AGILE and GRBs

Gamma Ray Imaging Detector
Silicon tracking detector
30 MeV – 50 GeV

GRID FoV

SA FOV
GRID FOV
Localized by Super-AGILE
Localized by IPN
Localized by SWIFT
Localized by Fermi-GBM
Localized by INTEGRAL
77 GRBs in the GRID-FOV until June 2009:

- 40 localized by Swift
- 20 localized by Fermi-GBM
- 15 localized by SuperAGILE
- 5 localized by INTEGRAL

15 also detected by MCAL (strong)
GRB 080721

Off-axis ~49°

fluence $8 \times 10^{-5}$ erg/cm² (20 keV – 5 MeV);

$E_{\text{peak}}$ 485 keV

(Konus-Wind, GCN 7995);

redshift 2.6 (GCN 7997);

Fluence is $\sim 10^{-5}$ erg/cm² (350 – 700 keV)
The first GeV-bright GRB after EGRET, associated with an afterglow with photometric redshift of 1.8 (A. Rossi et al., 2009, A&A).
70% the fluence of Konus in the range 0.5-5 MeV beta ~2.4, in agreement with the Konus value
a single Band model seems to fit the whole spectrum of GRB 080514B

$E_{\text{peak}} = 224 \text{ keV}$

$\alpha = -0.599$

$\beta = -2.48$

The same Band model fits the spectrum from 20 keV up to 50 MeV.

but also many non-detections above 100 MeV: AGILE-GRID upper limits

grb080723B/GCN8015: normalization $A = 0.023 \text{ keV}^{-1}\text{cm}^{-2}\text{s}^{-1}$
The Upper Limits are estimated with a Bayesian approach for a sample of 68 undetected GRBs from July 2007 until October 2009 with position inside the GRID FoV;

40 GRBs have spectral information (from Konus-Wind, Suzaku/WAM and Fermi/GBM), that is used to convert counts into flux;

In six cases the Upper Limit is stringent with respect to the extrapolation of the GRB spectrum at lower energy;

The corresponding 3 sigma upper limit is \( \sim 0.03 \, \text{ph cm}^{-2} \, \text{s}^{-1} \Rightarrow \sim 10^{-7} \, \text{erg cm}^{-2} \, \text{s}^{-1} \);

A likelihood search of gamma-ray delayed components (up to 3600 s after trigger) for the same events does not give positive results;

The detection rate of GRBs by AGILE/GRID is discussed and it is found that AGILE observes on average the same population as EGRET.
Upper limits in gamma rays: the sample

68 GRBs in the GRID-FOV July 2007 – October 2009:

36 localized by Swift
17 localized by Fermi-GBM
10 localized by SuperAGILE
5 localized by INTEGRAL

GeV emitting GRBs tend to be high-fluence events (2-year sample)

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However, today, after almost 8 years of data, the GRBs detected by AGILE appear to be less than expected.
AGILE
and
GRB 090818

$z = 0.54$
GRB 090818: among the brightest GRBs detected at MeV energies by AGILE MCAL
data and folded model
GRID, FT, G+L+S
\[ T = t_0, \ \delta T = 30 \text{ sec} \]
GRID, FT, G+L+S

T = t_0, \ delta T = 60 \ sec
GRID, FT, G+L+S

$T = t_0 + 60 \text{ sec}, \delta T = 30 \text{ sec}$
GRID, FT, G+L+S

\[ T = t_0 + 60 \text{ sec}, \quad \text{delta}T=60 \text{ sec} \]
on GRB 090618…

- Among the brightest events detected by MCAL at 1-10 MeV
- About 37 degree off-axis
- Clearly no gamma-ray emission above 100 MeV
  - Spectral index: $\beta \sim -3.2$
• **AGILE GRBs detected above 100 MeV:**
  
  • GRB 080514B (extended emission, same spectrum at keV – GeV);
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  • GRB 090510 (short with delayed gamma rays & spectral evolution);
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    (short, with delayed gamma rays & spectral evolution).
GRB 100724B: simultaneous GeV & MeV emission

• No time lag is found between the MeV and GeV emission. The two main bumps in the lightcurve show a remarkably similar shape at MeV and GeV.

