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AGILE Observation of Terrestrial gamma-Ray Flashes

Martino Marisaldi (INAF-IASF Bologna)

on behalf of the AGILE Team

III Fermi Symposium

Rome, May 9-12 2011

Outline

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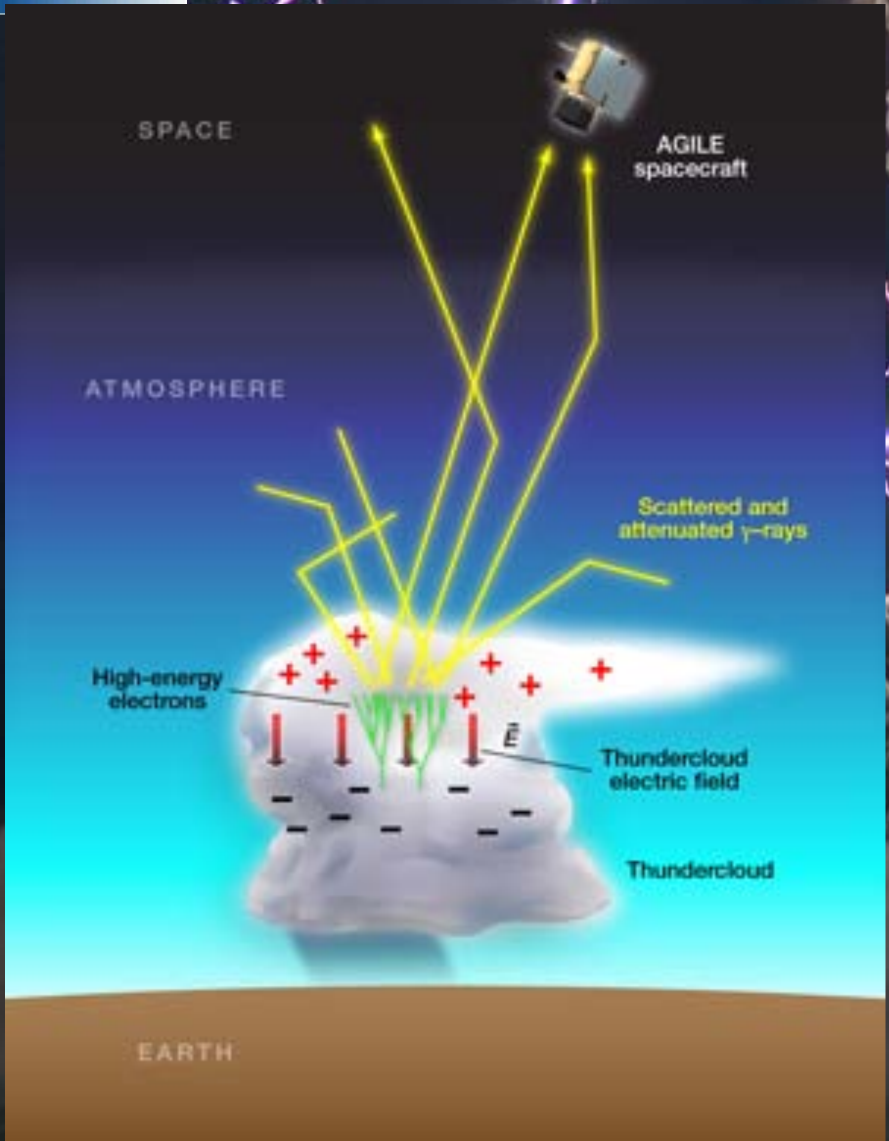

Credit: Alan Stonebraker

- AGILE TGF detection capabilities in context
- Characteristics of the AGILE TGF sample
- TGFs and global lightning activity
- High energy results:
  - Localization of TGFs in gamma-rays from space
  - High energy spectrum

Operating TGF detectors

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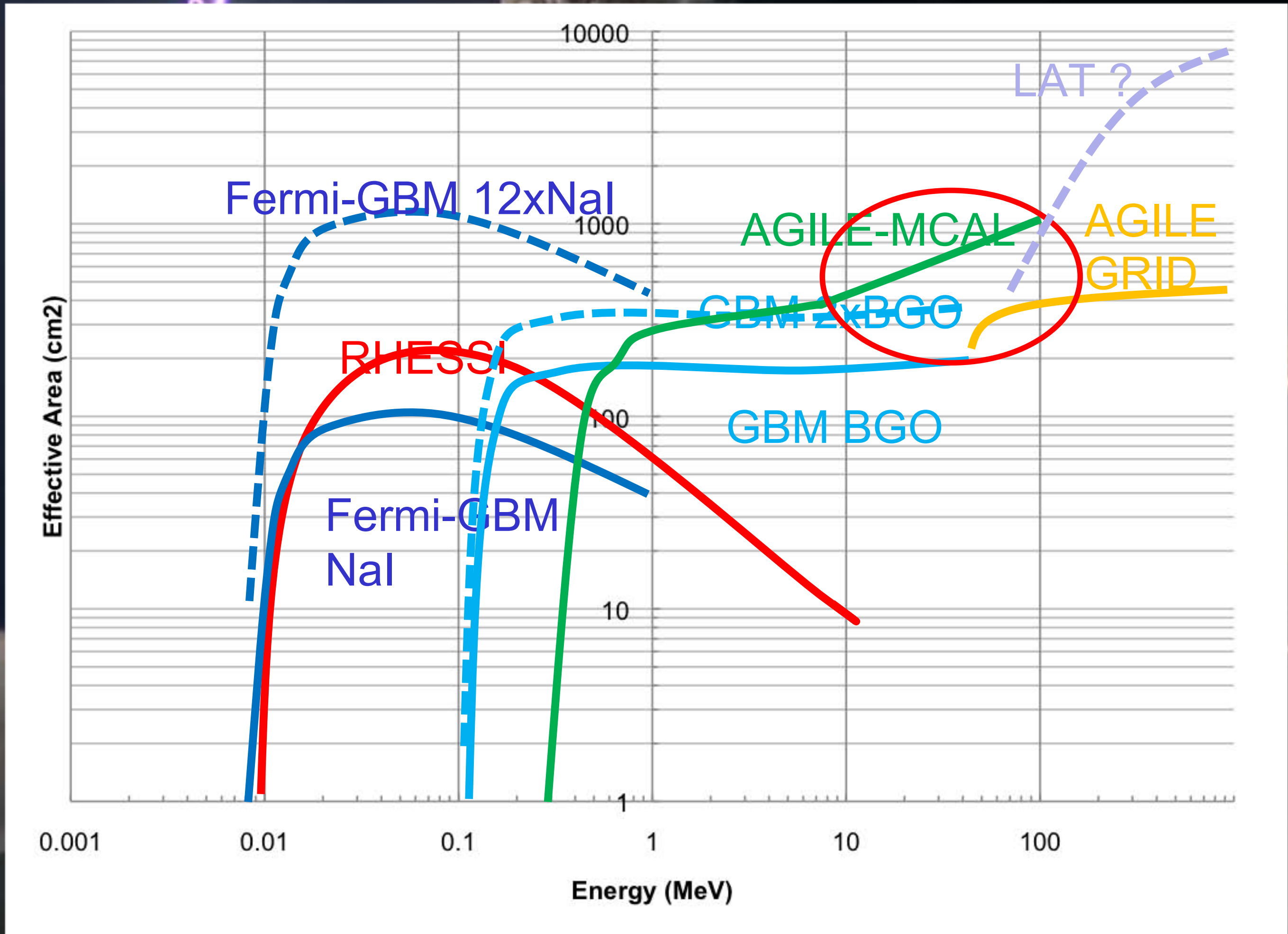
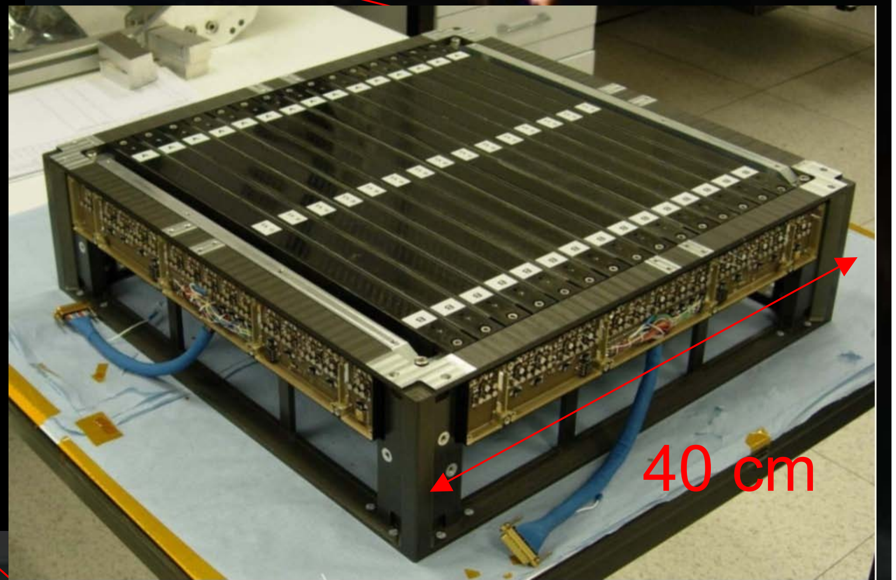
Effective Area vs. Energy



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

The AGILE payload

30 CsI(Tl) bars with Photodiode readout
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 <u>16ms, 1ms and 300μs</u>



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

MCAL TGF detection rate

> 250 class A TGFs + ~130 class B TGFs since June2008

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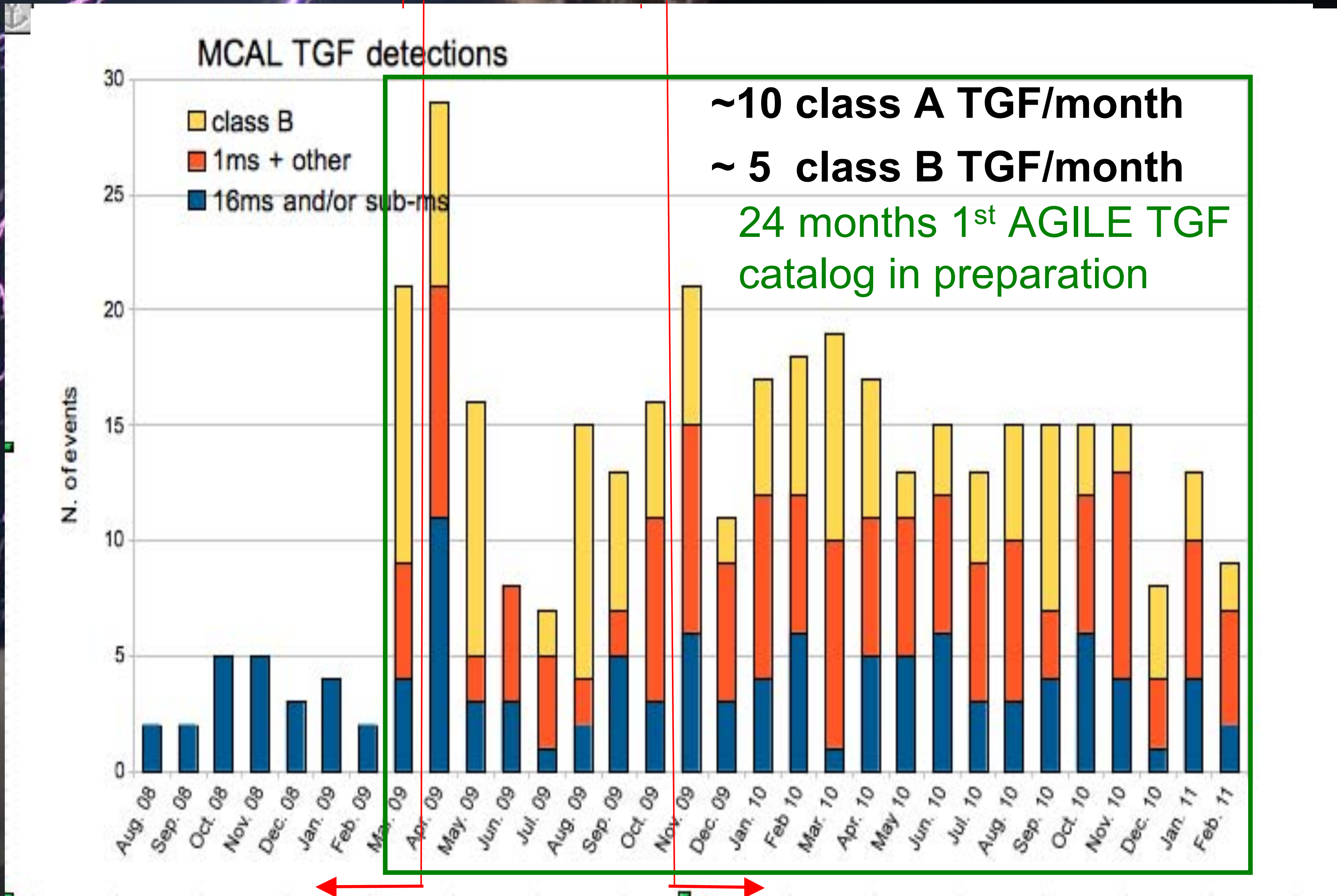

34 TGFs Published in M. Marisaldi et al., J. Geoph. Res., 115, A00E13, 2010.

After entering Spinning mode

The AGILE TGF sample

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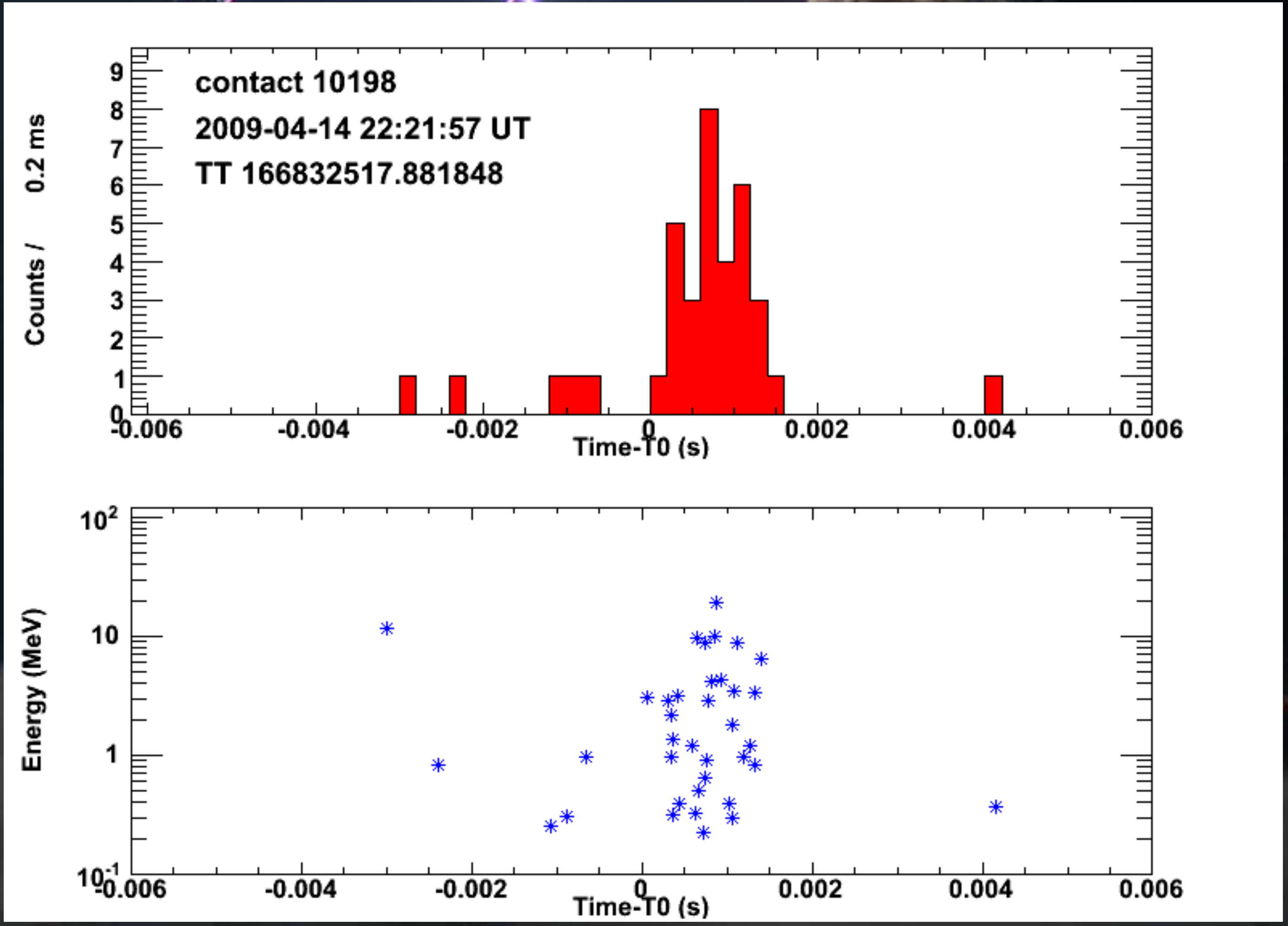


