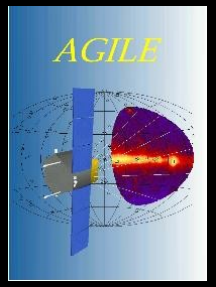

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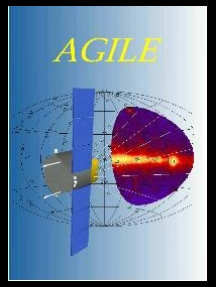
Observation of TGFs with AGILE: the current status

Martino Marisaldi (INAF-IASF Bologna)

on behalf of the AGILE Team

8th AGILE Workshop – the Third Birthday

April 28, Bologna, Research Area Conference Center



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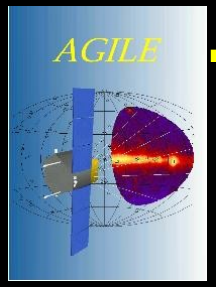
Outline

- TGF science: an overview
- AGILE-MCAL instrument and detection capabilities
- AGILE strength points in TGF science
- Characteristics of the AGILE TGF sample
- Comparison with the RHESSI and Fermi-GBM
- Work in progress
- Conclusions



Terrestrial Gamma-ray Flashes (TGF)

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Gamma-ray flashes with incoming direction compatible with the Earth surface.

Few millisecond typical duration; hard spectrum (up to tens MeV)

Discovered by BATSE (Fishman et al., Science, 1994) and observed by RHESSI up to 20 MeV (Smith et al., Science, 2005)

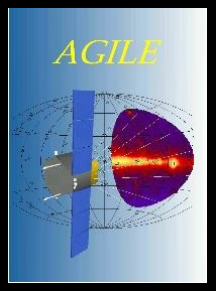
Clearly associated to lightning discharges during thunderstorms by means of correlation with VLF sferic waves detection on ground (Inan et al., GRL, 1996; Cummer et al., GRL, 2005)

>2008: Observed by AGILE and Fermi-GBM

2009: AGILE reports energy up to 40MeV (Marisaldi et al., JGR 2010)

Geophysical phenomena observed from space by instruments designed for gamma-ray astrophysics

Challenging detection: timing and energy range are key issues



1994: BATSE discovery of TGF

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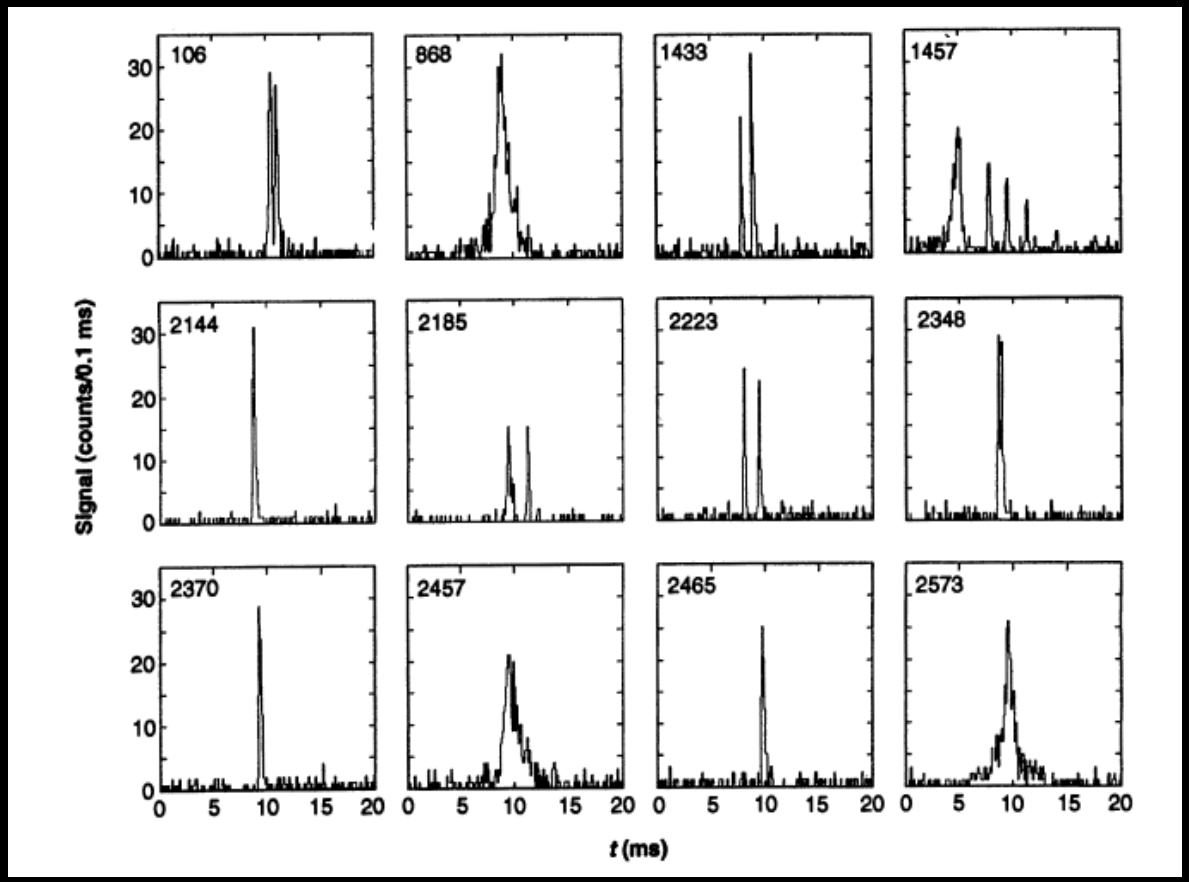

Fishman et al., Science, 1994

~ 70 TGF detected on 9 life-Years
typically 100 counts/TGF

Main limitations:

- On-Board Trigger Logic performances (shorter timescale 64ms)

- Large statistics BUT only 4 energy bins for time-tagged events

2005: RHESSI detection up to 20 MeV

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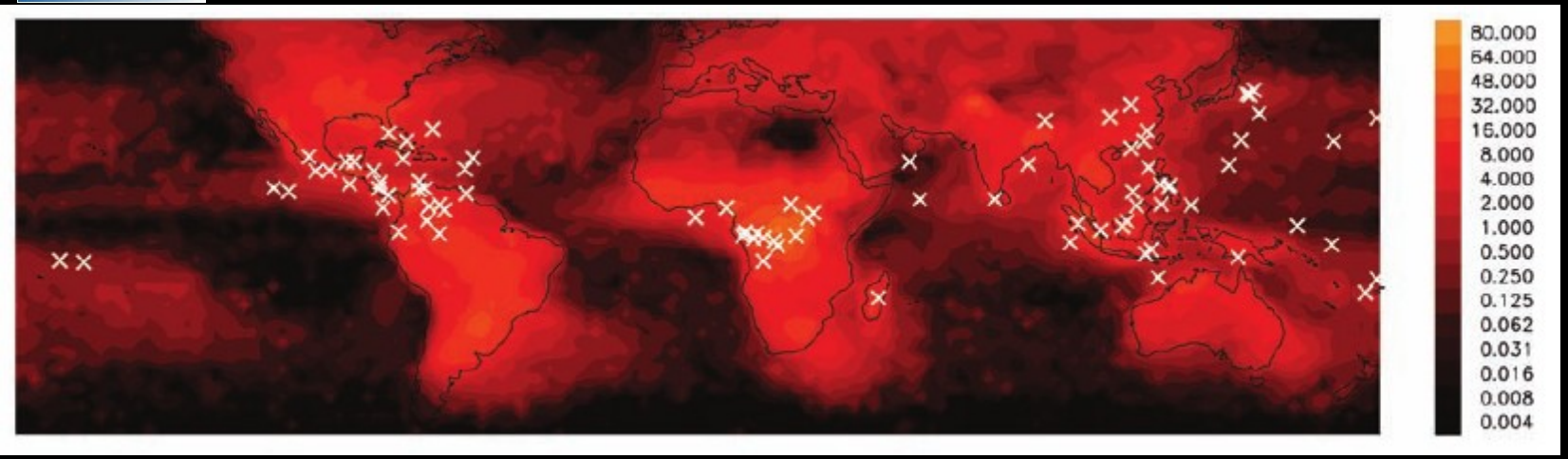
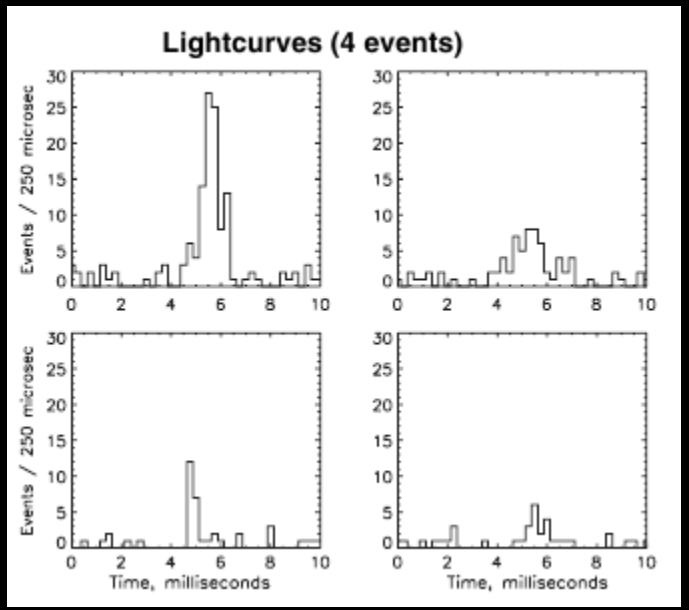


TGF Distribution with lighting frequency per km^2 per Year

Smith et al., Science, 2005



Contiuous time-tagged event list
NO ON-BOARD TRIGGER LOGIC
10– 20 TGF per month
Typically 20-30 counts/TGF
~800 TGFs reported in the 1st RHESSI TGF catalog (Grefenstette et al., JGR, 2009)

