Localization of Terrestrial gamma-Ray Flashes by AGILE

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on behalf of the AGILE Team
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Outline

• AGILE TGF detection capabilities in context
• Characteristics of the AGILE TGF sample
• NEW! Localization of TGFs in space
• Conclusions
Operating TGF detectors

Effective Area vs. Energy

Data from: Smith et al. (2002), Meegan et al. (2009), Labanti et al. (2009), Tavani et al. (2009)

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The AGILE Mini-Calorimeter (MCAL)

30 CsI(Tl) bars with Photodiode readout, like these
1400 cm$^2$ geometrical area
~300 cm$^2$ effective area @ 1 MeV
330 keV – 100 MeV energy range
14% energy resolution FWHM @ 1.3 MeV
2 µs timing accuracy in photon-by-photon mode
Clever, fully-programmable trigger logic on time scales from 8s to 16ms, 1ms and 300µs

Labanti et al., NIM A (2009): instrument paper
Fuschino et al., NIM A (2008): trigger logic
Marisaldi et al., JGR (2010): TGF detections
Why AGILE is good for TGF science?

- MCAL energy range is extended up to 100 MeV: probing the high energy tail of the TGF spectrum
- Efficient trigger at **ms** and **sub-ms** time scale (the TGF time scale): not biased toward brightest events
- **Segmented independent detectors**: low dead time and pile-up
- **Photon-by-photon data** download for triggered events with 2µs time resolution
- **<100µs absolute timing accuracy**: mandatory for sferics correlation
- **AGILE orbit at 2.5° inclination** is optimal for mapping the equatorial region, where most of the events take place, with unprecedented exposure
> 190 class A TGFs + ~130 class B TGFs since June 2008

~10 TGF/month since Mar.'09

34 TGFs Published in M. Marisaldi et al., J. Geoph. Res., 115, A00E13, 2010.

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The AGILE TGF sample

Average properties:

Number of counts = 17.3 +/- 6.4

Duration = (1.7 +/- 0.9) ms

Energy = (4.0 +/- 1.7) MeV
LIS-OTD High Resolution Full Climatology available at http://thunder.msfc.nasa.gov/data/

Good match between AGILE TGF pattern and lightning map. Fuschino et al., in preparation

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TGF production $\sim300\text{km}$ close to sub-satellite point, Cummer et al., GRL (2005)

cluster over western Africa

cluster over Sumatra and the Borneo
Cumulative spectrum

110 TGFs  1806 photons  142 $\gamma$ E> 10 MeV  26 $\gamma$ E> 20 MeV

Preliminary

cutoff powerlaw
$F(E) \sim E^{-\alpha} e^{-E/E_0}$

fit the 0.5-30 MeV range

$\alpha = 0.4 \pm 0.2$
$E_0 = 6.6 \pm 1.2$ MeV

red. $\chi^2 = 1.5$ (34 d.o.f.)

E0 compatible with the $\sim$7.6 MeV average energy for RR electrons

significant detection of $\gamma$ >40 MeV: challenge for emission models
Imaging TGFs from space?

- MCAL detected TGF photons up to 40 MeV and possibly above
- So, why not looking for detections in the AGILE gamma-ray imager (GRID) sensitive above 20 MeV?
- It would be the first direct localization of TGFs in gamma-rays
Imaging TGFs from space with AGILE GRID

Two ways to bypass it...

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Imaging TGFs from space with AGILE GRID

1. Albedo filtering disabled
   ~ 100 days between 2008 – 2009
   for test purposes

Forward events.
Cannot be default because of telemetry limitations

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2. Sometimes the albedo filter can “mistake” a track with the complementary one

So, events coming from the Earth can be accepted by the on-board filter and sent to telemetry: **Reverse events**
GRID events vs MCAL TGFs


13 GRID events within 2 ms from TGFs T0!

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Geographical distribution

AGILE footprint
GRID $\gamma$ projection

Reverse event direction (TGF source)
Geographical distribution

Event clustering at < 400 km from AGILE footprint
Consistency with previous detections based on RHESSI TGFs and sferics
(Cummer et al., GRL 2005, Cohen et al., GRL 2010)
Do GRID photons come directly from the production region?

- **Good:**
  - The incoming photon direction tracks the production region.
  - AGILE
  - Distance: 540 km

- **Bad:**
  - The incoming photon direction does not track the production region. No way to be aware of it. Is it probable???
  - AGILE
  - Distance: 15-20 km

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Do GRID photons come directly from the production region?

Compton and pair production cross section in air become equivalent at ~25MeV: Compton interaction for low-energy GRID events cannot be ignored.

<3% probability to scatter above 40 km: the GRID photon tracks the source within the angular resolution.
High energy photons track well the electric field orientation at the source. A new tool to probe remotely the production site electric field.

Conclusions

• AGILE is an important instrument for TGF science:
  - the only one with energy range extended up to 100 MeV
  - the only one with <1ms trigger logic
  - photon-by-photon with μs timing
  - ~equatorial orbit

• AGILE detects ~10 TGFs / month with current selection criteria. Rate can be almost doubled with improved selections

• First TGFs localized in space by means of the AGILE gamma-ray imager. Work in progress: improve the detections, implications for production models