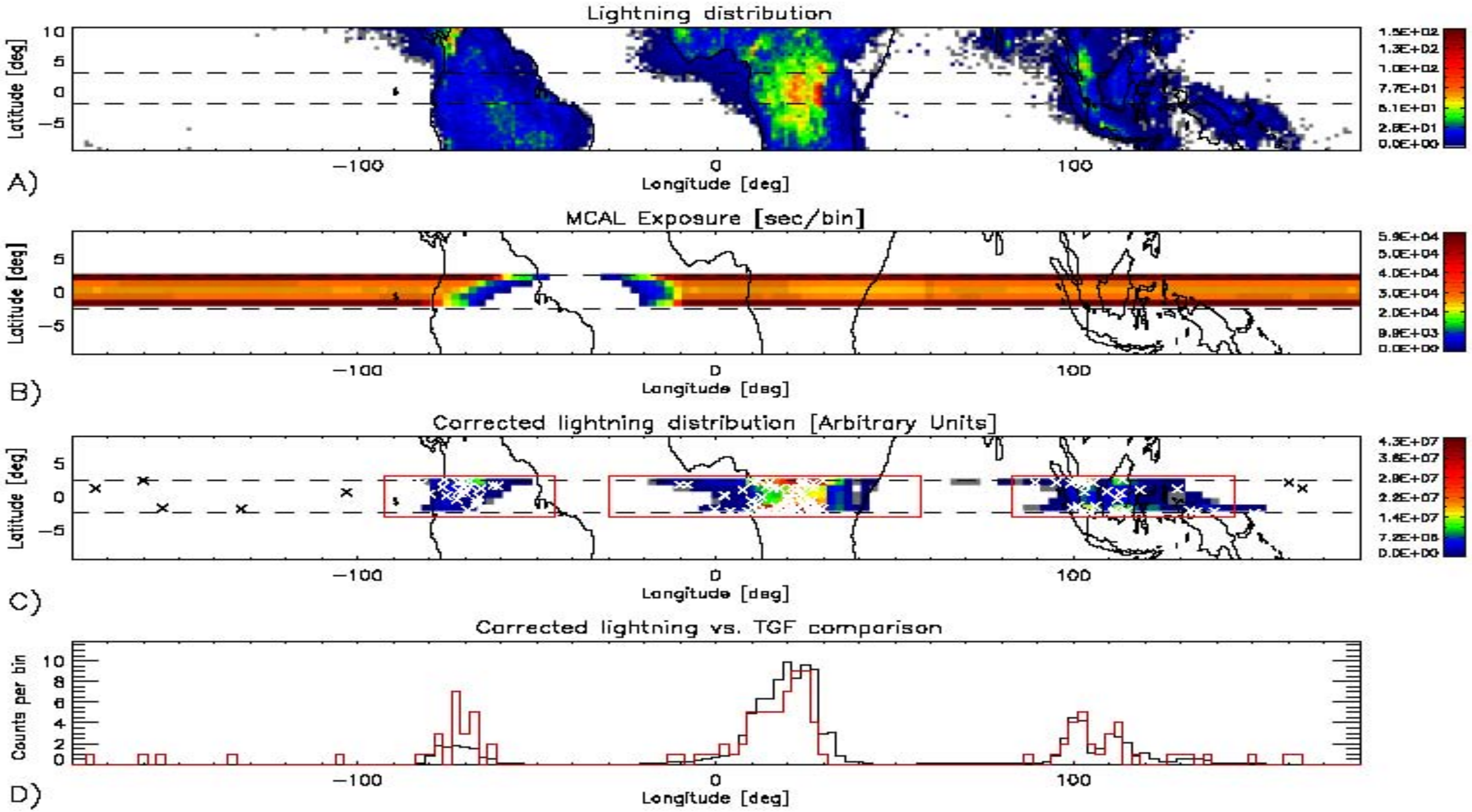
Average properties A AND B class:

Number of counts = 14 +/- 9

Duration (= (0.8 +/- 0.4) ms

Energy = (4.0 +/- 1.7) MeV

TGF-lightning correlation



For more information see the poster by F. Fuschino on May 11-12

LIS-OTD high resolution full climatology available at http://thunder.msfc.nasa.gov/

Imaging TGFs in gamma rays

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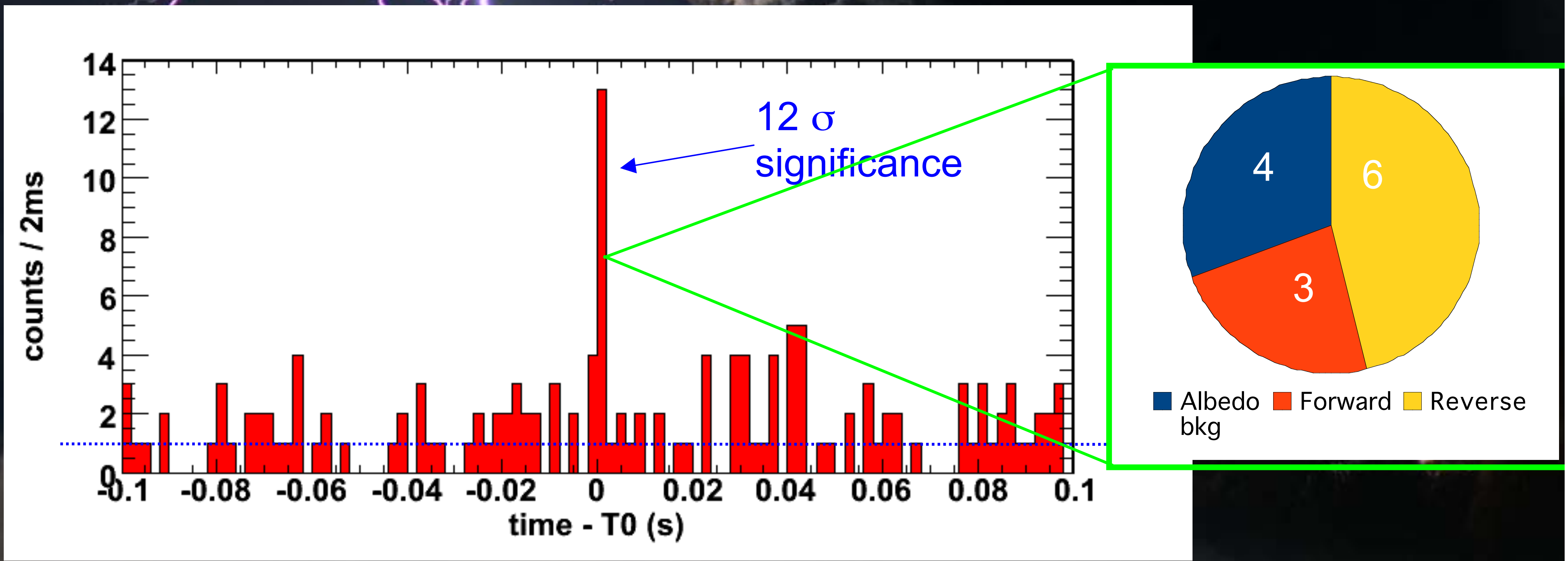
Search for GRID events in temporal coincidence with 119 MCAL TGFs detected between Jun. 2008 – Dec. 2009



13 GRID events within 2 ms from TGFs T0!

Geographical distribution

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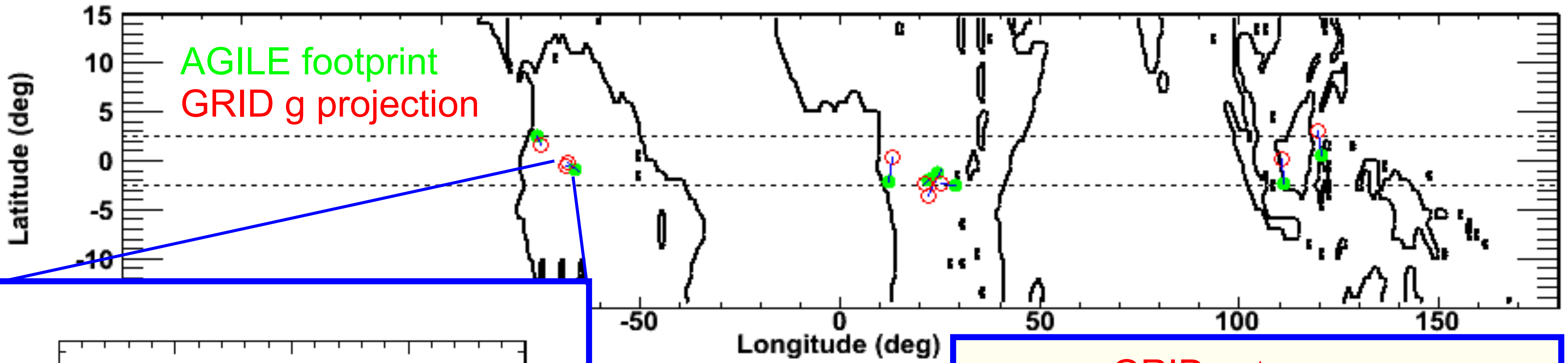

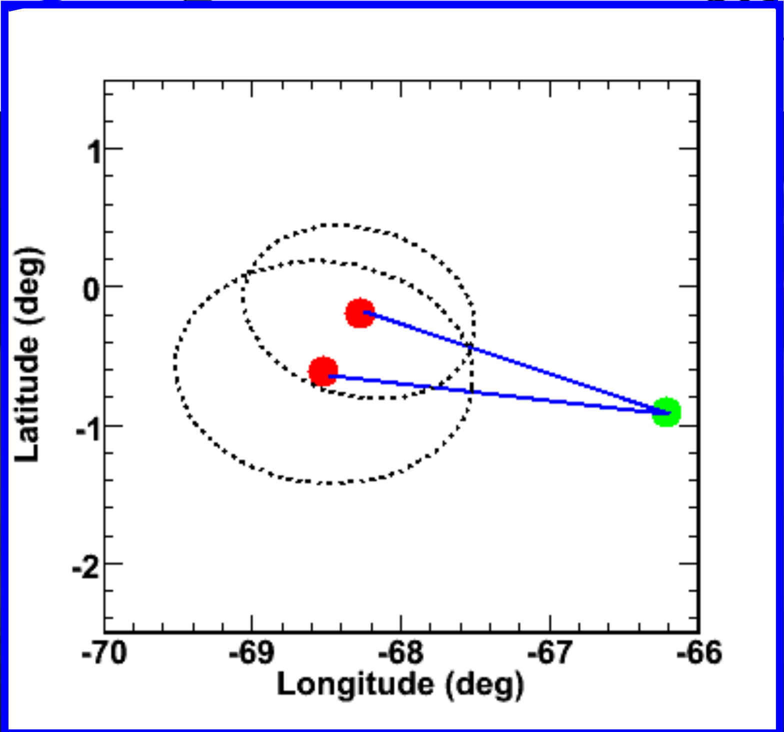

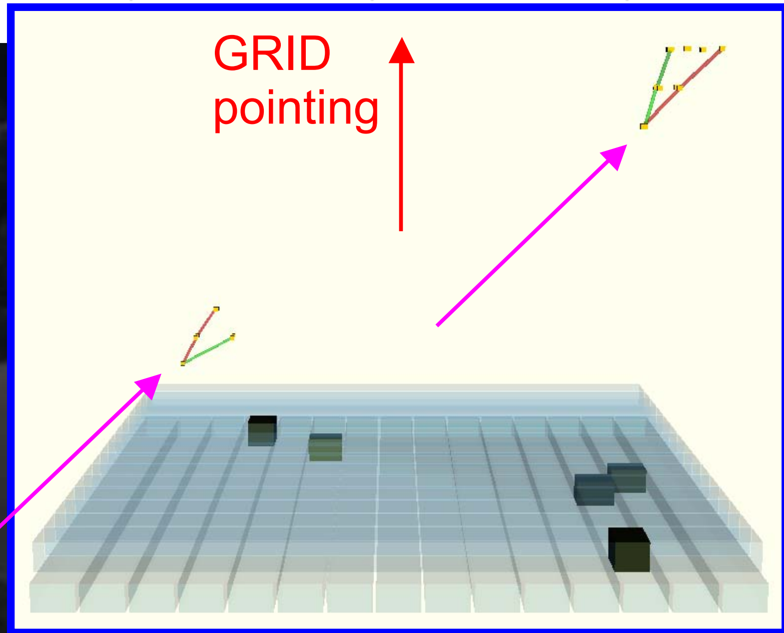

Reverse event direction (TGF source)

TGF 12809-19 in details (2010 Oct. 16 20:44:55 UT)