RREA Production model

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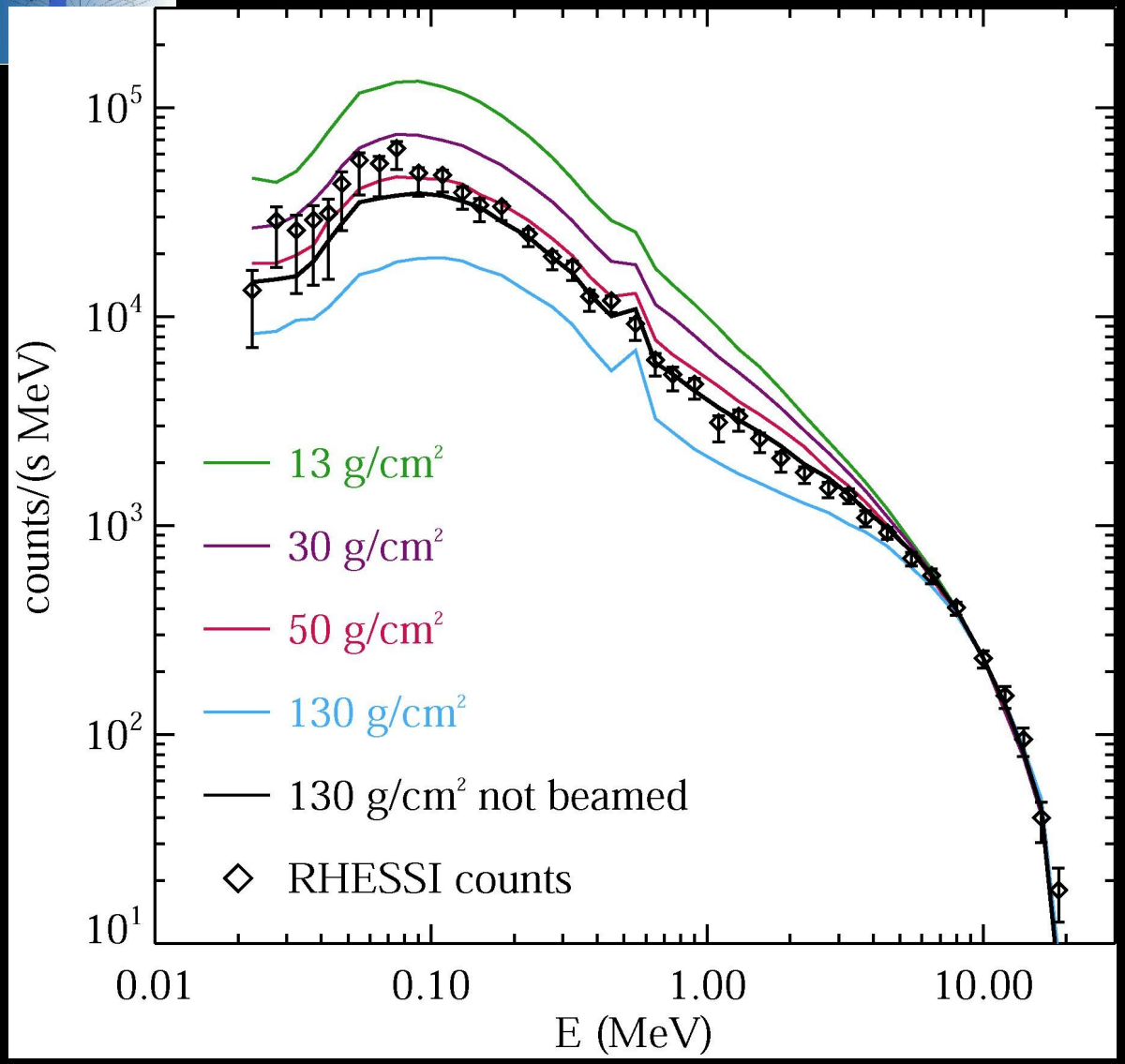

Dwyer and Smith, GRL (2005)
Carlson, Lehtinen and Inan (2007)

Relativistic Runaway Electron Avalanche (RREA) with relativistic feedback (Dwyer 2008)

Bremsstrahlung + Compton scattering

RHESSI cumulative spectrum is compatible with a production altitude of 15-21 km (just above tropical thunderstorms)

Still hint for individual spectral variability: differences in production altitudes or viewing angle?

BATSE events seem produced at higher altitude (two different populations?) but discrepancy is reduced if dead-time effects are properly accounted for (Grefenstette et al., 2008; Ostgaard et al., 2008)

The AGILE Mini-Calorimeter (MCAL)

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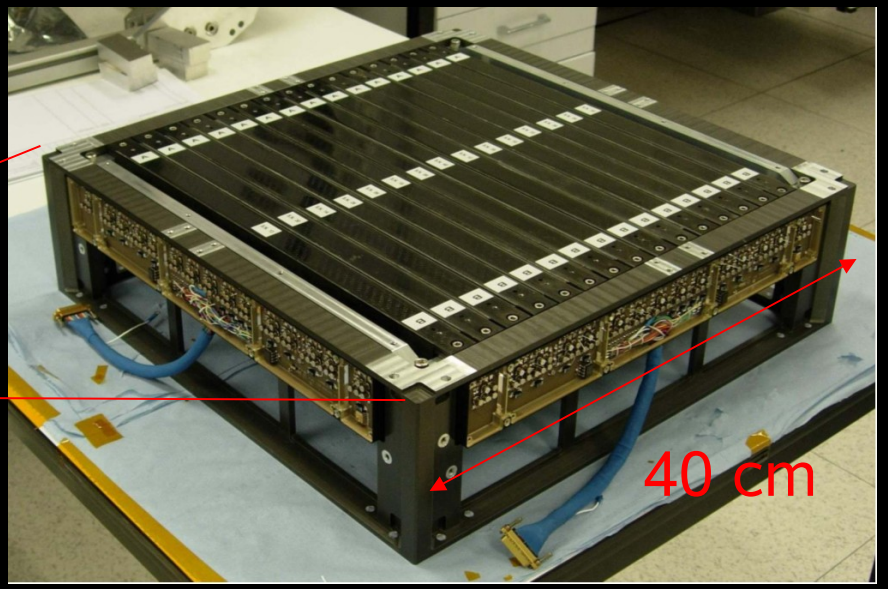
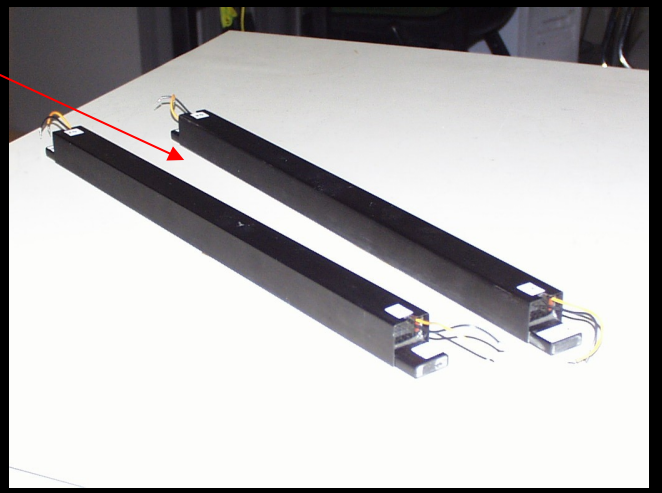
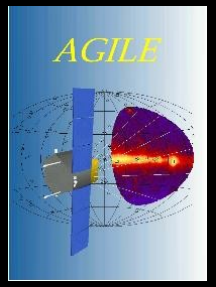


30 CsI(Tl) bars with Photodiode readout, like these
1400 cm² geometrical area
~300 cm² effective area @ 1 MeV
330 keV – 100 MeV energy range
14% energy resolution FWHM @ 1.3 MeV
2 μs timing accuracy in photon-by-photon mode
Clever, fully-programmable trigger logic on time scales from 8s to 16ms, 1ms and 300μs



Labanti et al., NIM A (2009): instrument paper
Fuschino et al., NIM A (2008): trigger logic
Marisaldi et al., A&A (2008): GRB detections
Marisaldi et al., JGR (2010): TGF detections



Why AGILE is good for TGF science?

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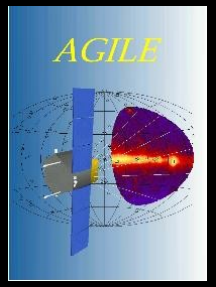
- MCAL energy range is extended up to **100 MeV**: probing the high energy tail of the TGF spectrum
- Efficient trigger at **ms** and **sub-ms** time scale (the TGF time scale): not biased toward brightest events
- **segmented independent detectors**: low dead time and pile-up



Why AGILE is good for TGF science?

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- **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

MCAL TGF detection rate

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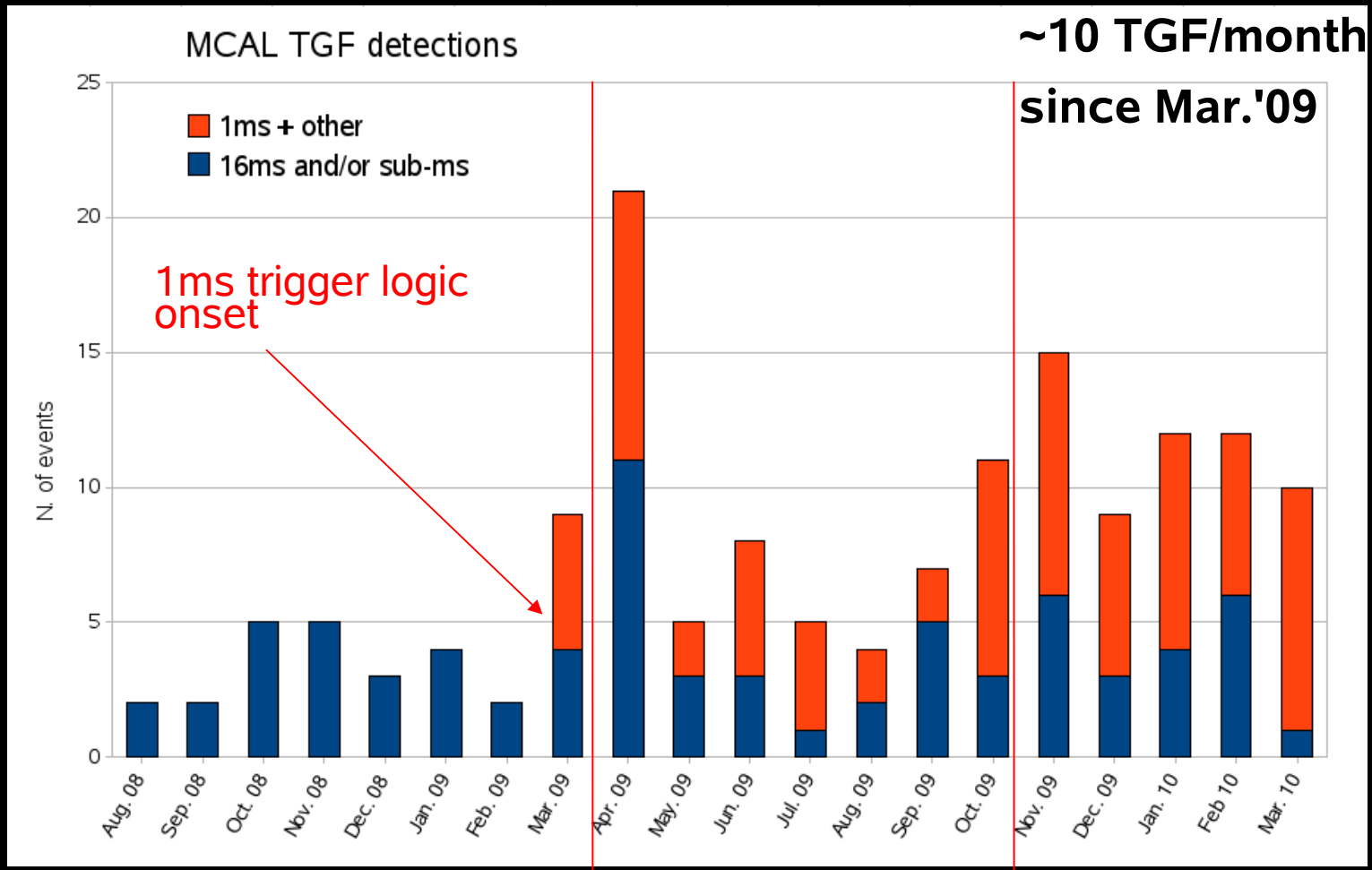
153 good candidates between June '08 – Mar. '10