• Due to the spinning operative mode, GRB 100724B remained within the AGILE/GRID FoV between $t_0+6s$ and $t_0+125s$.

• The GRB is not detected during the next “transit” in the FoV ($t_0 + 410s$, $t_0 + 529s$).
GRB 100724B: spectral evolution


A: $t_0$, $t_0 + 40$ s; photon index = 2.01 ± 0.04

B: $t_0 + 40$ s, $t_0 + 57$ s; photon index = 2.19 (+0.26, -0.19)

C: $t_0 + 57$ s, $t_0 + 90$ s; photon index = 2.35 (+0.08, -0.07).

A variation at $4.2\sigma$ is found in the spectral indices.
• AGILE GRBs detected above 100 MeV:

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  (extended emission, same spectrum at keV – GeV);

• **GRB 090401B (complete coverage by Swift);**

• GRB 090510
  (short with delayed gamma rays & spectral evolution);

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  (short, with delayed gamma rays & spectral evolution).
GRB 090401B: prompt emission

68% of the gamma-ray photons are emitted during prompt emission;

32% of the gamma rays are in the “extended” emission
GRB 090401B: a complete coverage of the afterglow

\[ F_v \sim t^{-\alpha}, \]
\[ \alpha_1 \simeq 1.16 \pm 0.03, \]
\[ \alpha_2 \simeq 1.47 \pm 0.02, \]
\[ t_{\text{break}} = 574 \text{ s} \]

(P. Schady et al., Swift report 208)
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GRB 130427A

- Outside the AGILE FoV for the first 200 s
- Detected by the automated flaring source pipeline
- First detection by likelihood of the extended emission
GRB 130427A

- Outside of the GRID FoV for the first ~ 200 s
- Strong prompt detection by MCAL
GRB 130427A

FM, 10h on 27 Apr, 04:00 -- 14:00

fov=60, alb=90, E > 100MeV

E > 50MeV

sqrt(TS)=5.2 , Gal/Iso free

E > 30MeV

sqrt(TS)=4.8 , Gal/Iso free
GRB 130427A

FM, 20h from 27 Apr 04:00
fov=60, al=90, E > 100MeV

FM, 24h AFTER, from 28 Apr 00:00
fov=60, al=90, E > 100MeV
• **AGILE GRBs detected above 100 MeV:**

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• GRB 130327B (confirmation by LAT, no Swift Detection);
• GRB 130427A (first detection by likelihood analysis by AGILE/GRID);

• **GRB 131108A** (short, with delayed gamma rays & spectral evolution).
AGILE
and
the “short”
GRB 090510

z = 0.903
AGILE: GRB 090510

T0 = 2009-05-10 00:23:00 UT
168999780.445 TT
Orbit: 10553
Energy range: 0 - 1 MeV
Selected bars: 7FFF 7FFF
MCAL Team - INAF/IASF-Bologna
Gamma-ray tail
(delayed emission)
\[ F = t^{-1.32} \]
AGILE – GRB 090510: interval: 2
Interval 1

Interval 2
GRB 090510 has been localized by Swift and detected also by Fermi/LAT (Ackermann et al. 2010) and AGILE (Giuliani et al. 2010). The redshift is 0.903 (De Pasquale et al. 2010).
GRB 090510: the delayed emission

GRB 090510: spectral evolution in a short GRB

Powerlaw with cutoff

\[ \alpha_1 = 0.6 \pm 0.3 \]
\[ E_c = 2.8 \pm 0.9 \text{ MeV} \]
\[ 1.8 \times 10^{-5} \text{ erg/cm}^2 (0.5 - 10 \text{ MeV}) \]