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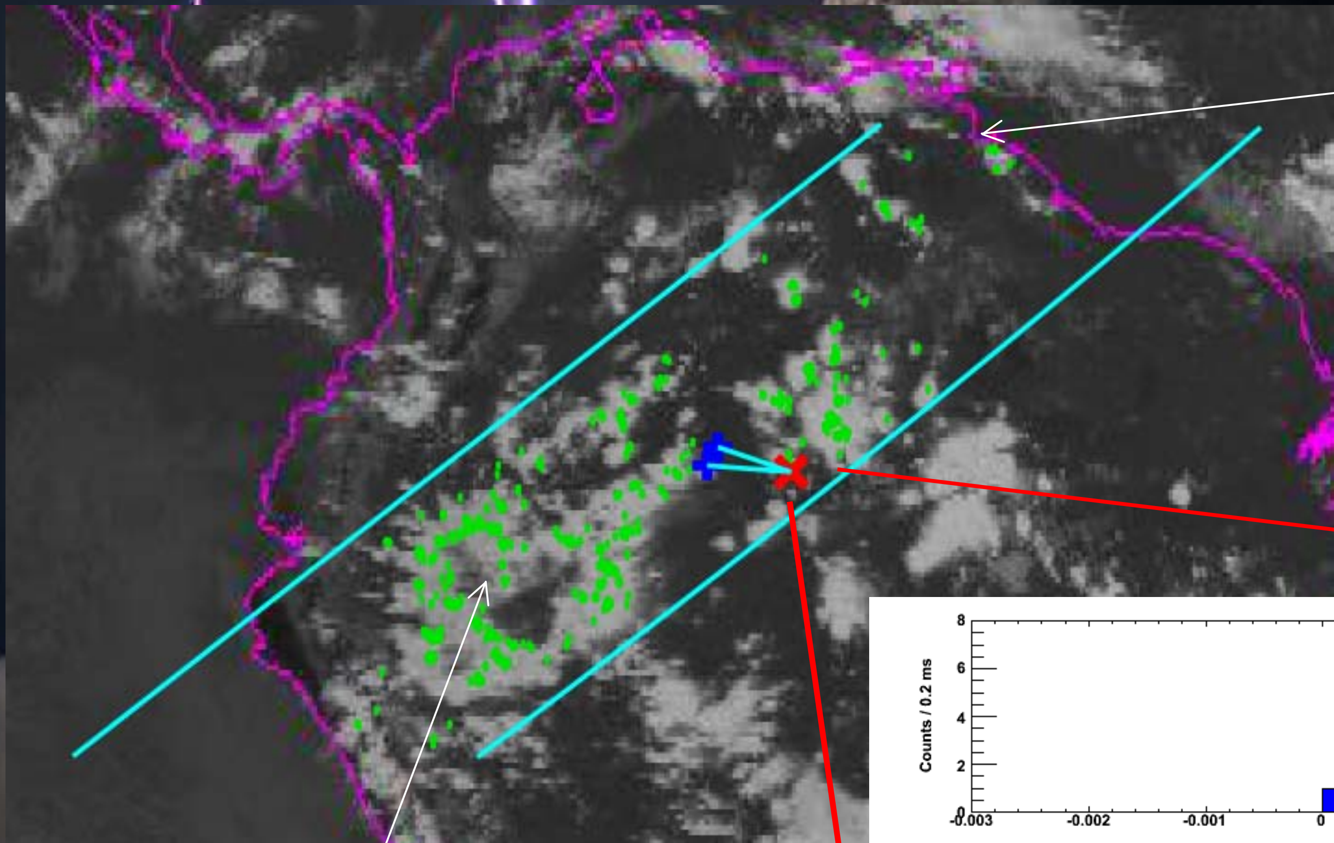
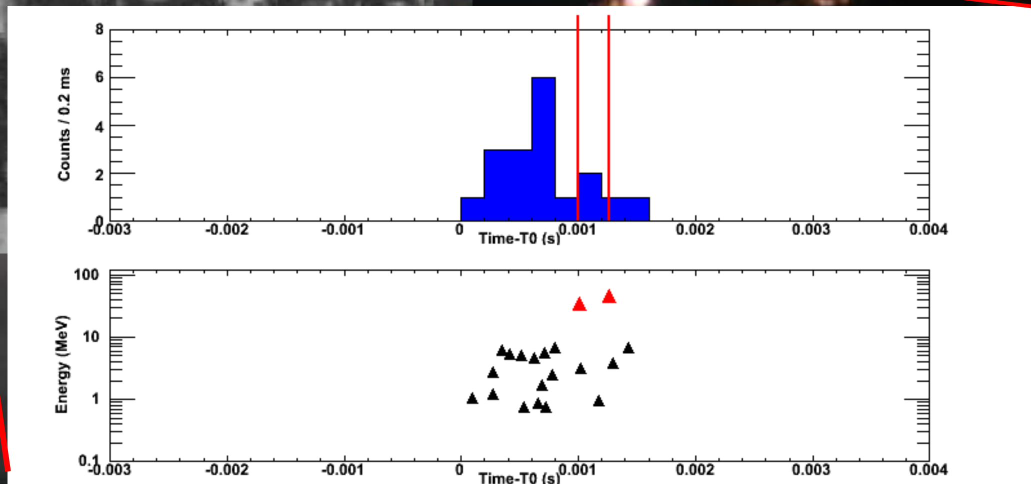
Credits: B. Carlson, Univ. Bergen

GOES IR image ~5 minutes before TGF



TRMM-LIS pass ~1 hour before TGF



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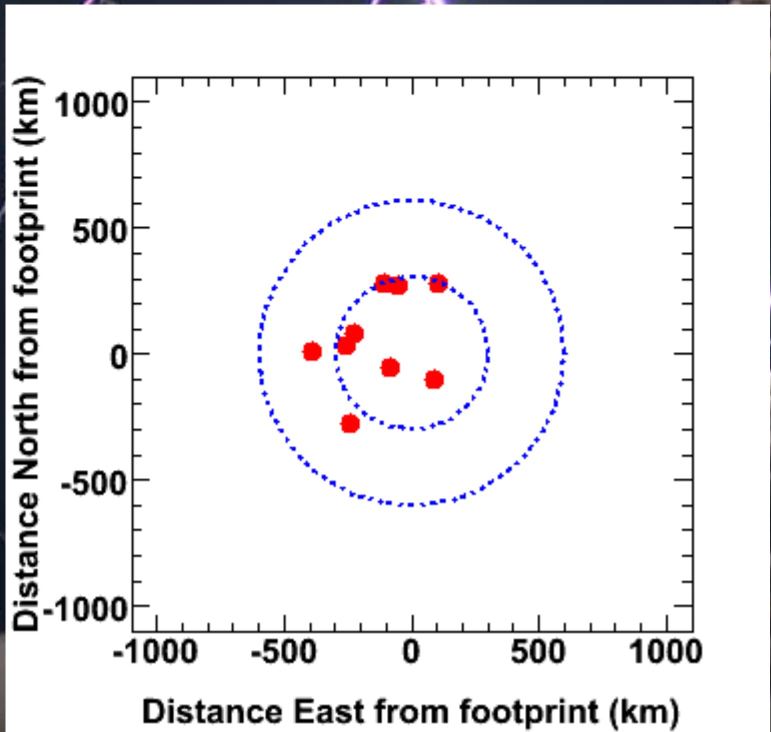
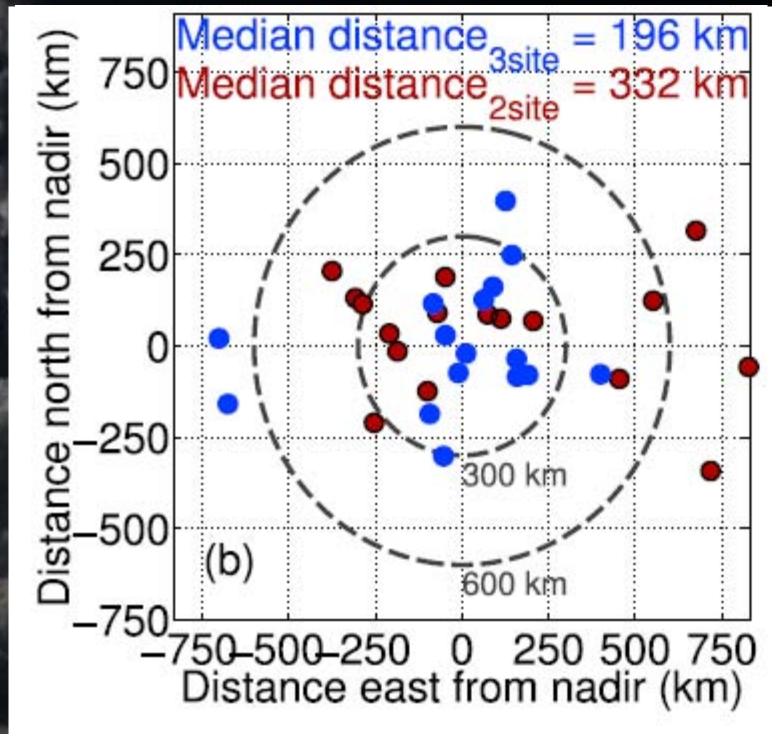
Geographical distribution





Event clustering at < 400 km from AGILE footprint
Consistency with pervious detections based on RHESSI TGFs and sferics
(Cummer et al., GRL 2005, Cohen et al., GRL 2010)

Results published in Marisaldi et al., Phys. Rev. Letters 105, 128501 (2010)

Cumulative spectrum

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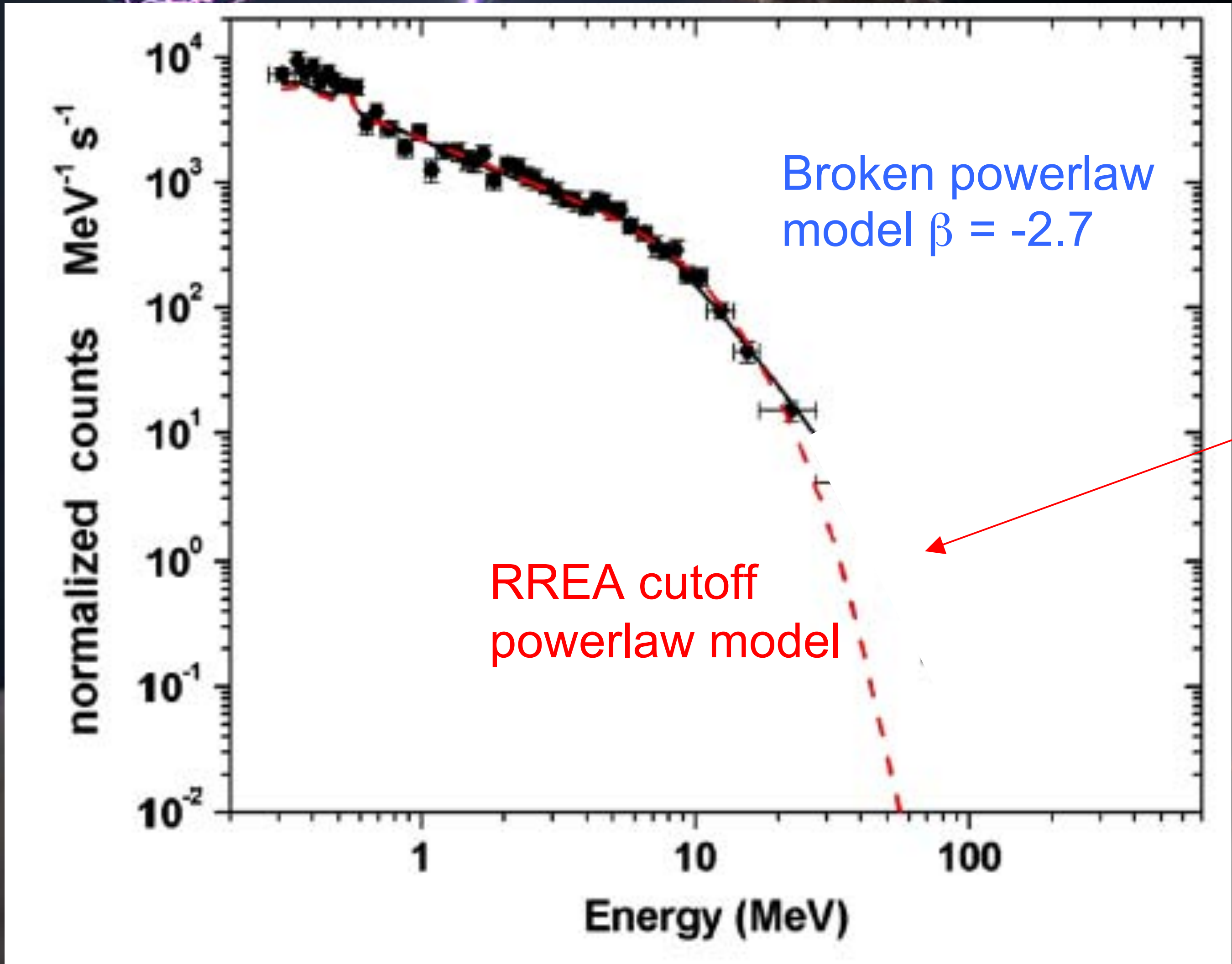
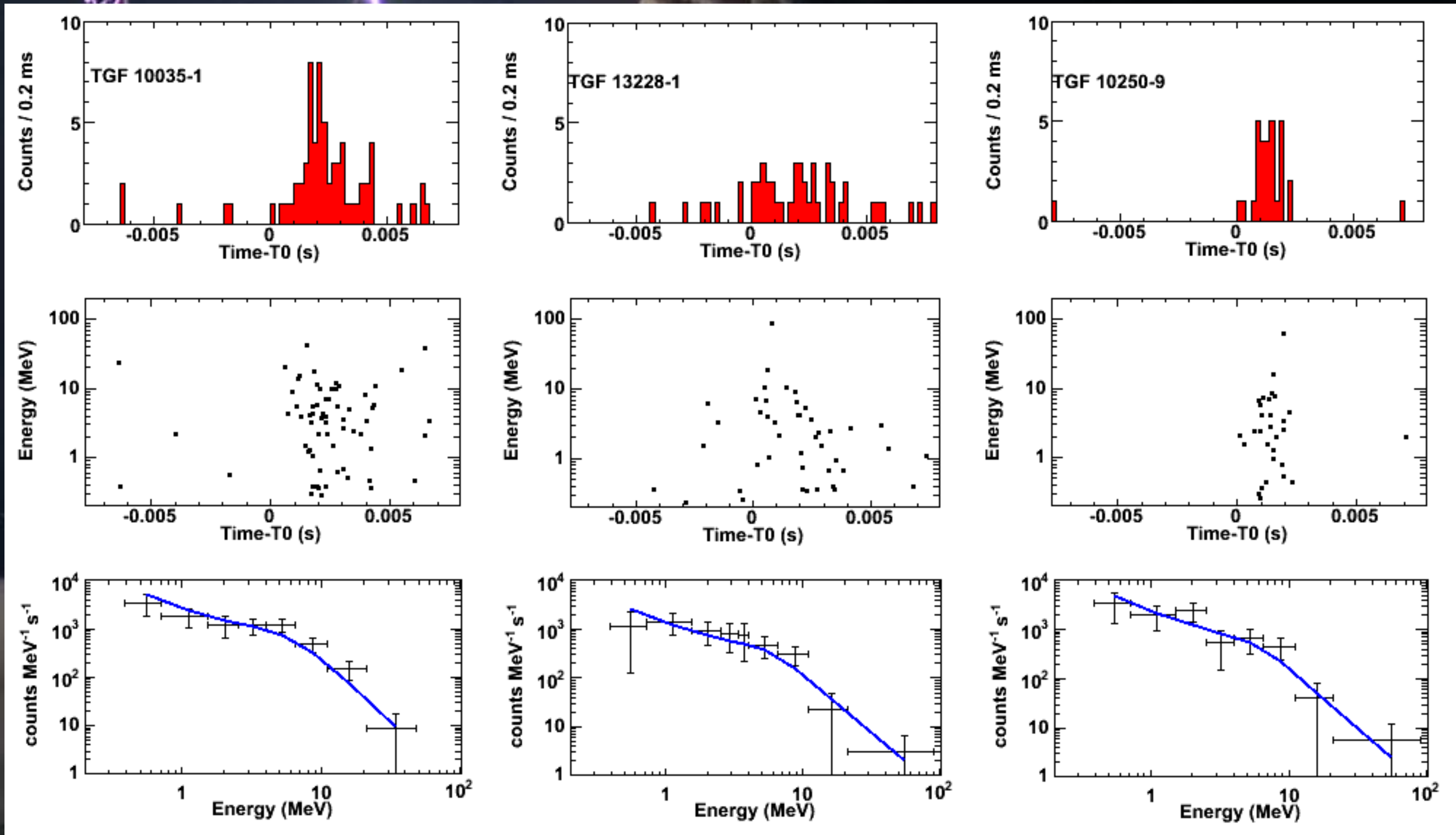
110 TGFs 1806 photons 142 γ E> 10 MeV 26 γ E> 20 MeV



significant detection of γ >40 MeV uneplained by standard RREA model: challenge for emission models

Results published in Tavani et al., Phys. Rev. Letters 106, 018501 (2011)

High energy events



AGILE

Conclusions

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- **AGILE is an important instrument for TGF science:**
  - **energy range extended up to 100 MeV**
  - **<u>the only one</u> with <1ms trigger logic**
  - **photon-by-photon with μs timing**
  - **~equatorial orbit**
- **AGILE detects ~10 TGFs / month with current selection criteria. Rate can be 50% increased with improved offline selections**
- **7% TGFs can be localized in space by means of the AGILE gamma-ray imager.**
- **Energy spectrum seems harder than previously expected, challenging current theoretical models.**

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THANK YOU!