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

After entering Spinning mode

The AGILE TGF sample

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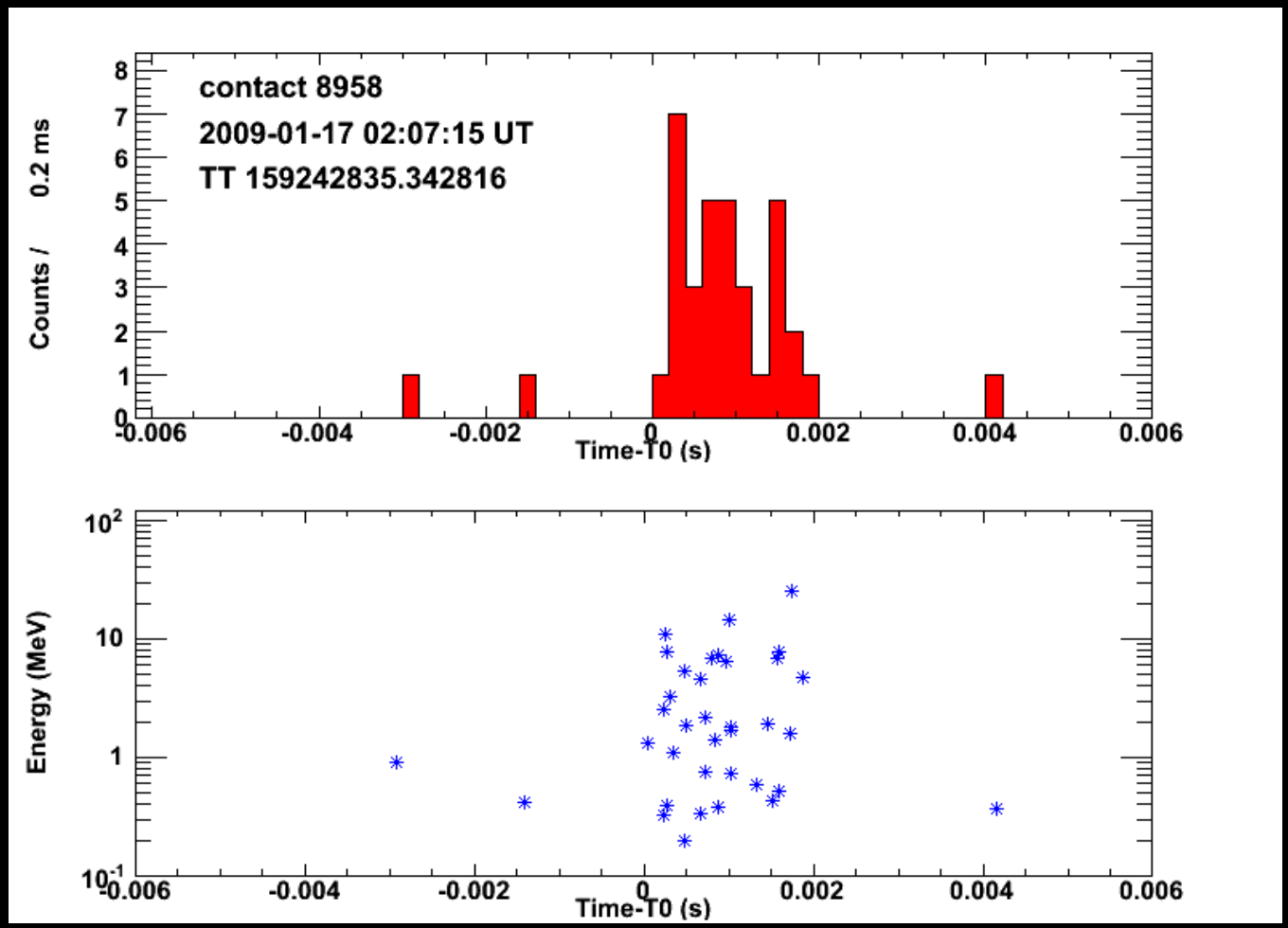

Average properties:

Number of counts =

17.3 +/- 6.4

Duration =

(1.7 +/- 0.9) ms

Energy =

(4.0 +/- 1.7) MeV

TGFs and Lightnings

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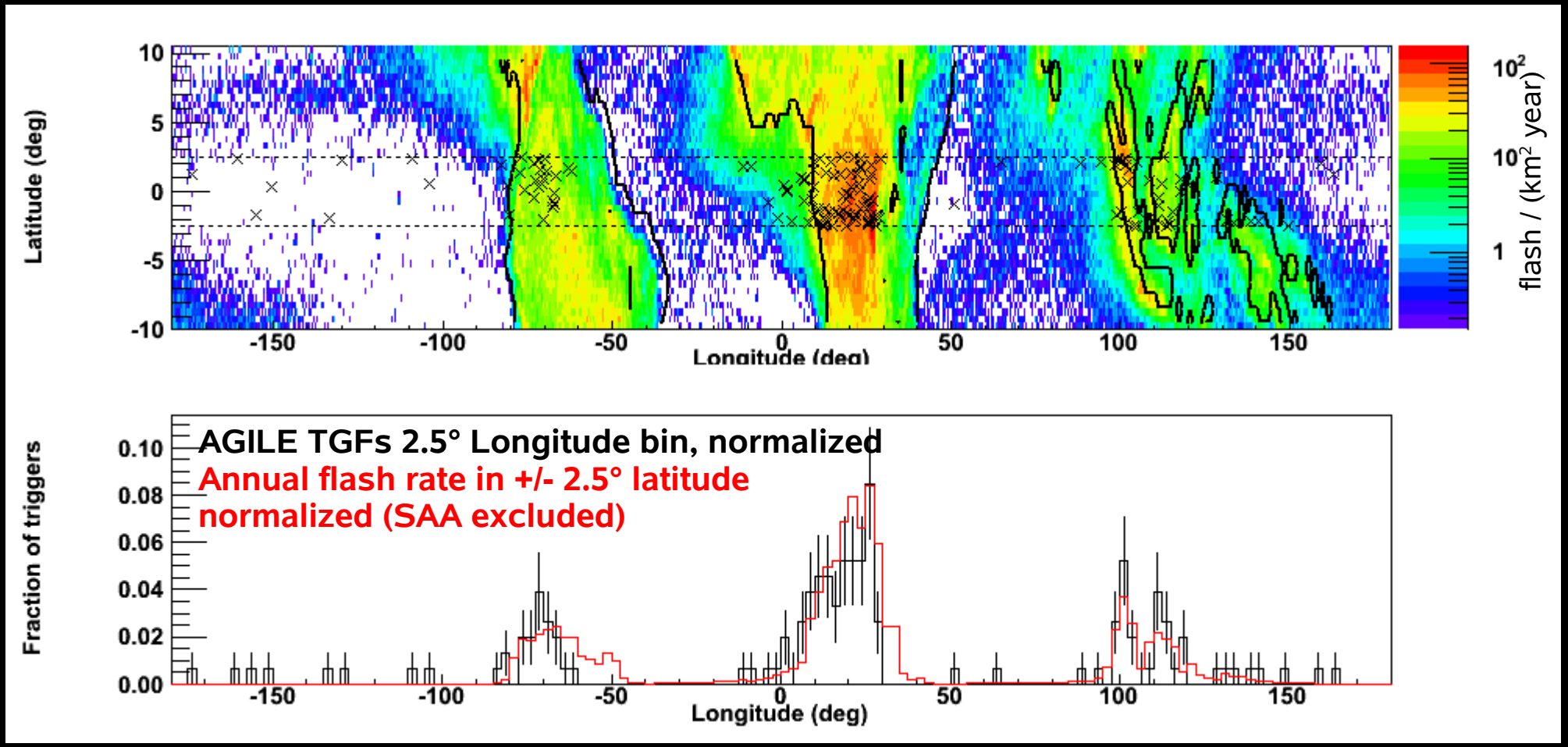
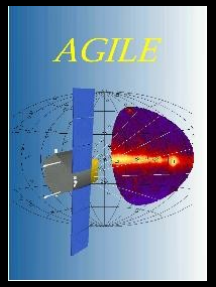
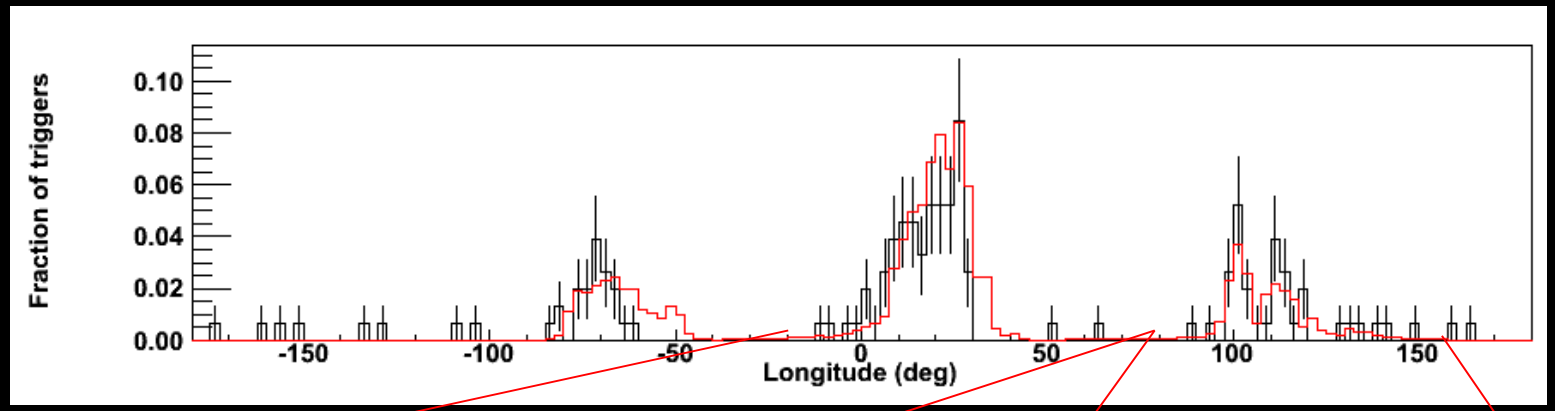