Powerlaw without cutoff

\[ \alpha_2 = 1.6 \pm 0.1 \]
\[ 3.1 \times 10^{-6} \text{ erg/cm}^2 (0.5 - 10 \text{ MeV}) \]
\[ \alpha_3 = 1.4 \pm 0.4 \]
\[ 2.9 \times 10^{-5} \text{ erg/cm}^2 (25 - 500 \text{ MeV}) \]
on the “short” GRB 090510…

• one of the shortest events with remarkable high-energy emission

• For a $z \sim 0.9$, $E(\text{iso}) = 10^{52}$ ergs

• MeV and gamma-ray emission above 100 MeV
  – Interval 1: $E(\text{peak}) \sim 3$ MeV
  – Interval 2: $E(\text{peak}) > 50$ MeV

  » $F = t^{-1.3}$
GRB 131108A

- Bright and distant
- During the first 80 seconds after T0 the GRID instrument detected 66 photons compatible with the GRB, most of which below 100 MeV
- Fluence of \((2.56 \pm 0.32) \times 10^{-5}\) erg/cm\(^2\) in the energy band 30 MeV - 1 GeV.
- Redshift 2.4 (GCN 15470)

\[ E > 30 \text{ MeV} \]
At $T_0 = 20:41:55$ UTC the GRB was in the GRID FOV, at an off-axis angle of 40°. It crossed the FOV during the following 110 s.

In the following rotations of the satellite, the GRB region was observed with the GRID several times. Detected by both GRID and MCAL.
GRB 131108A (Giuliani et al. 2014)

MCAL Light Curve:

Bright initial peak detected from 300 keV to a few MeV (width 0.1 s)

Above the background up to 20-25 seconds.
MCAL Light Curve:

Bright initial peak detected from 300 keV to a few MeV (width 0.1 s).

Above the background up to 20-25 seconds.
● the selected events have arrival directions within 20 from the position of GRB131108A.

● after an initial bright peak, the signal remains compatible with a constant rate for about 20-30 sec.

● The time bins after T0+20 s can be roughly fitted by a function of \( t^{\text{a}} \) with a = 1.1.
the gamma-ray spectrum

spectral index of 2.6 +/- 0.1.

no evidence of change in the spectrum during the GRB.
Spectral Energy Distribution
Spectral Energy Distribution
Spectral Energy Distribution

Fluence [MeV/cm²]

Phon Energy [MeV]

Konus/Window
GB M
MCA
GRI D
LAT
Spectral Energy Distribution
**gamma-ray lightcurve**

- Extended (delayed) emission ...... **X**  **X**  **X**  **X**  **X**
- Delayed onset ........................ **X**  **X**
- L ~ t^-a ............................... **X**  **X**  **X**  **X**
- Prompt emission ....................... **X**  **X**
- Long afterglow ........................ **X**

**gamma-ray spectrum**

- “extra” component ..................... **X**  **X**
Conclusions

• Gamma-ray emission above 100 MeV only from a sub-class of GRBs

• For several GRBs, both prompt & delayed emission

• In several cases, spectral indices ~ 3, and exp. cutoffs

• Some short GRBs, only delayed gamma rays with dramatic evolution: GRB 090510, 131108A
the future above 100 MeV…

- gamma-ray detection from space is crucial for GRB studies.

- sensitivity in the range 10 MeV – 100 GeV.

- next-decade proposed mission/ideas:
  - GAMMA-400
  - GAMMA-LIGHT
MCAL GRB catalog

• Contains the data of the 85 hard gamma-ray bursts observed by the MCAL (April 2007 - October 2009)

• Timing data for 84 and spectral data for 21 bursts

MCAL GRB catalog – timing analysis

MCAL GRB catalog – spectral analysis

MCAL GRB catalog

The AGILE MCAL Gamma-ray Burst Catalog

GRB observed from April 2007 to October 2009
(AGILE Pointing Mode)

http://www.asdc.asi.it/mcalgrbcat/
AGILE contribution to IPN

- Partecipation to catalog of Short Burst di Konus (arXiv:1301.3740)
  - 23 detections by AGILE