Credit: Alan Stonebraker

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Extra slides

MCAL high energy calibration

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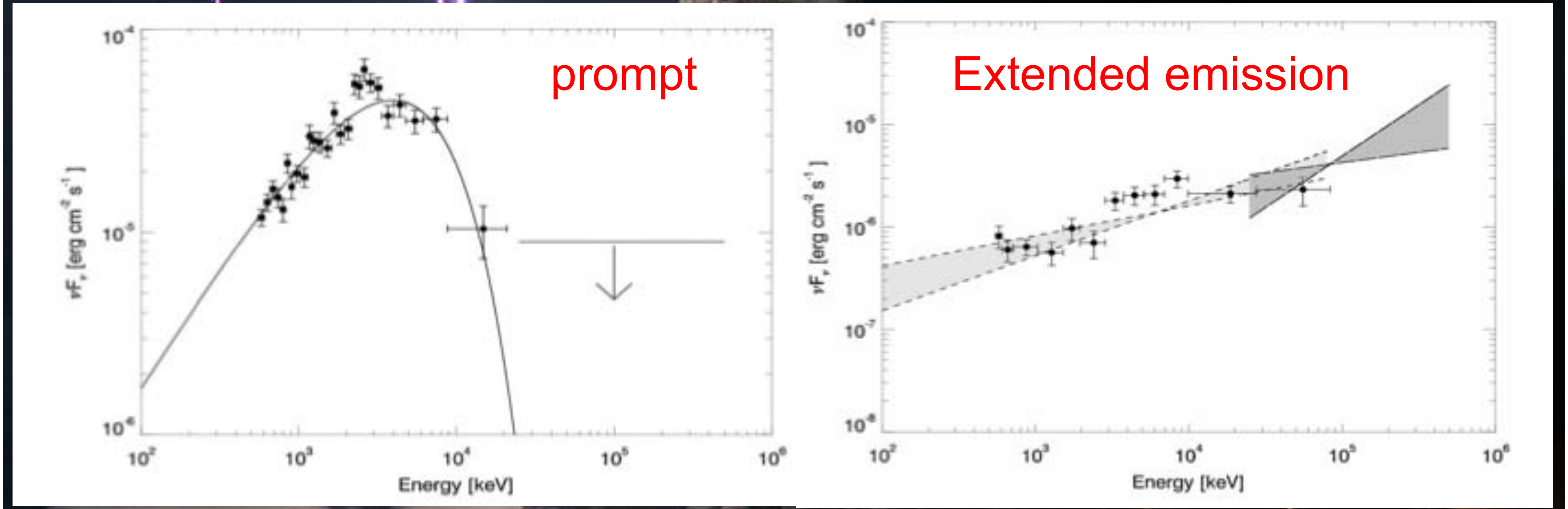
GRB 090510



Giuliani et al., ApJL 708 (2010) L84

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

1994: BATSE discovery of TGF

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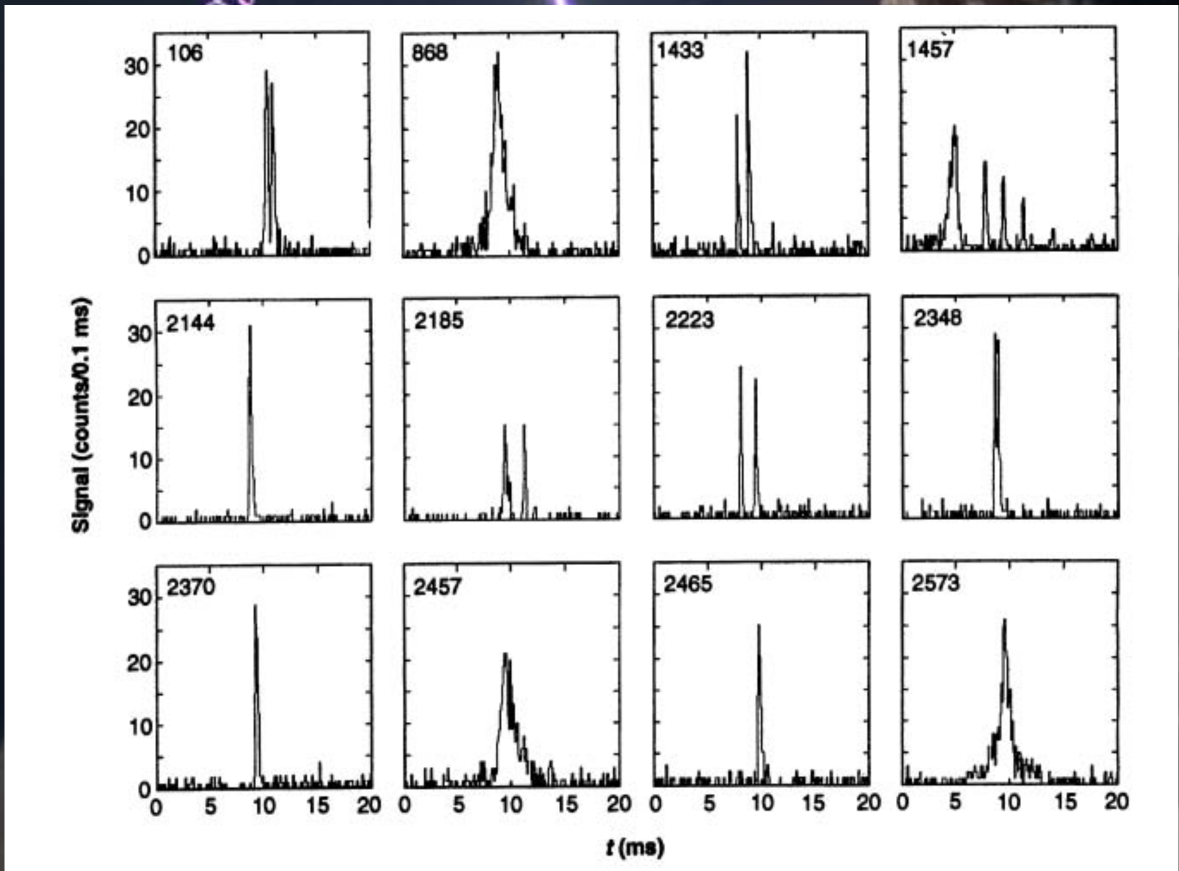

Fishman et al., Science, 1994

~ 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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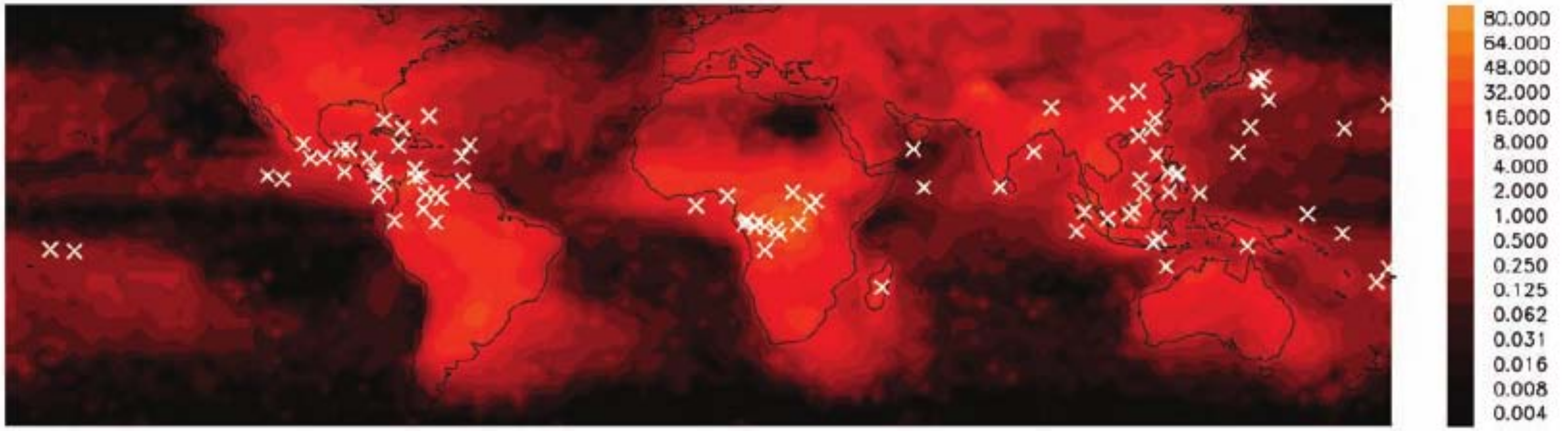
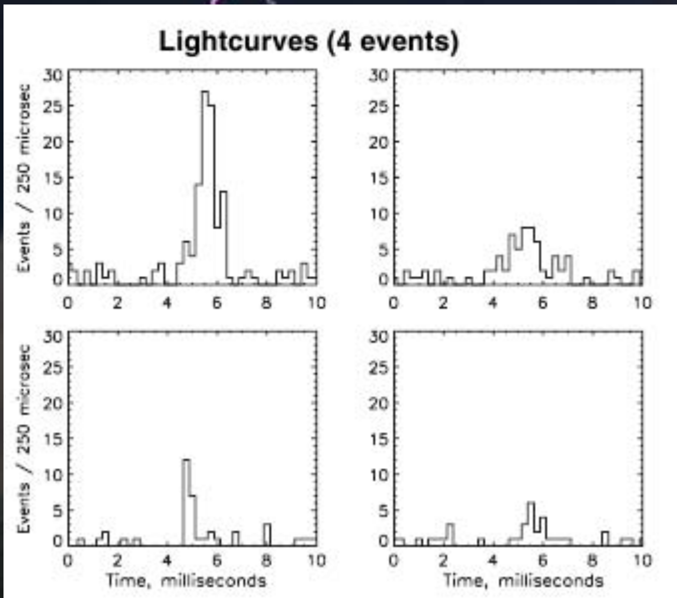


TGF Distribution with lighting frequency per km^2 per Year

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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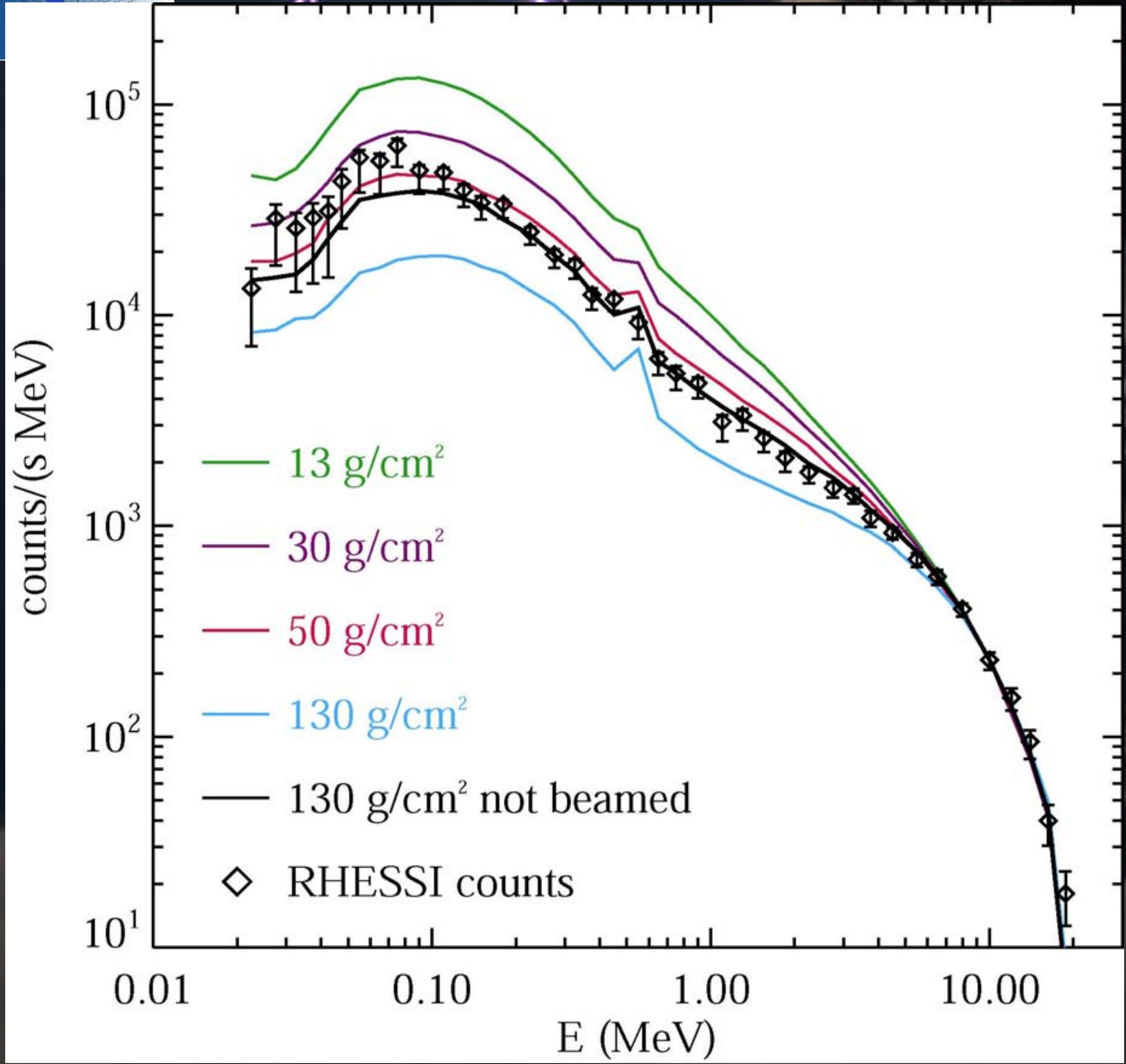

Relativistic Runaway Electron Avalanche (RREA) with relativistic feedback (Dwyer 2008)

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)

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

AGILE

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
- **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

Recent developments

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- **Observations**
  - space observations by Fermi and AGILE
  - airplane observations (the ADELE experiment)
- **Climatology**
  - RHESSI TGFs vs. lightning occurrence and tropopause height (Smith et al., JGR, 2010)
- **Modeling**
  - relativistic feedback, flux and dose estimates (Dwyer 2008, 2010)
  - VLF signature of relativistic runaway electrons (Fullekrug et al., 2010)
- **New missions**
  - ASIM, Taranis, Firefly