LIS-OTD High Resolution Full Climatology available at http://thunder.msfc.nasa.gov/data/

Good match between AGILE TGF pattern and lightning map





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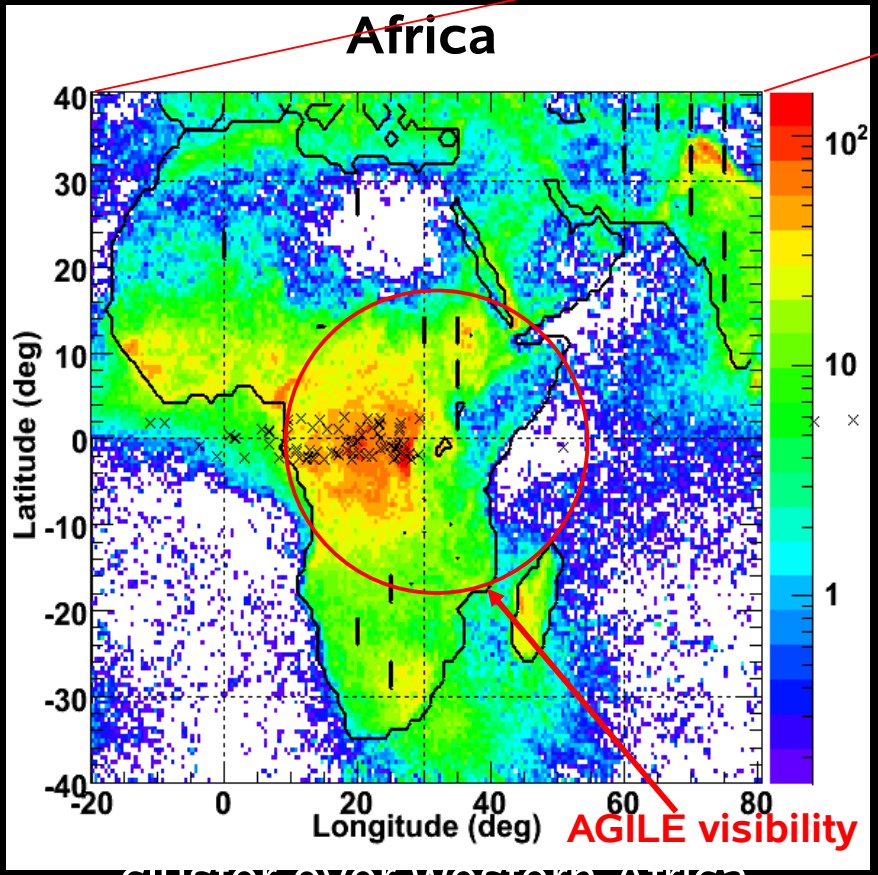

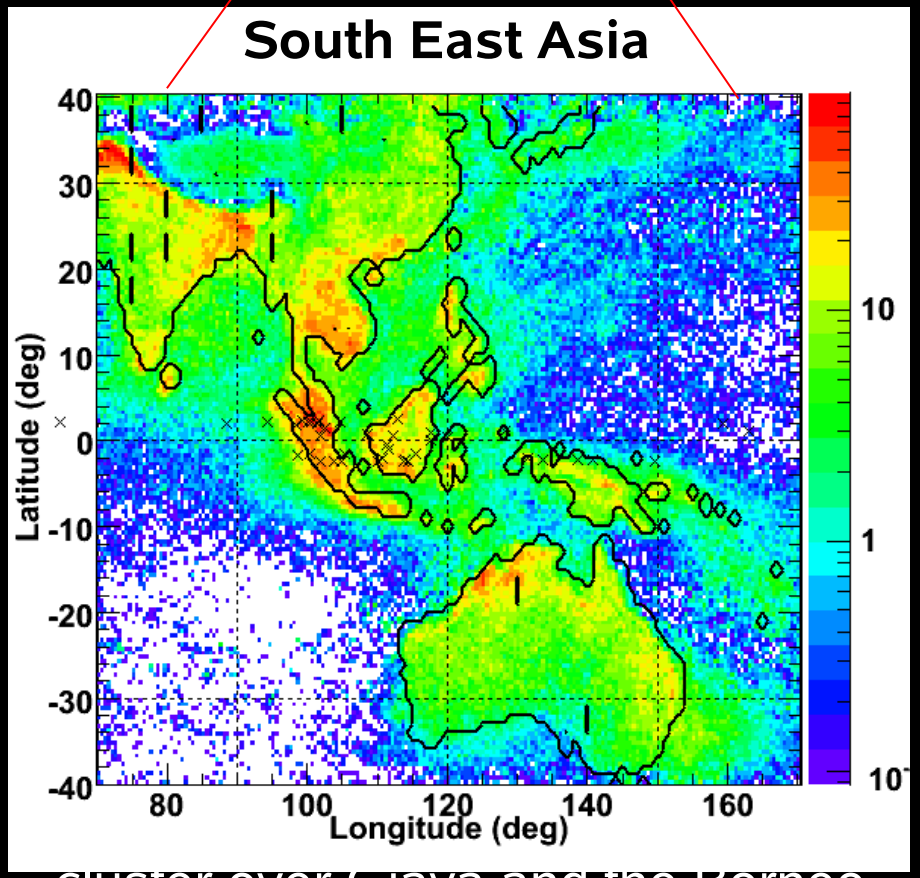

cluster over western Africa

cluster over Giava and the Borneo

TGF production <~300km close to sub-satellite point, Cummer et al., GRL (2005)

Cumulative spectrum

110 TGFs 1806 photons 142 γ E> 10 MeV 26 γ E> 20 MeV

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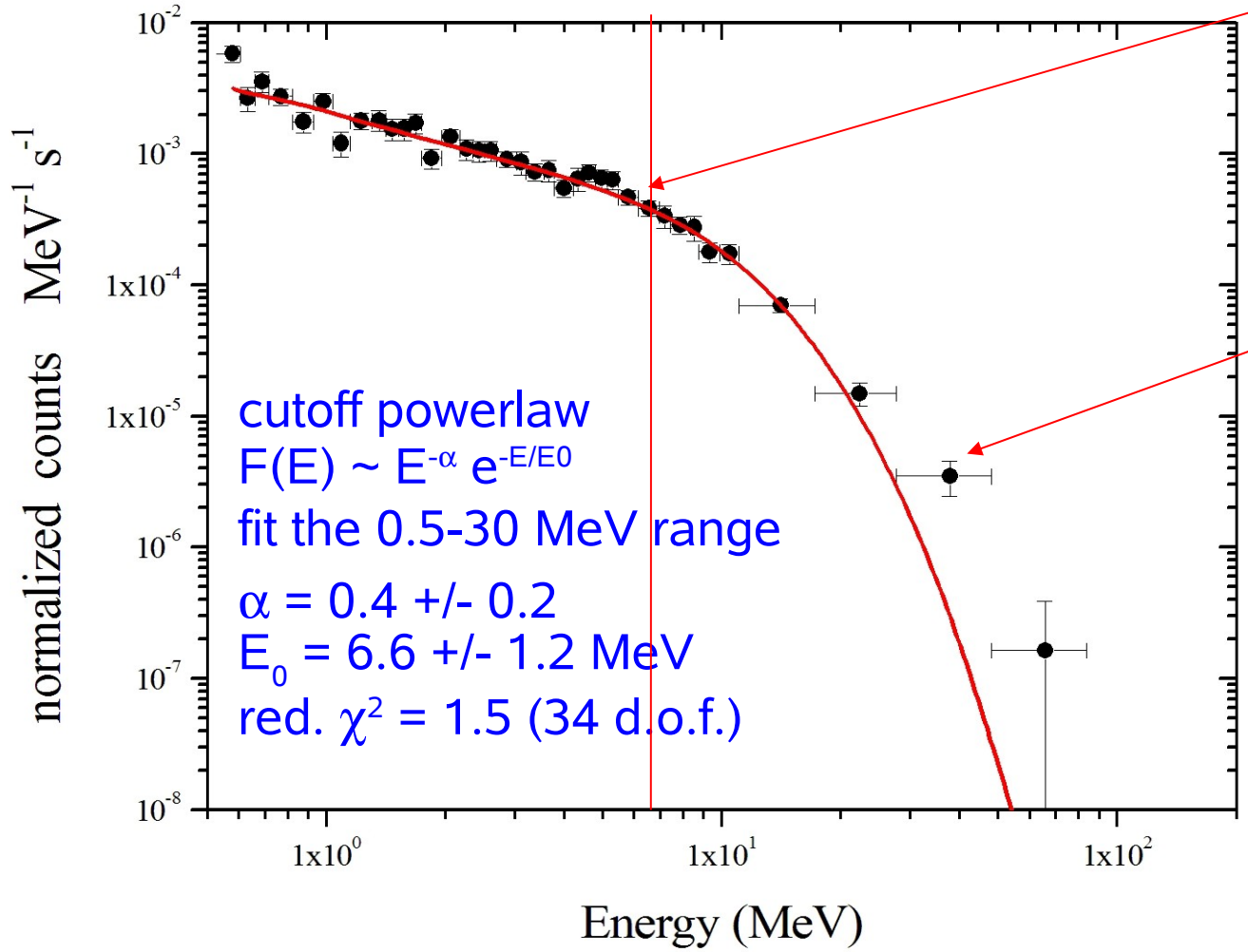
Preliminary



E0 compatible with the ~7.6 MeV average energy for RR electrons

significant detection of γ >40 MeV: challenge for emission models

need for an extra component?