- Partecipation to the IPN supplement to GBM catalog – (arXiv:13
  - 67 detections by AGILE

- 33 GCN by IPN with AGILE authors

- GRB data sent to IPN ~ 240
Conclusions

• Only a small subsample of GRBs emits in gamma rays: the overall detection rate (AGILE + Fermi) is $\lesssim$10 events per year (consistent with the expectations of Band et al. 2009);

• GeV emitting are the brightest GRBs ($10^{-5}$ erg/cm² at keV – MeV) and have high minimum Lorentz factor (600 – 1000);

• Both classes of long (e. g. GRB 080514B, GRB 090401B, GRB 100724B, GRB 130327B, 130427A) and short (e. g. GRB 090510) are detected in the gamma energy band.

• Some events have a single spectrum (e. g. GRB 080514B; GRB 100724B) other have additional spectral components (e. g. GRB 090510);

• Gamma-ray emitting GRBs seem to be characterised by high fluence and high Lorentz factor. It is still debated if gamma-rays are produced in internal (prompt) or external (afterglow) shocks.

• AGILE detected all the major characteristics of HE GRB (delayed emission, extended emission, power-law extracomponent)
• A cross calibration work with Fermi has started.
Preliminary info on GRB 130327B

- GRB detected by AGILE GRID (GCN 14344) and Fermi/LAT (GCN 14347)

- No XRT detection (GCN 14398) → no redshift known
GRB 130327B

TITLE: GCN CIRCULAR
NUMBER: 14344
SUBJECT: GRB 130327B: gamma-ray detection by AGILE
DATE: 13/03/27 23:24:56 GMT
FROM: Ettore Del Monte at IASF/INAF <eta.grb@iasf.inaf.it>


The AGILE Gamma Ray Imaging Detector (GRID) detected emission from GRB 130327B, localised by Fermi/GBM (http://con.gsfc.nasa.gov/other/386065447.fermi). The GRB occurred at approximately 23 deg off-axis in the field of view of the AGILE/GRID.

A preliminary analysis of the AGILE/GRID data in temporal coincidence with the GRB shows a significant excess of gamma-ray events above 80 MeV at the location of the event. Most of the events detected by the AGILE/GRID have times between ~ t0 + 9 sec and t0 + 14 sec where t0 is 27 March 2013 at 08:24:04.05 UT.

The GRB was also detected also by the AGILE/MCAL, operating in the energy range 0.5 - 100 MeV.

A more detailed analysis of the AGILE data is in progress. More observations of this interesting burst are strongly encouraged.
## A quick comparison

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<thead>
<tr>
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<th>AGILE</th>
<th>FERMI/LAT</th>
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<tbody>
<tr>
<td>$A_{\text{eff}}$ (100 MeV) (cm$^2$)</td>
<td>~400</td>
<td>~ 2000-2500</td>
</tr>
<tr>
<td>$A_{\text{eff}}$ (10 GeV) (cm$^2$)</td>
<td>500</td>
<td>~ 8000-10000</td>
</tr>
<tr>
<td>FOV (sr)</td>
<td>2.5</td>
<td>2.5</td>
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<tr>
<td>sky coverage</td>
<td>1/5</td>
<td>whole sky</td>
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<tr>
<td>Energy resolution</td>
<td>50 %</td>
<td>10 %</td>
</tr>
<tr>
<td>(~ 400 MeV)</td>
<td></td>
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<tr>
<td>PSF (68 % cont. radius)</td>
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<tr>
<td>100 MeV</td>
<td>3° - 4°</td>
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<tr>
<td>1 GeV</td>
<td>&lt; 1°</td>
<td>&lt; 1°</td>
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GRB 131108A

![Graph showing Fluence (100 MeV-10 GeV) vs. T_{90} (50 keV-300 keV) in seconds.](image-url)
GRB 131108A
GRB 131108A

Hyper-fluent GRBs