MCAL Burst Trigger Logic

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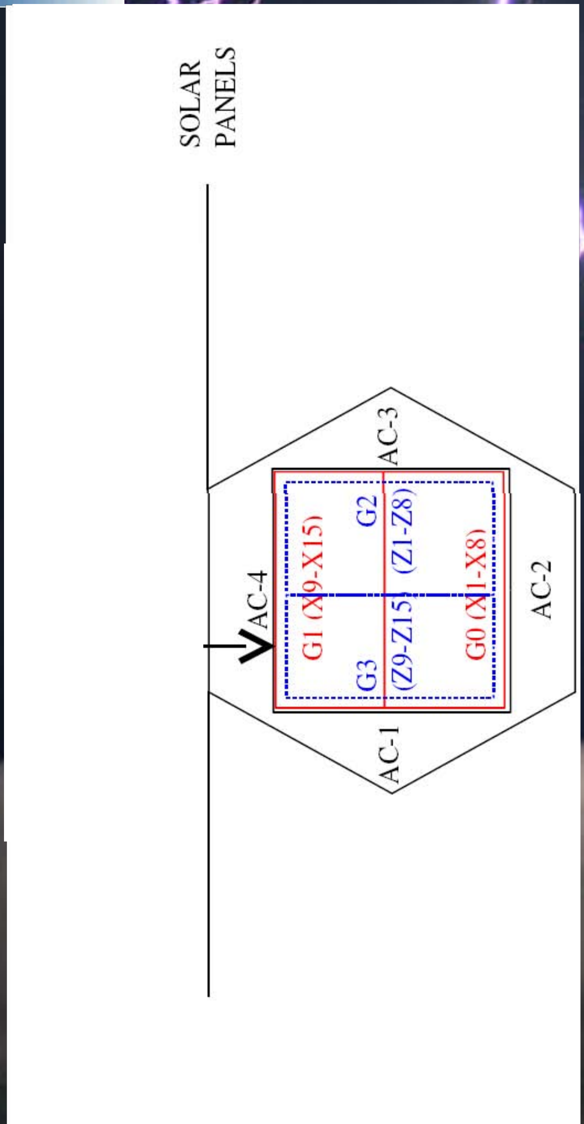

- Long (SW evaluated) time windows: 64ms, 256ms, 1.024s, 8.192s
4 spatial zones and 3 energy ranges

- Short (HW evaluated) time windows: sub-millisecond, 1ms, 16ms
First trigger logic at ~1ms time scale

- Very flexible: more than 2000 parameters for full configuration; dedicated look-up tables to accept/reject triggers
- Current threshold settings:
  - 16ms: >22 counts
  - 1ms: >10 counts
  - 293ms: > 8 counts

Trigger selection

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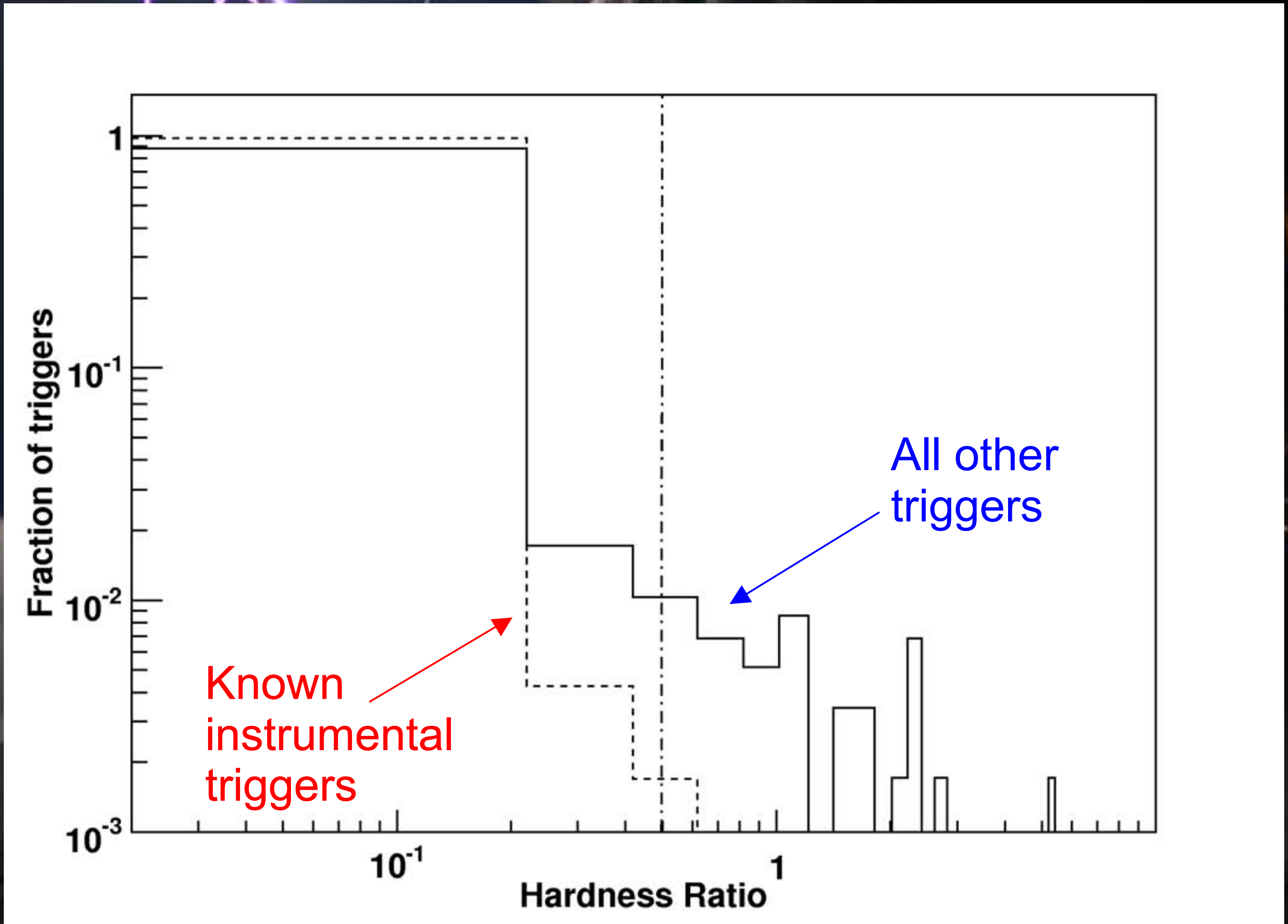
Key parameter: Hardness Ratio

HR = (n. evt E>1.4 MeV) / (n. evt. E<1.4 MeV)

Selection criteria to reject known instrumental triggers: HR > 0.5



AGILE vs RHESSI: longitude and local time

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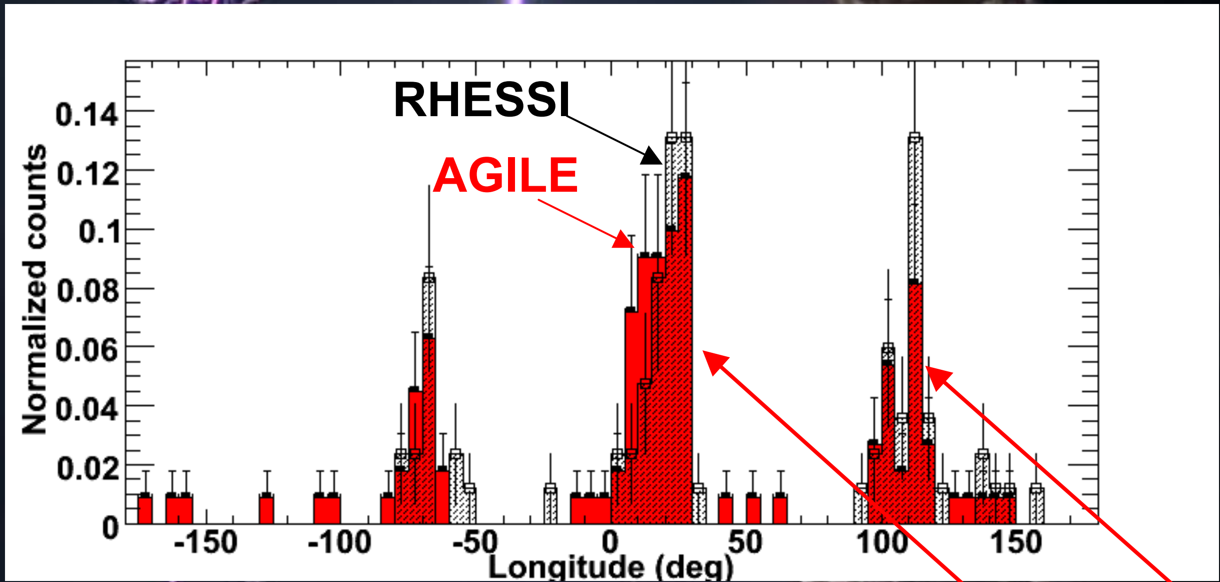
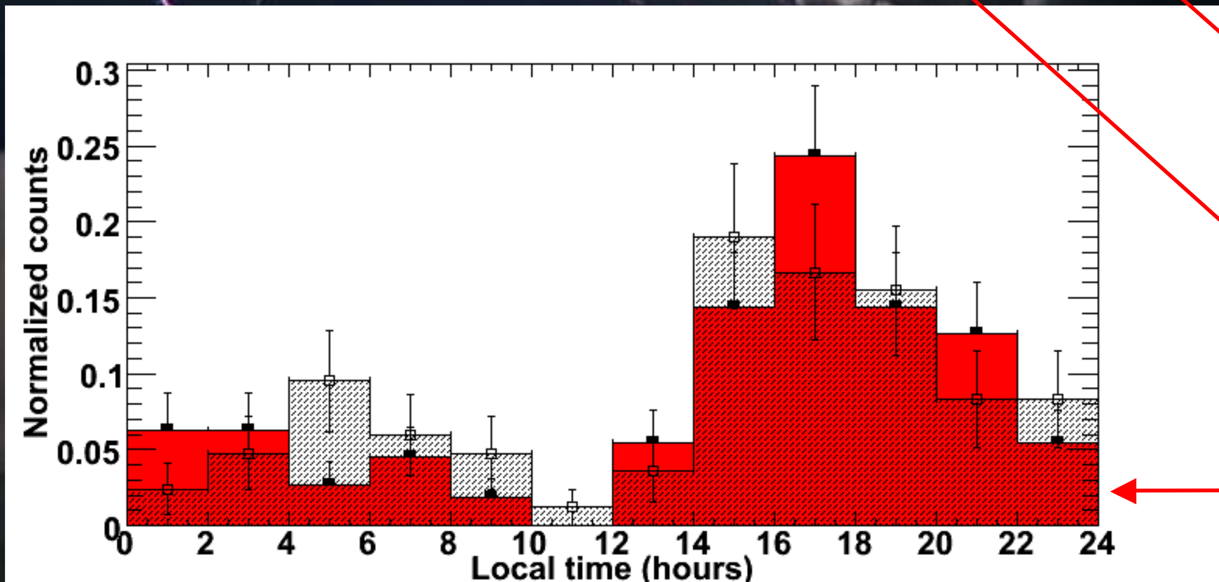




1st RHESSI TGF catalog Grefenstette et al., JGR, (2009)