AGILE vs RHESSI: longitude and local time

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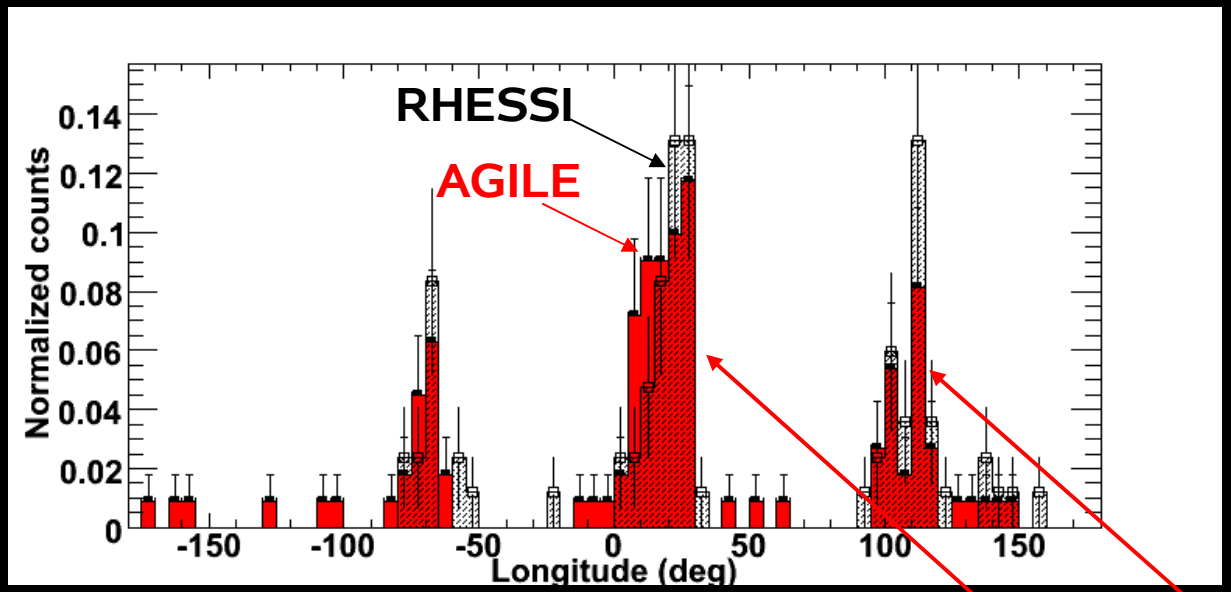

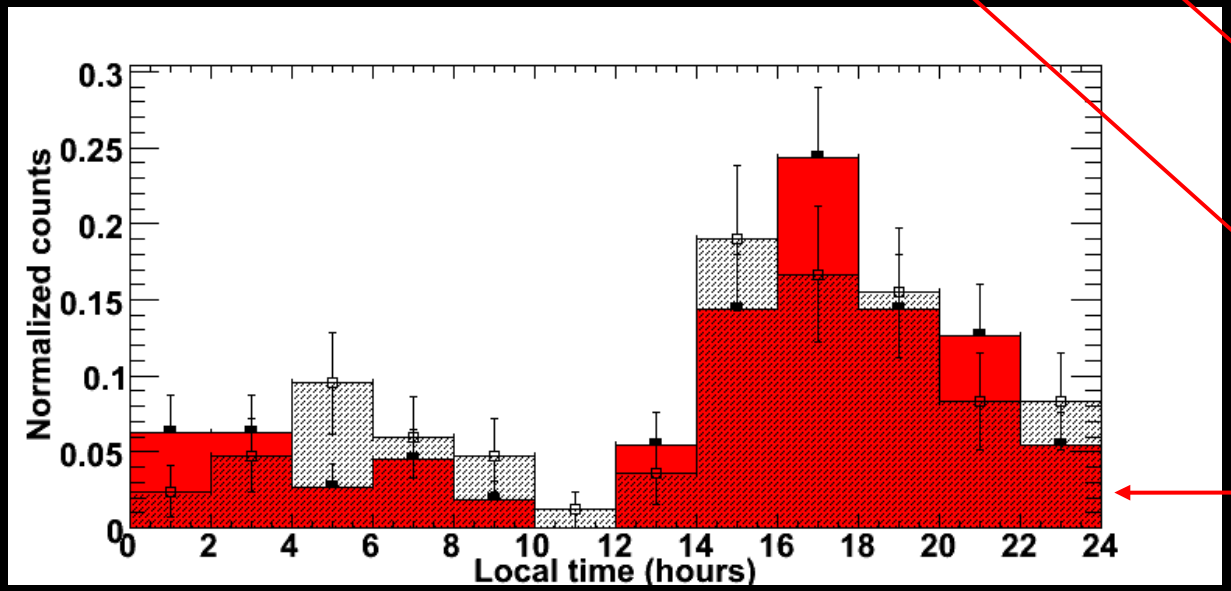

1st RHESSI TGF catalog Grefenstette et al., JGR, (2009)

selected RHESSI TGFs in a +/- 2.5° latitude belt (like AGILE orbit) T_0 < 1st Jan. 2006: 84 TGFs

Longitude and local time distributions are compatible

double peaked feature on South East Asia

sharp cut on western Africa

late afternoon occurrence peak

AGILE vs Fermi-GBM

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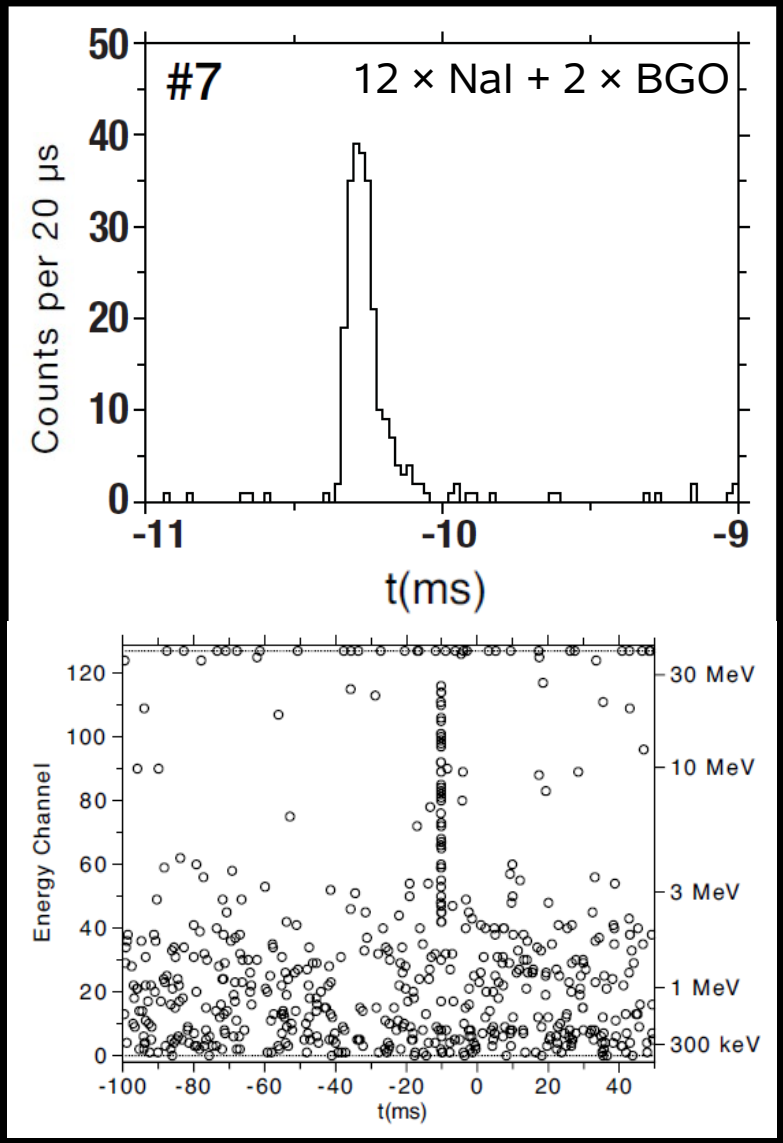
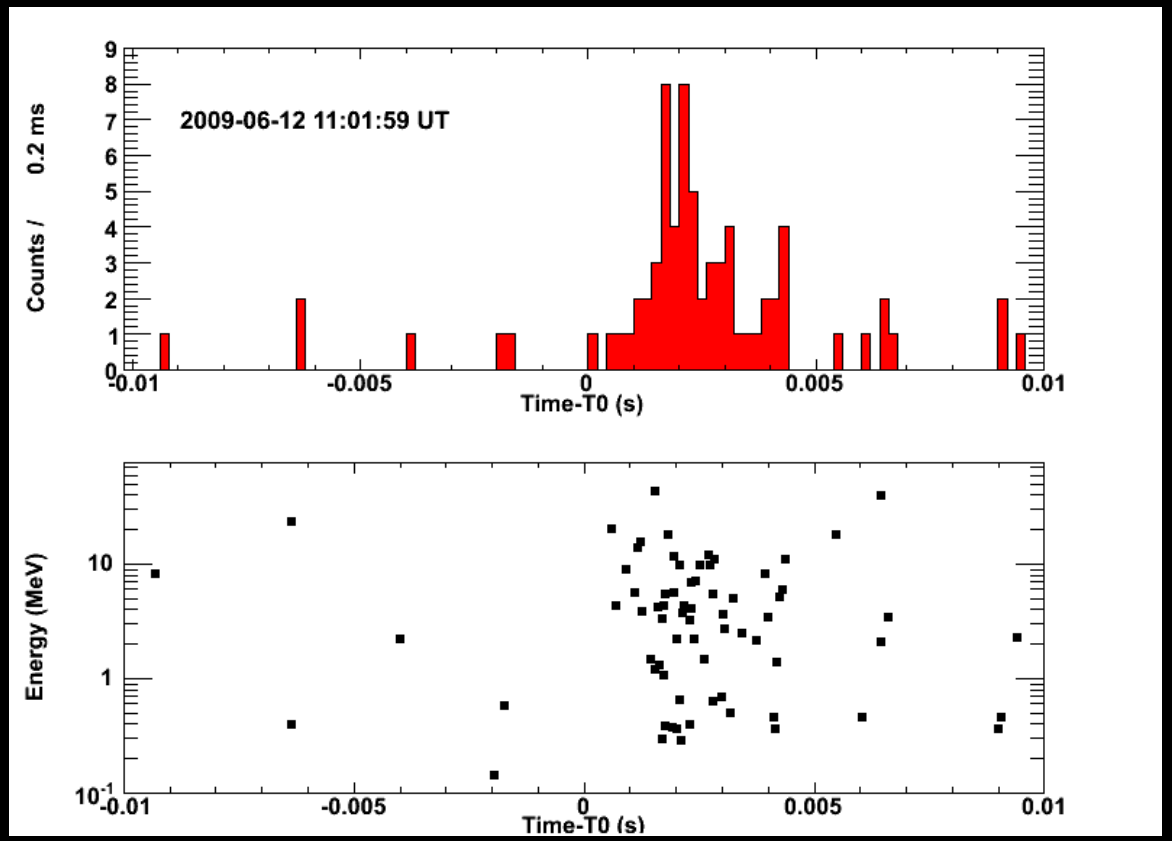
Fermi TGF #7



AGILE TGF 11026-1



Fermi:
+ larger effective area and lower threshold: more statistics on single events
- trigger on time >=16ms: less events, brightness bias (AGILE triggers on >=290μs)

from A. Von Kienlin, presentation at the 7th AGILE WS

AGILE vs Fermi-GBM

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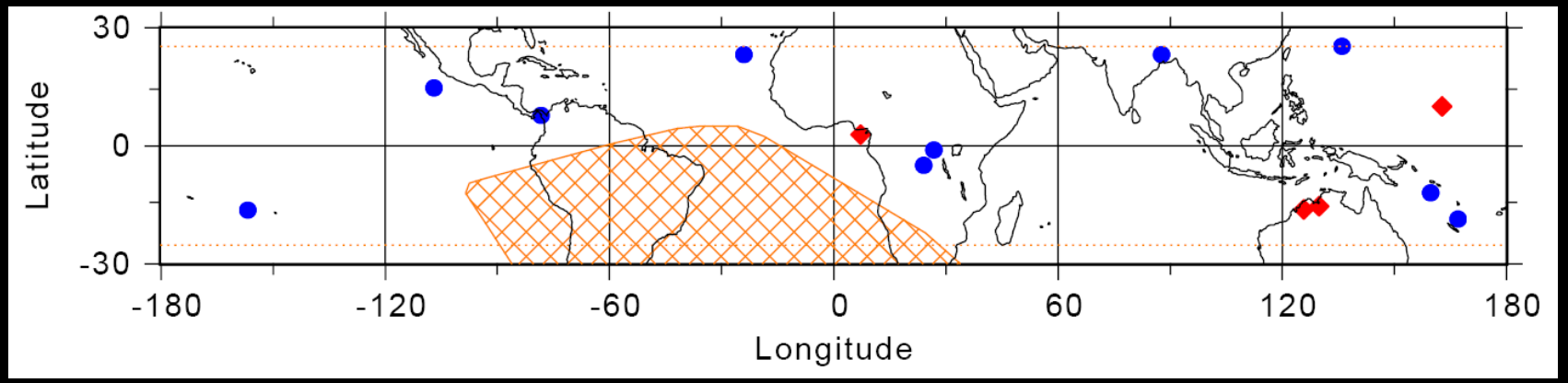
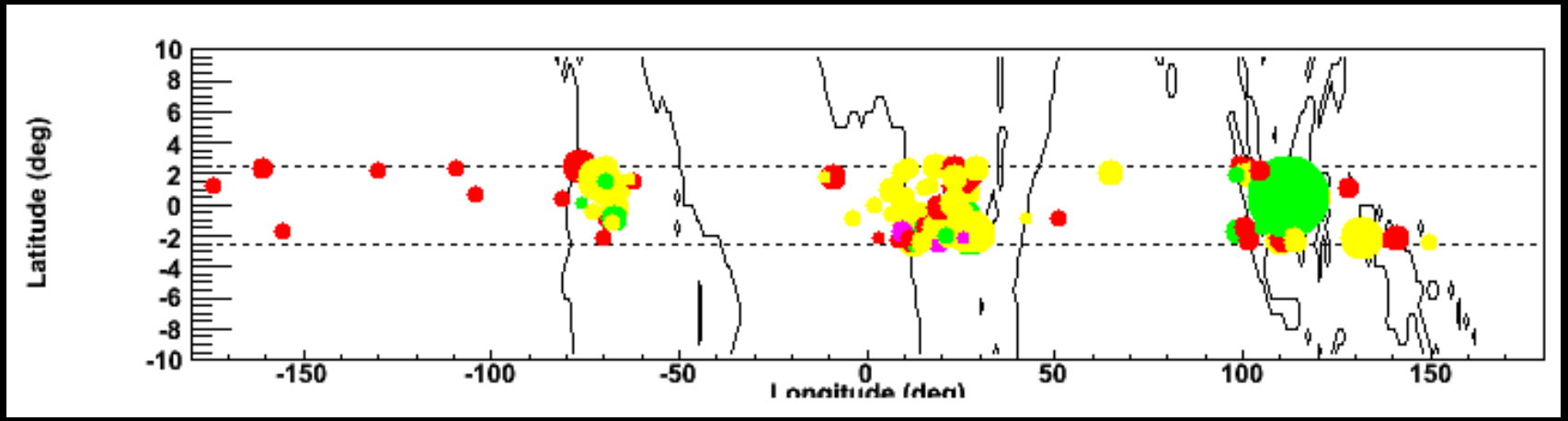
Fermi-GBM:
14 TGF

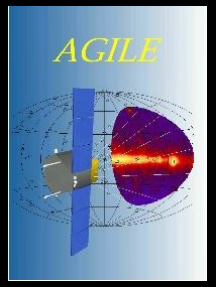
(more since Dec.'09)