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

Trigger 11026-1 in details

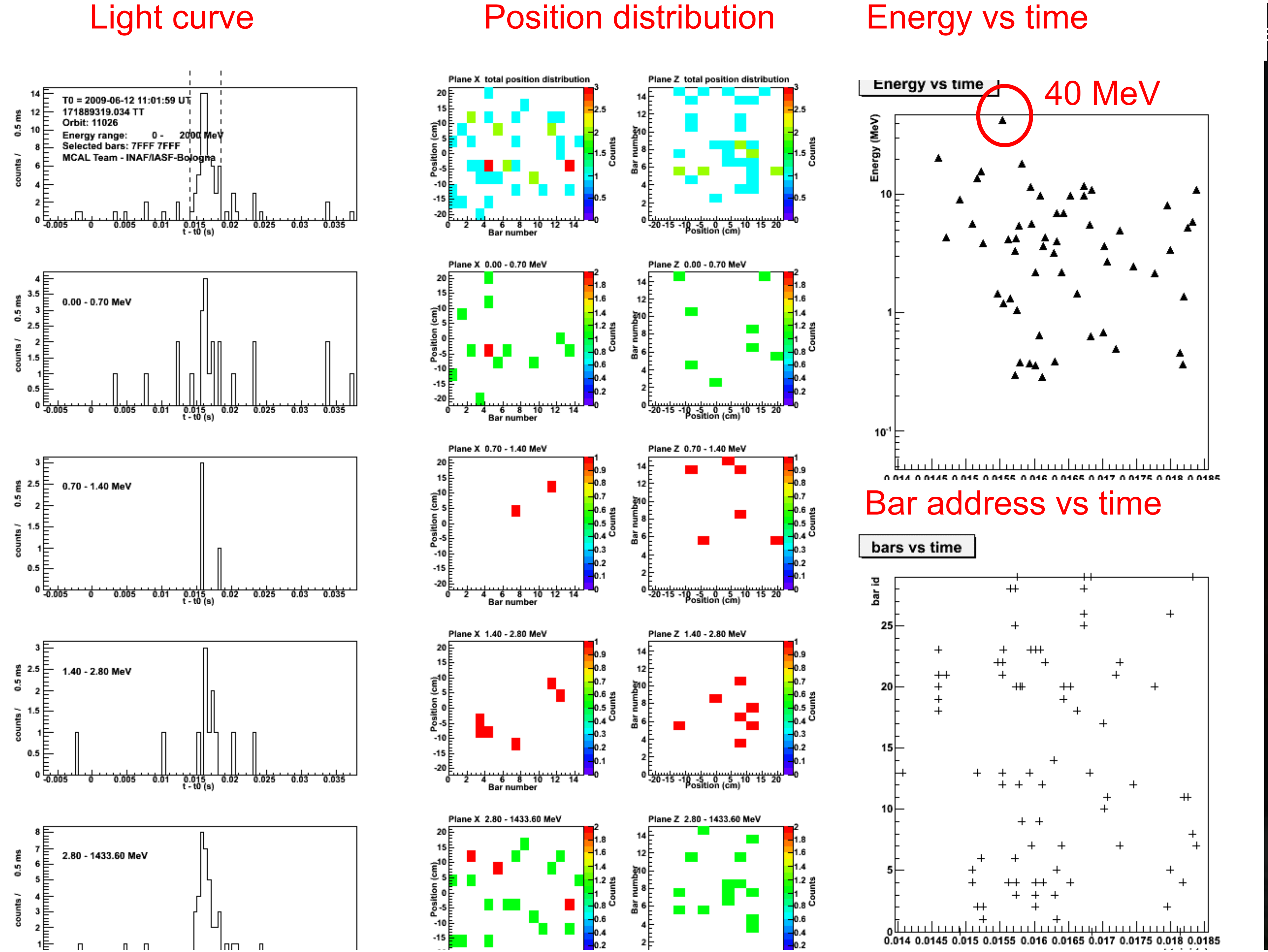
All range

<0.7 MeV

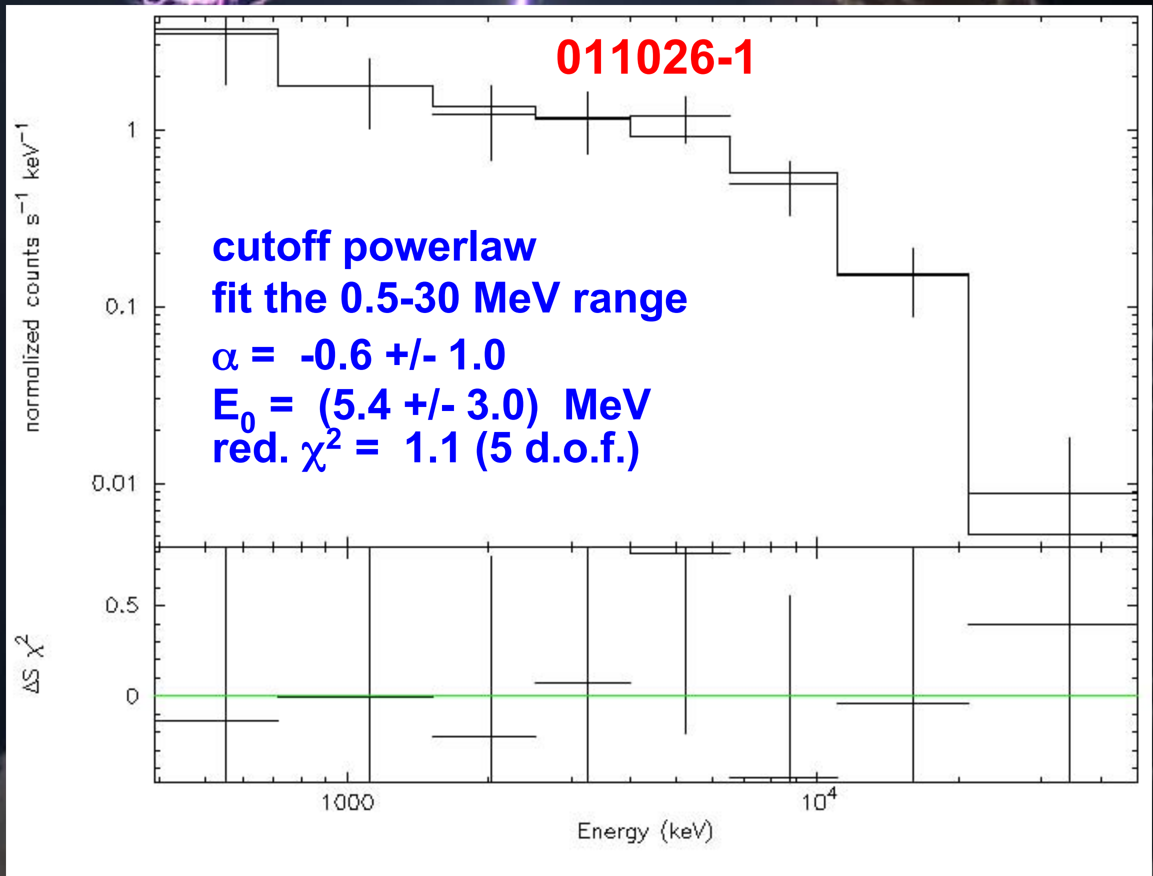
0.7-1.4 MeV

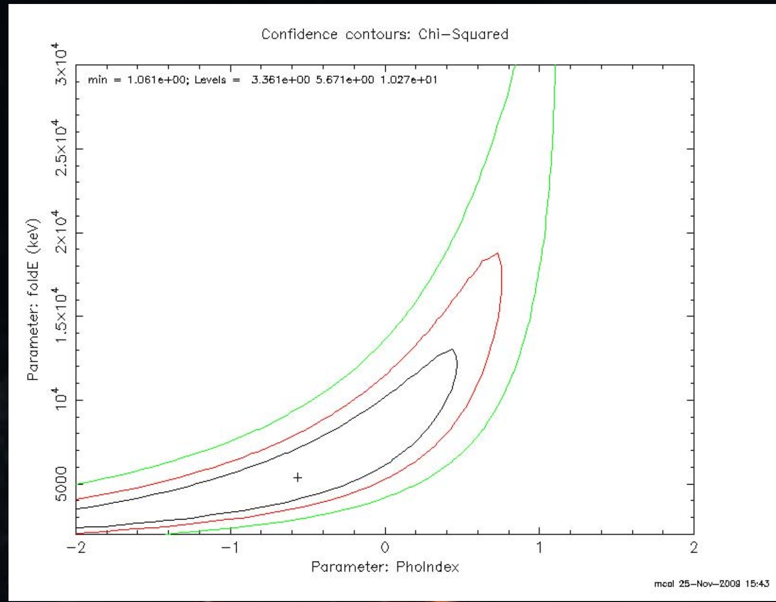
1.4-2.8 MeV

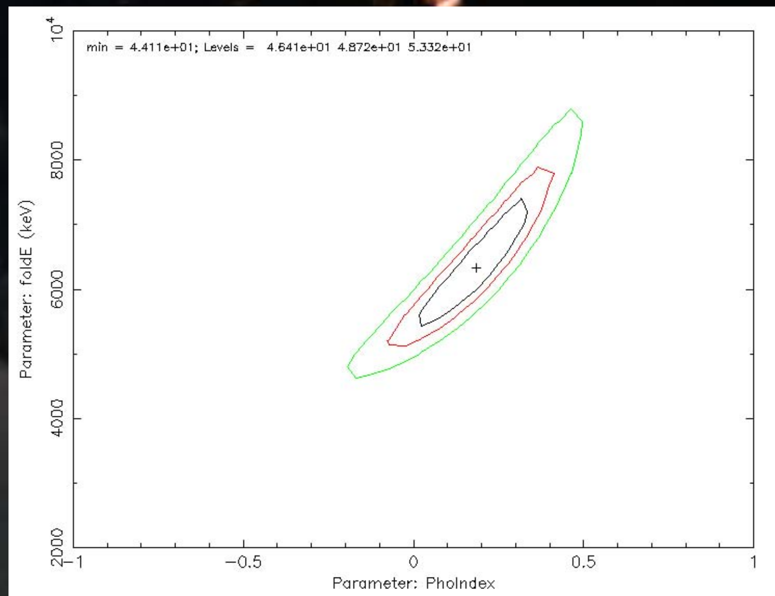
>2.8 MeV



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

AGILE-MCAL vs RHESSI

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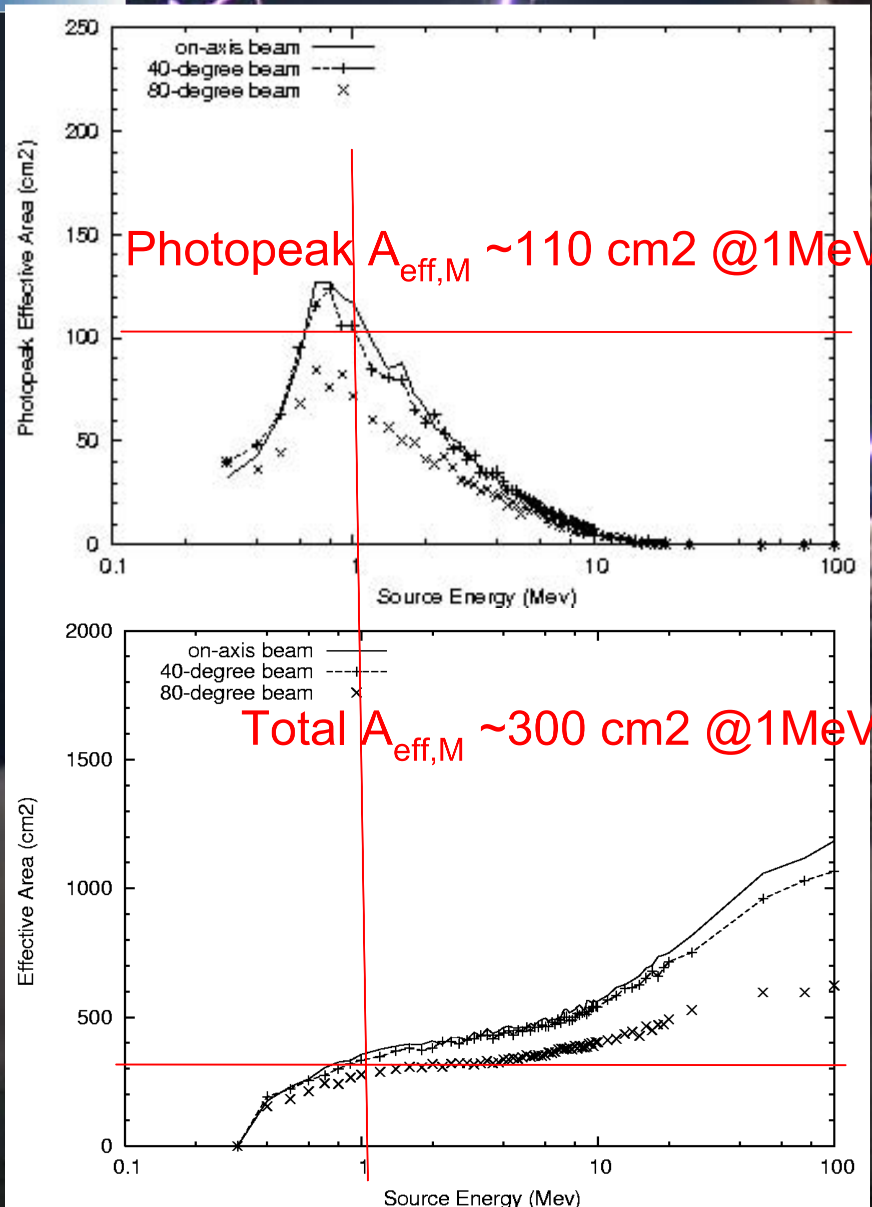
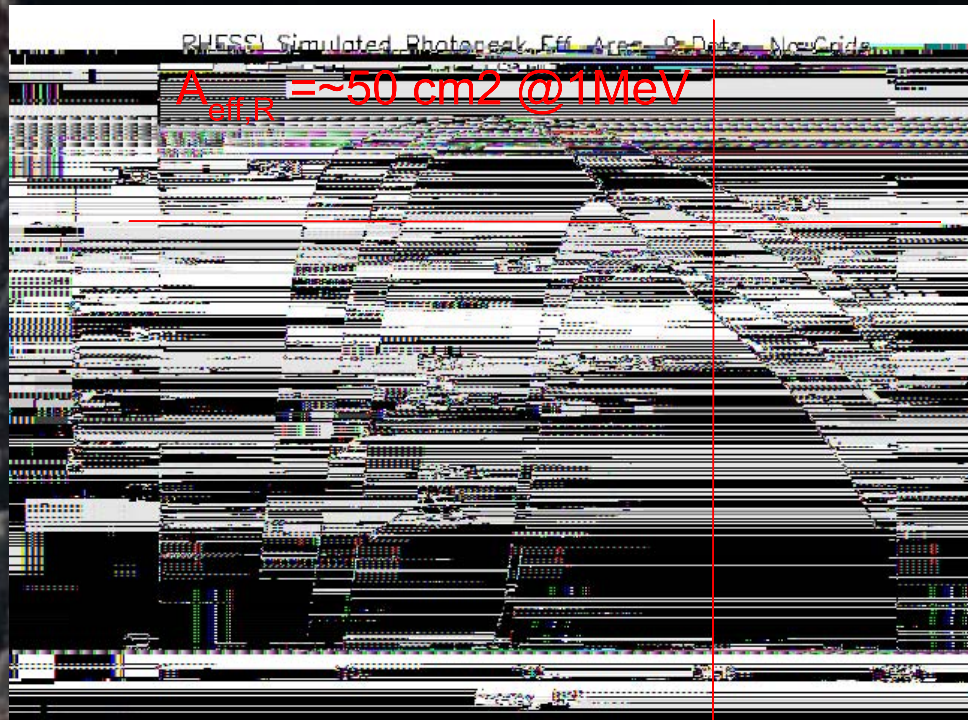
MCAL



Labanti et al., (2009)

RHESSI



Smith et al., (2002)

AGILE vs RHESSI: cumulative spectrum

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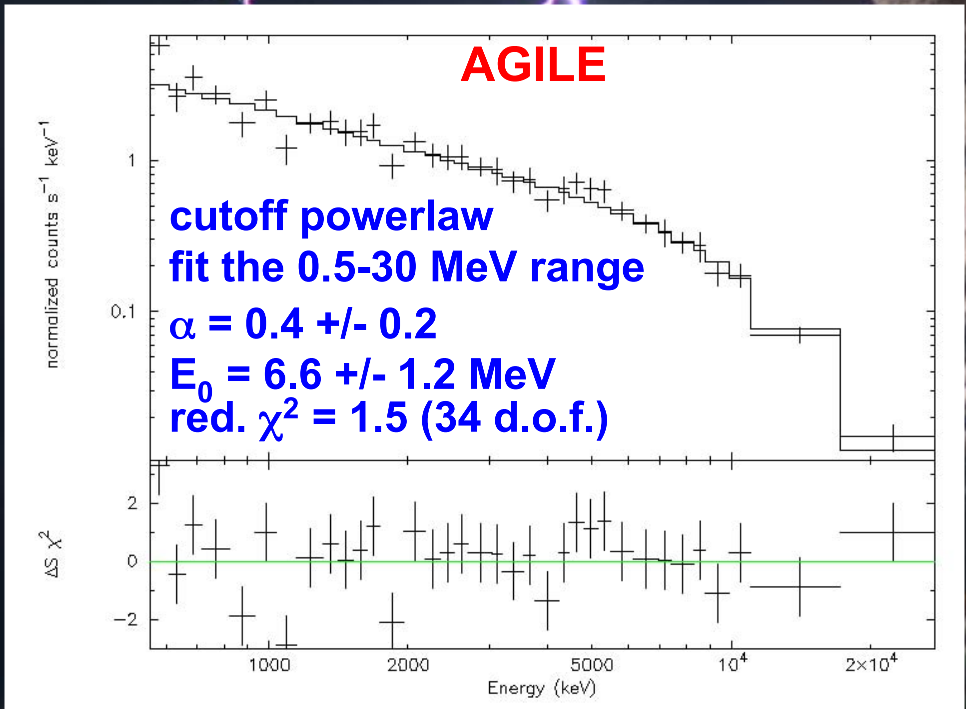

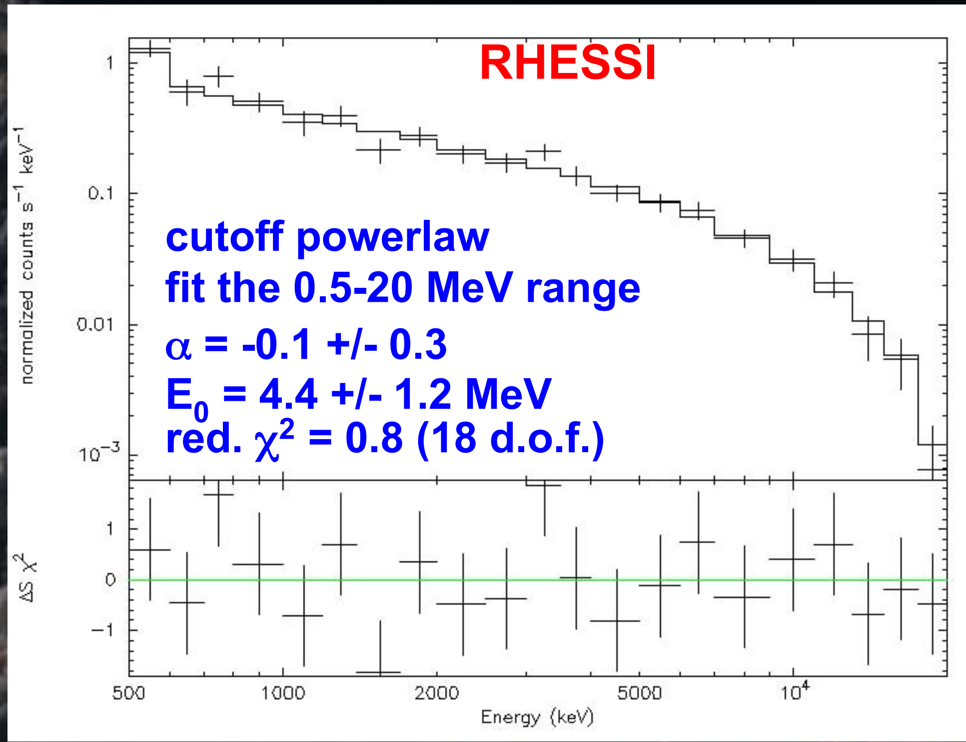

Spectral shapes are compatible
AGILE model fits well RHESSI data too
BUT AGILE seems to select a harder population