AGILE:
153 TGF



Trigger 11026-1 in details



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Light curve

Position distribution

Energy vs time

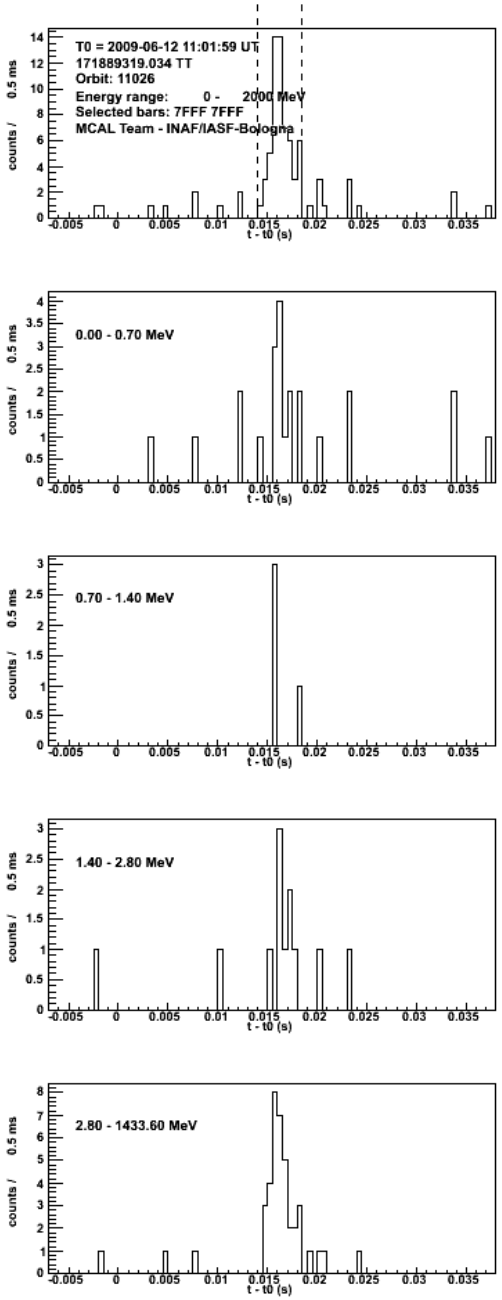
All range

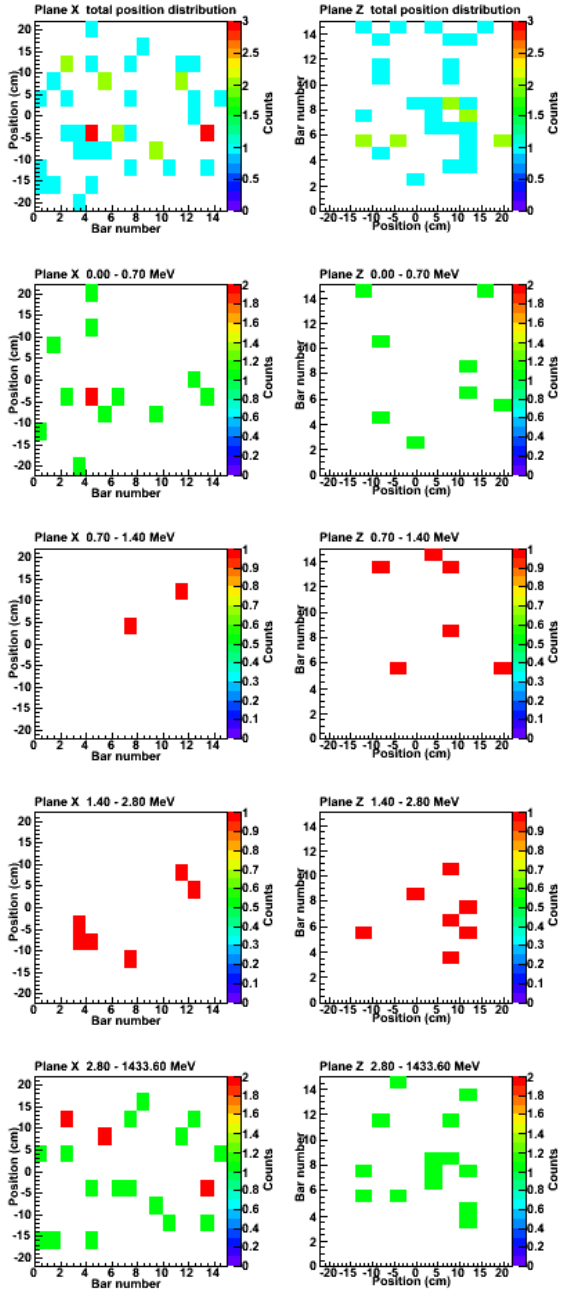
<0.7 MeV

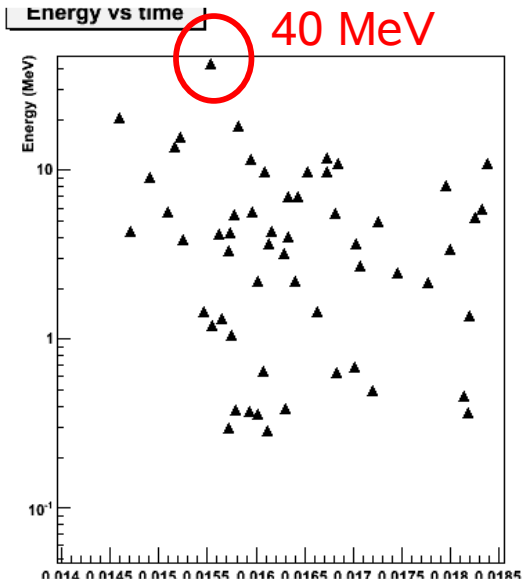
0.7-1.4 MeV

1.4-2.8 MeV

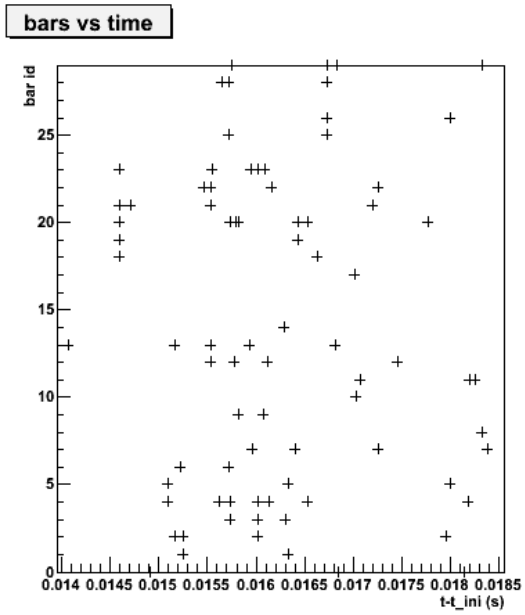
>2.8 MeV





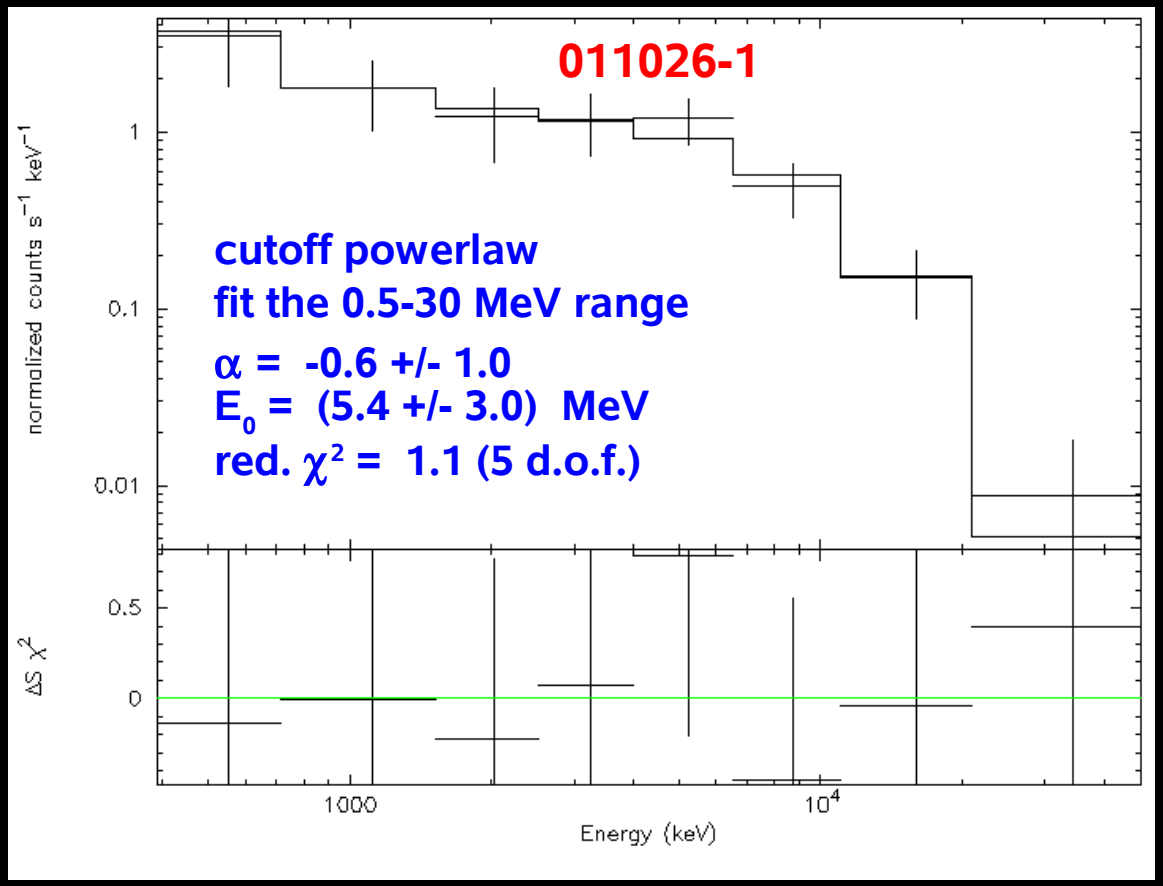


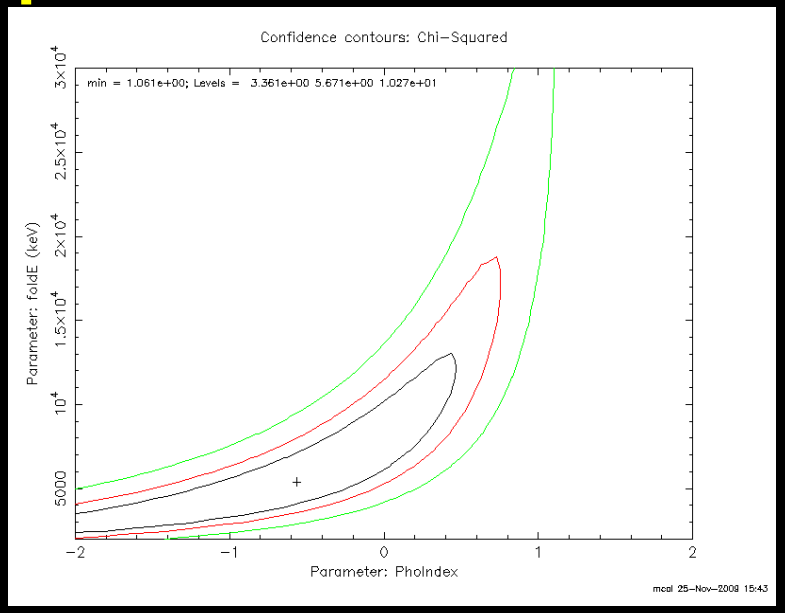
Bar address vs time

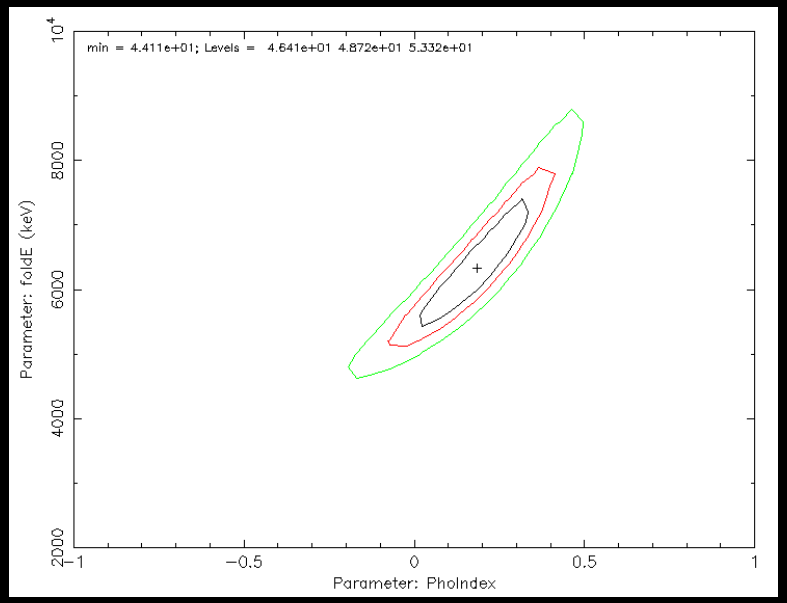


M. Ma

Single TGF energy spectrum







Spectral parameters are poorly constrained due to limited statistics

011026-1 spectrum is compatible with cumulative spectrum

Need more bright events

Increasing statistics
are we looking at the tip of the iceberg?

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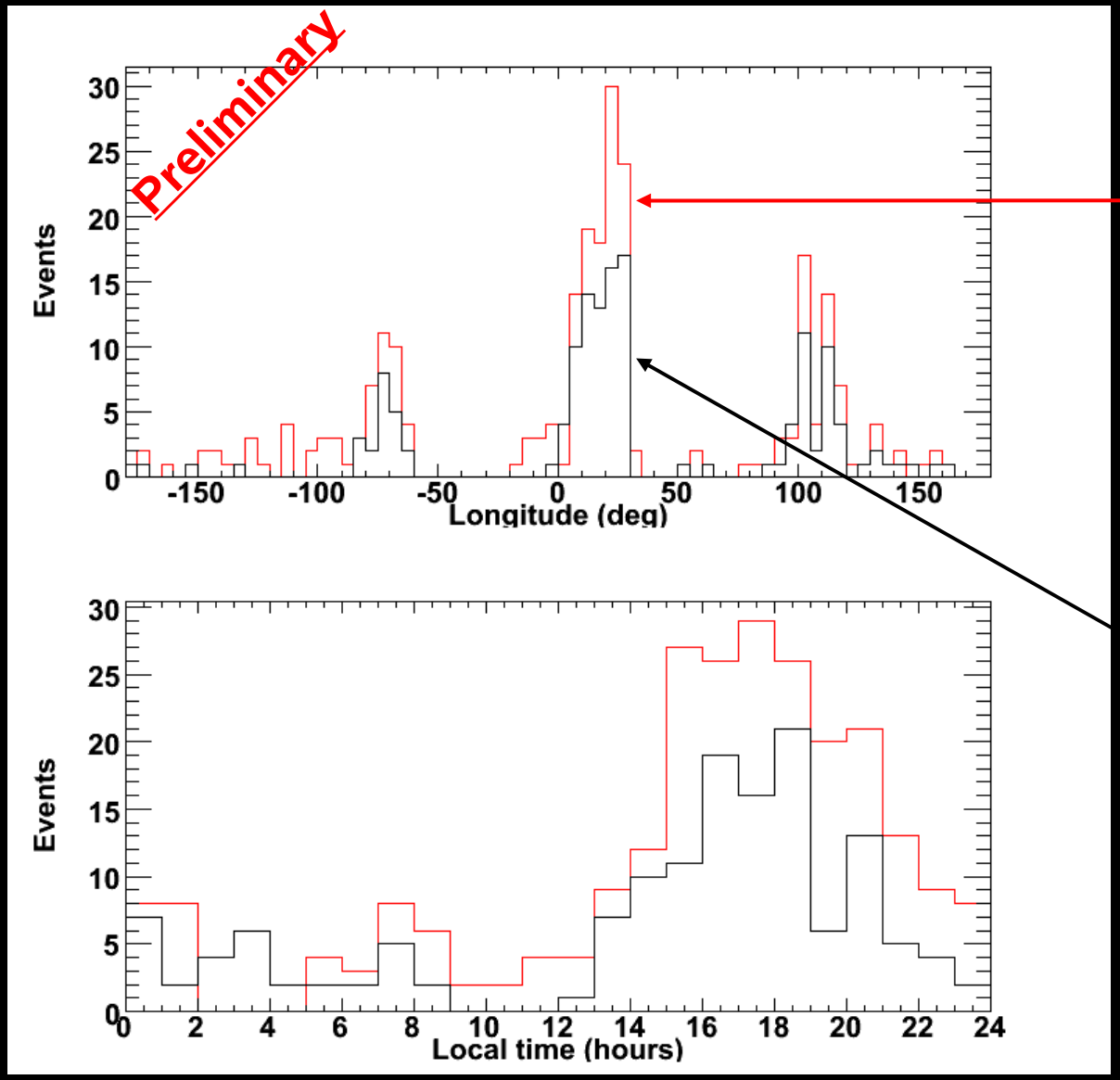
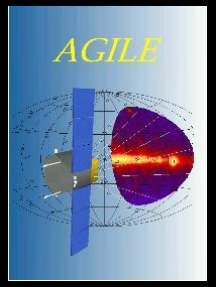


improvements on selection criteria to extract fainter/softer events

modified selection:
>=7 counts & HR>0.4
+ automatic topological selection

factor ~1.6 - 2 in statistics
still room for improvements

standard selection:
>=10 counts & HR>0.5
+ visual inspection
153 events up to Mar. '10



Work in progress

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- on-line TGF archive
- possibility of TGF alerts
- link with meteo data
- study of the TGF mechanism

Work in progress: near real-time monitoring and alert

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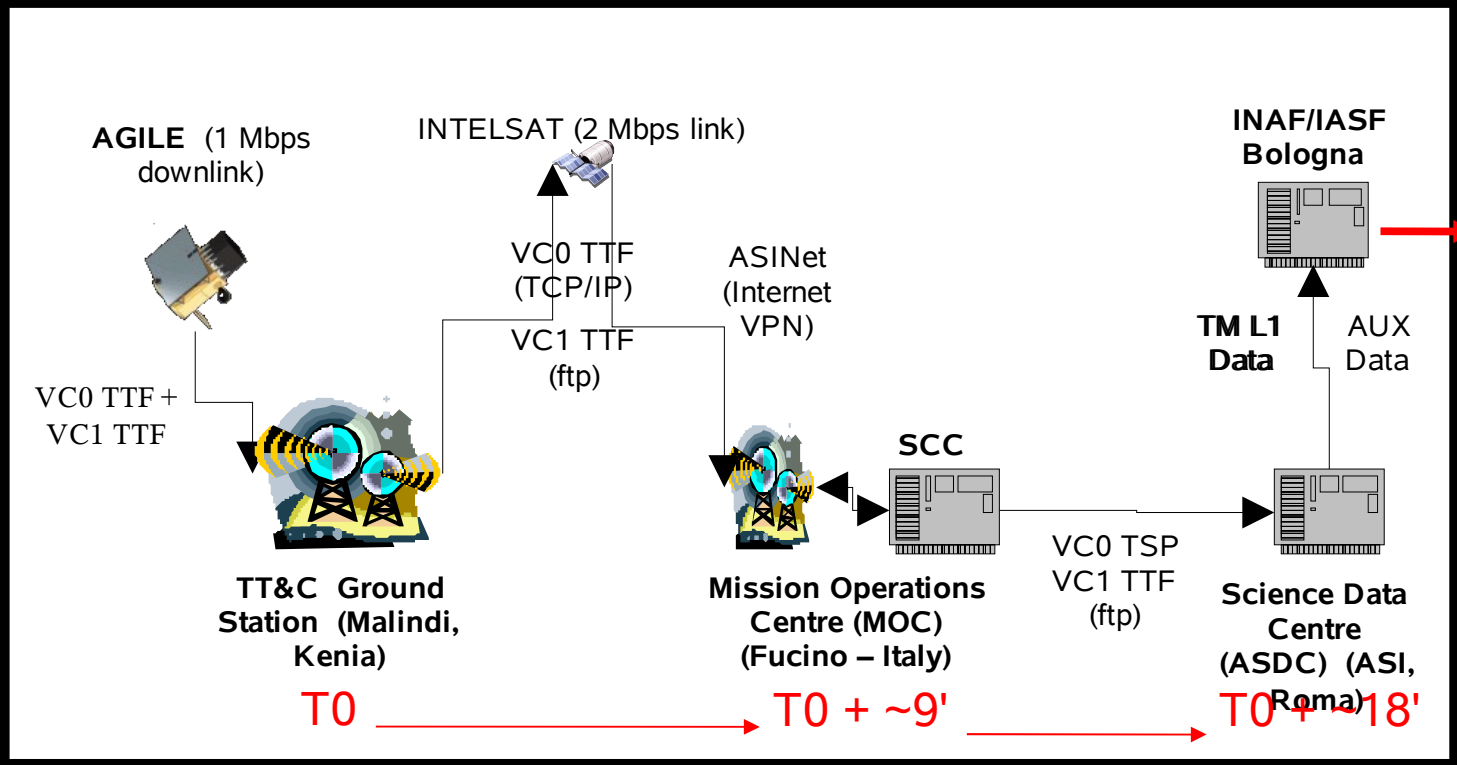

Scientific analysis:

Apply calibration

Spurious trigger rejection

Standard products (light curves, event topology, intensity duration, hardness ratio)

Write trigger info to web-accessible DB

Issue alert

<u>Very fast real-time alert system:</u>
In 20-30 minutes from telemetry download an alert to the community can be issued
Suitable for real-time correlation with meteo observations
Potentially useful for air navigation: add high energy information to storm-tracking monitoring systems

Work in progress: real-time monitoring system prototype

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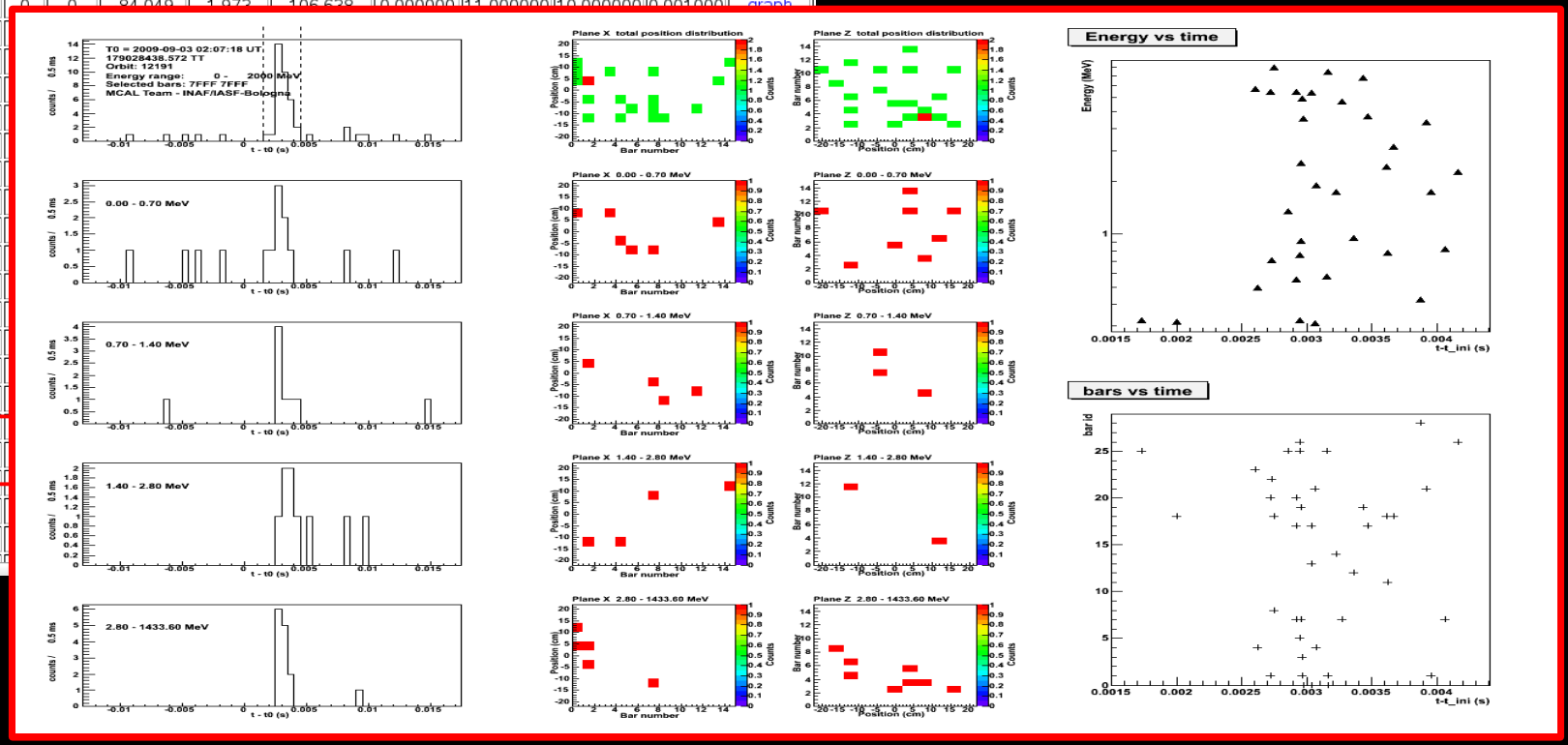
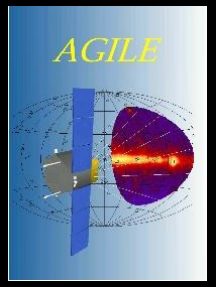
Current triggers selection geographical map here)

Orbit	Trigger	Date	Time	Type	sub-ms	1ms	16ms	Lon (deg)	Lat (deg)	Theta (deg)	HR	Count	Peak	T90	Graphics
12192	9	2009-09-03	04:06:35	GRB	0	1	0	-9.246	1.819	44.896	0.100000	11.000000	9.000000	0.001000	graph
12192	8	2009-09-03	04:02:03	GRB	1	0	0	-25.286	2.237	56.429	0.083333	13.000000	12.000000	0.001000	graph
12192	7	2009-09-03	03:45:29	GRB	1										
12192	6	2009-09-03	03:38:31	GRB	1										
12192	5	2009-09-03	03:35:01	BUS	1										
12192	4	2009-09-03	03:25:07	GRB	1										
12192	3	2009-09-03	03:05:14	BUS	1										
12192	2	2009-09-03	02:59:42	GRB	1										
12191	17	2009-09-03	02:34:36	GRB	1										
12191	16	2009-09-03	02:33:41	GRB	1										
12191	15	2009-09-03	02:33:04	GRB	1										
12191	14	2009-09-03	02:32:30	GRB	1										
12191	13	2009-09-03	02:31:19	GRB	1										
12191	12	2009-09-03	02:30:41	GRB	1										
12191	11	2009-09-03	02:29:55	GRB	1										
12191	10	2009-09-03	02:29:18	GRB	1										
12191	9	2009-09-03	02:26:44	GRB	0										
12191	8	2009-09-03	02:26:02	GRB	1										
12191	7	2009-09-03	02:07:18	GRB	1										
12191	6	2009-09-03	01:59:44	BUS	1										
12191	5	2009-09-03	01:37:30	GRB	1										
12191	4	2009-09-03	01:35:31	GRB	1										





Conclusions

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- 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 at least doubled with improved selections
- AGILE and RHESSI TGF samples are consistent concerning longitude, local time distribution and spectral shape
- Cumulative spectrum with significant detection above 40 MeV: challenge for production models
- A real-time monitoring and alert system can be implemented for correlation with other meteo resources