AGILE vs RHESSI: cumulative spectrum

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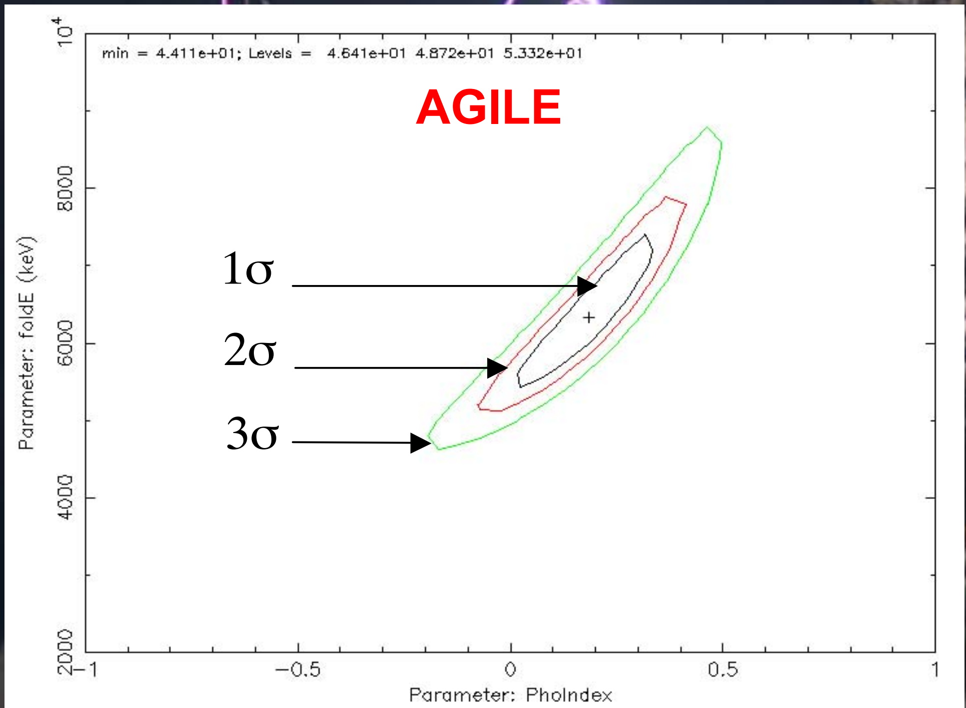
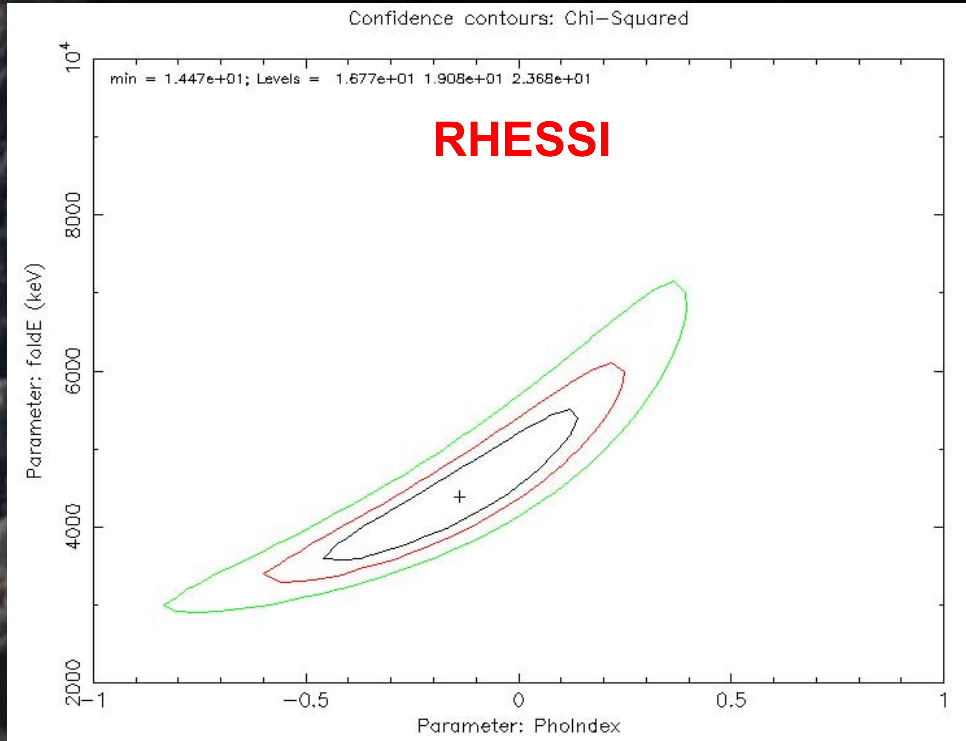
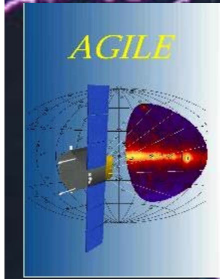
E cutoff vs. alpha confidence intervals





Spectral shapes are compatible
BUT AGILE seems to select a harder population



AGILE vs Fermi-GBM

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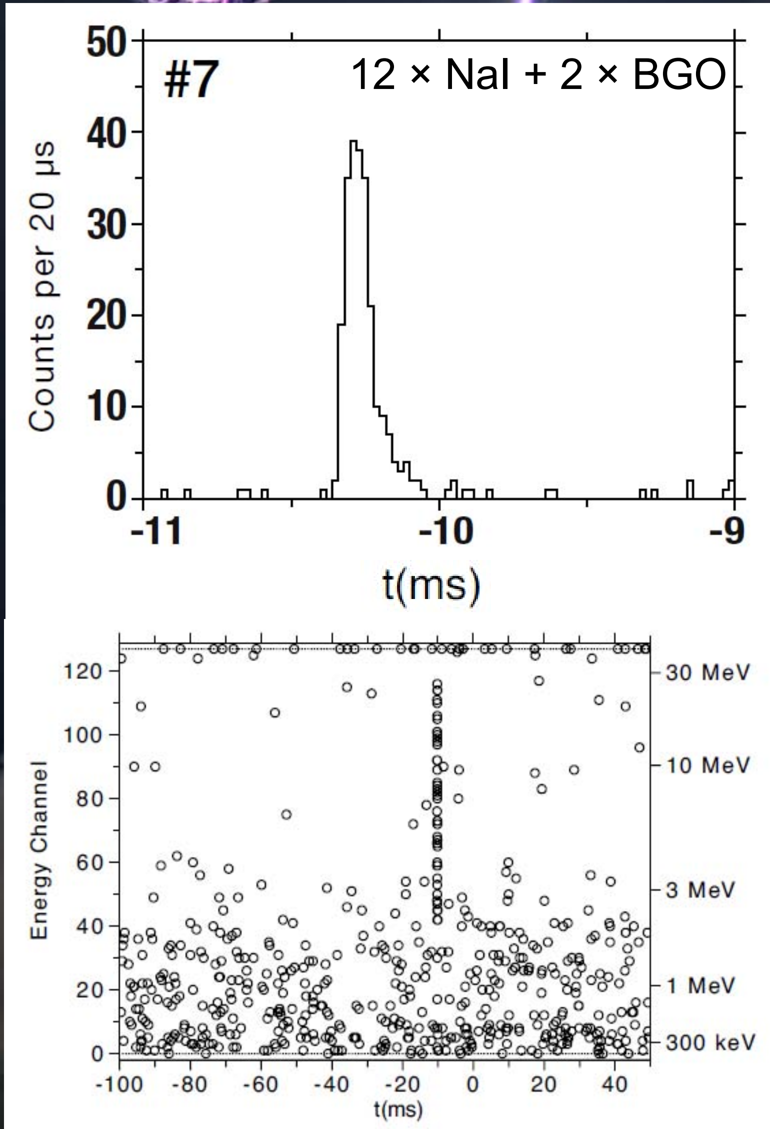
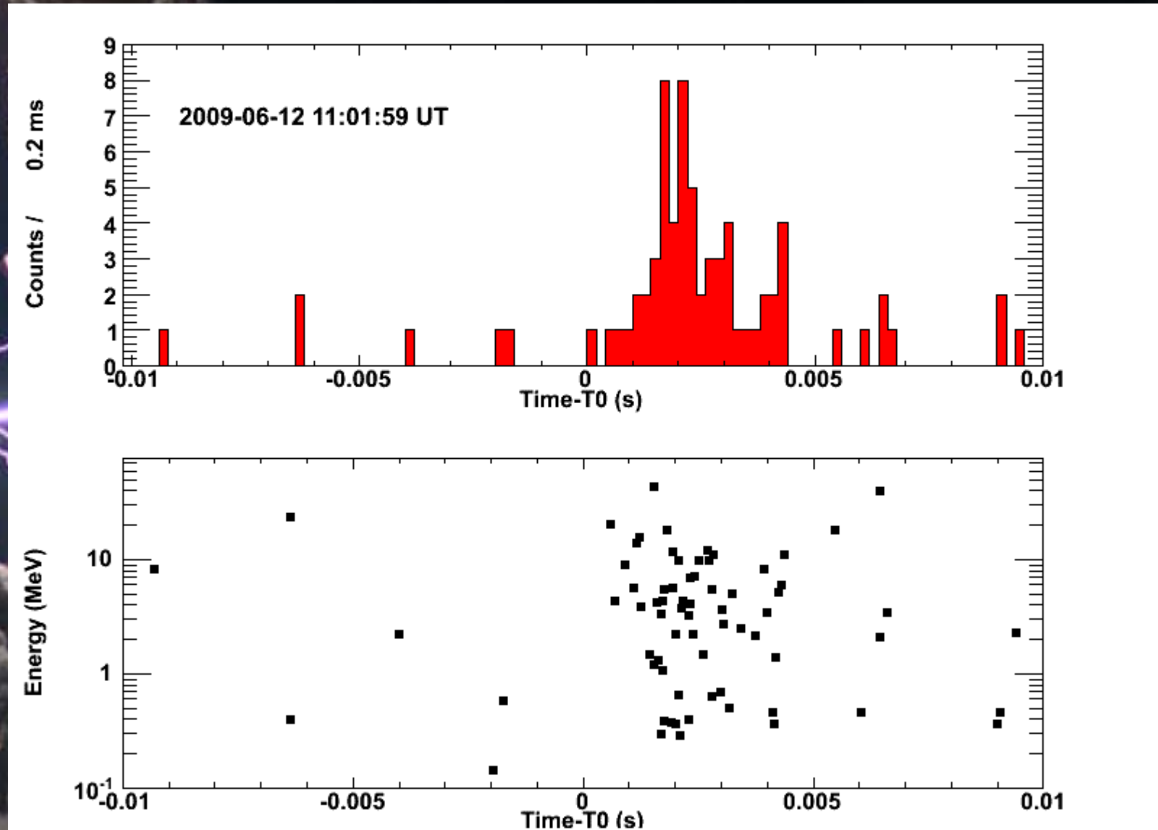
Fermi TGF #7



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

Imaging TGFs from space?

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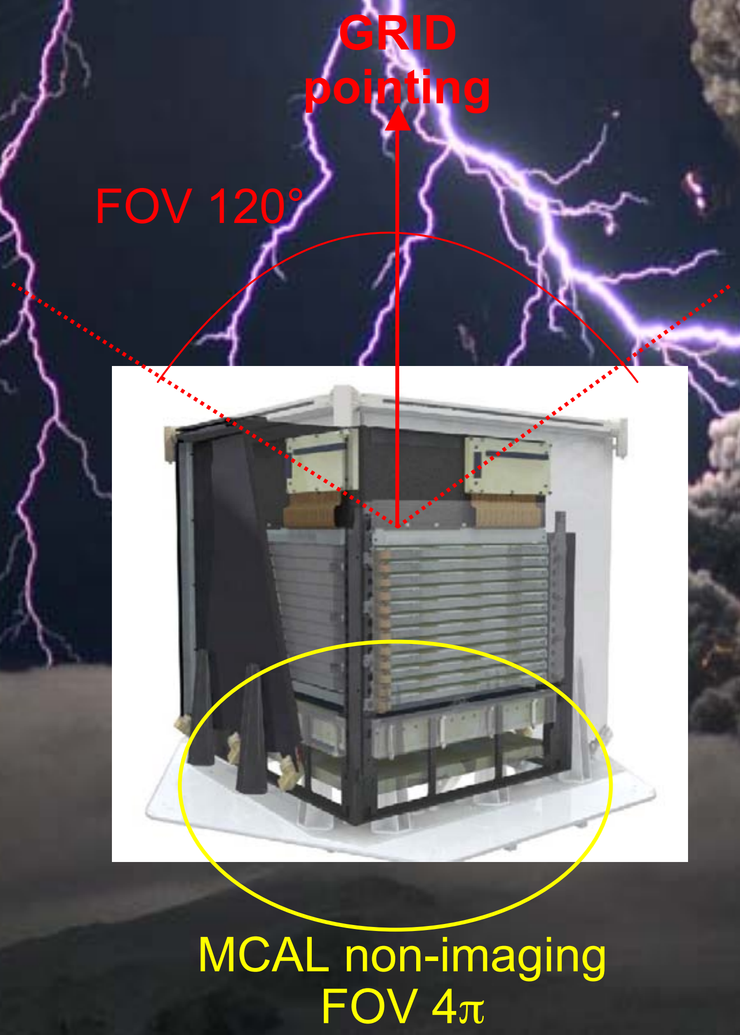
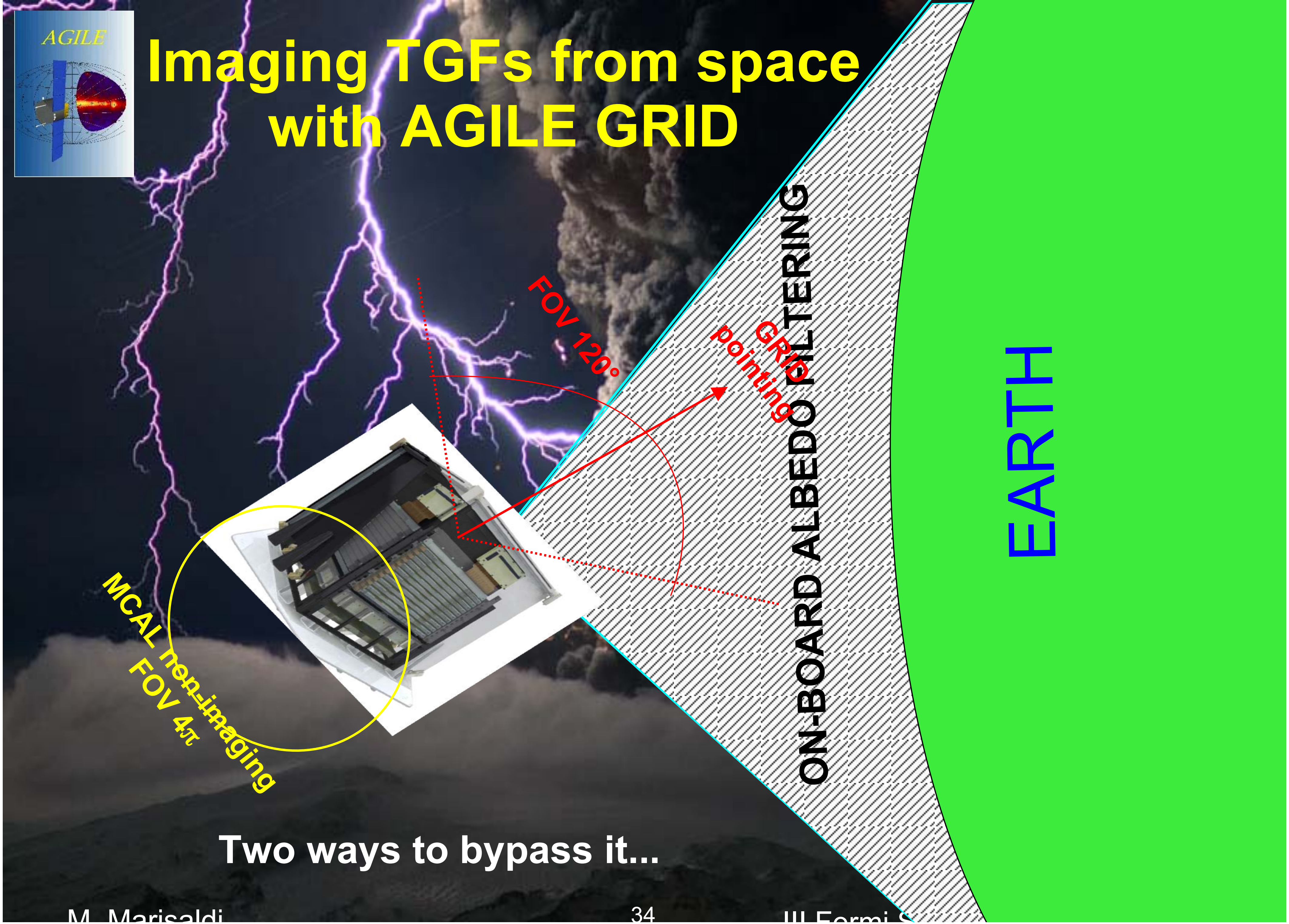
- MCAL detected TGF photons up to 40 MeV and possibly above
- So, why not looking for detections in the AGILE gamma-ray imager (GRID) sensitive above 20 MeV?
- It would be the first direct localization of TGFs in gamma-rays



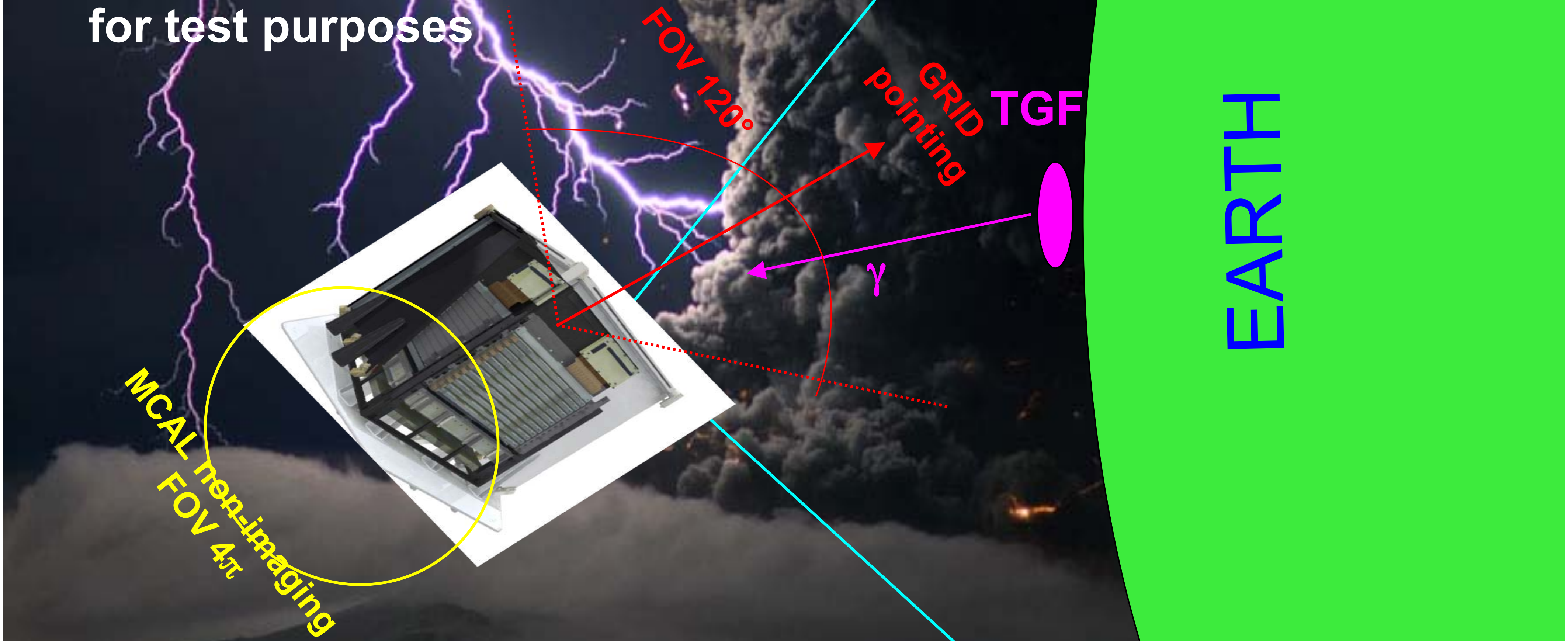
Imaging TGFs from space with AGILE GRID



Two ways to bypass it...

Imaging TGFs from space with AGILE GRID

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

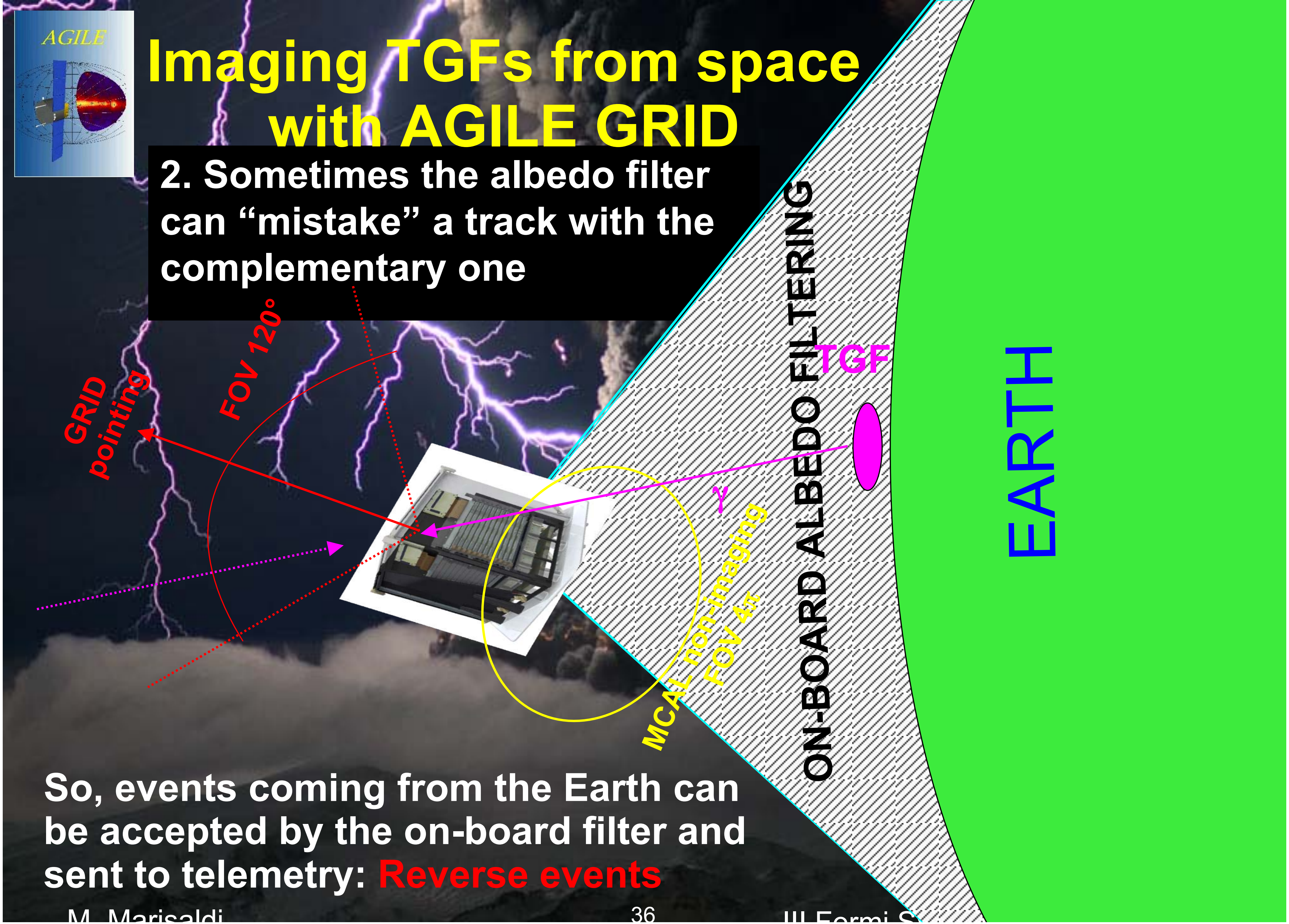


Forward events.

Cannot be default because of telemetry limitations

Imaging TGFs from space with AGILE GRID

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

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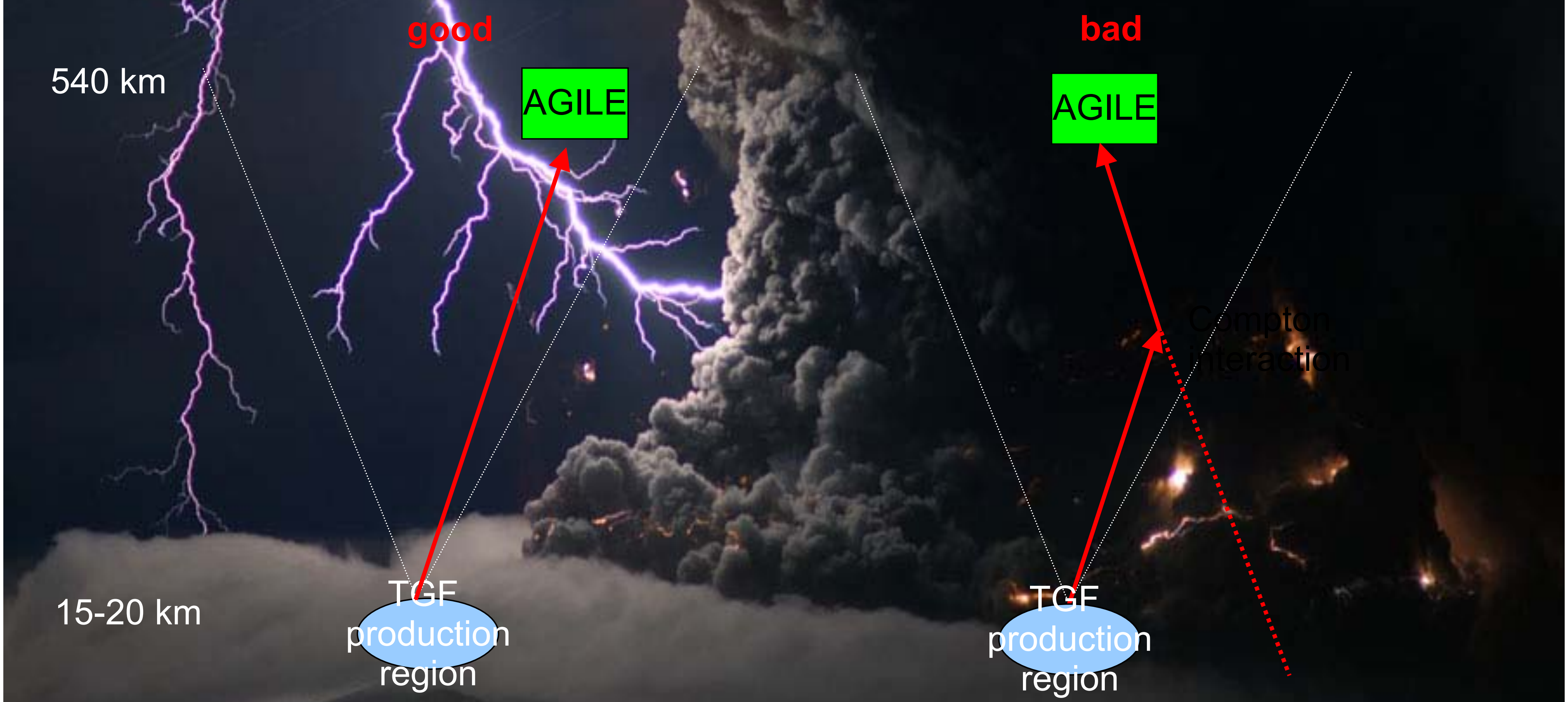
Do GRID photons come directly from the production region?



the incoming photon direction tracks the production region.

the incoming photon direction DOES NOT tracks the production region. No way to be aware of it. Is it probable???

Do GRID photons come directly from the production region?

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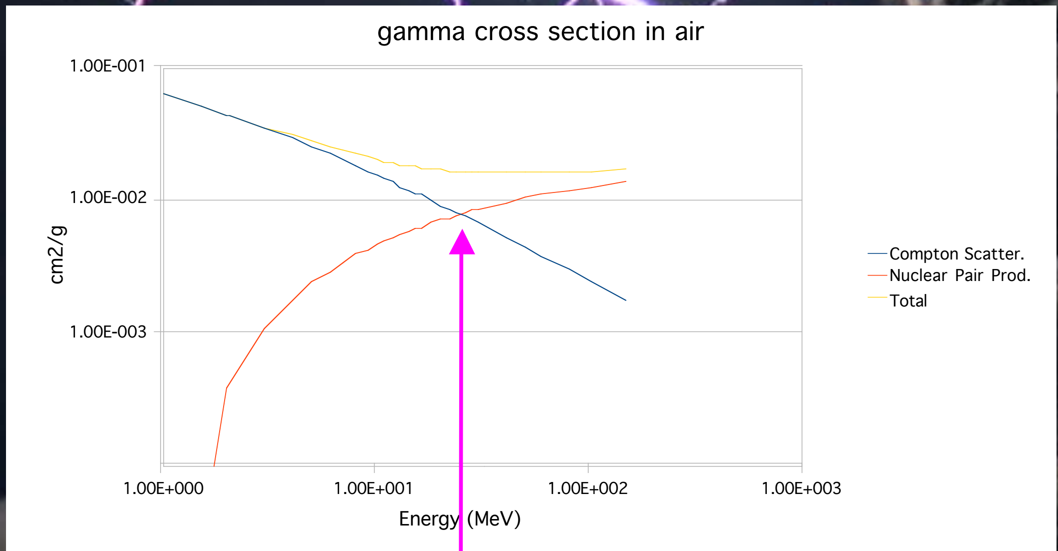
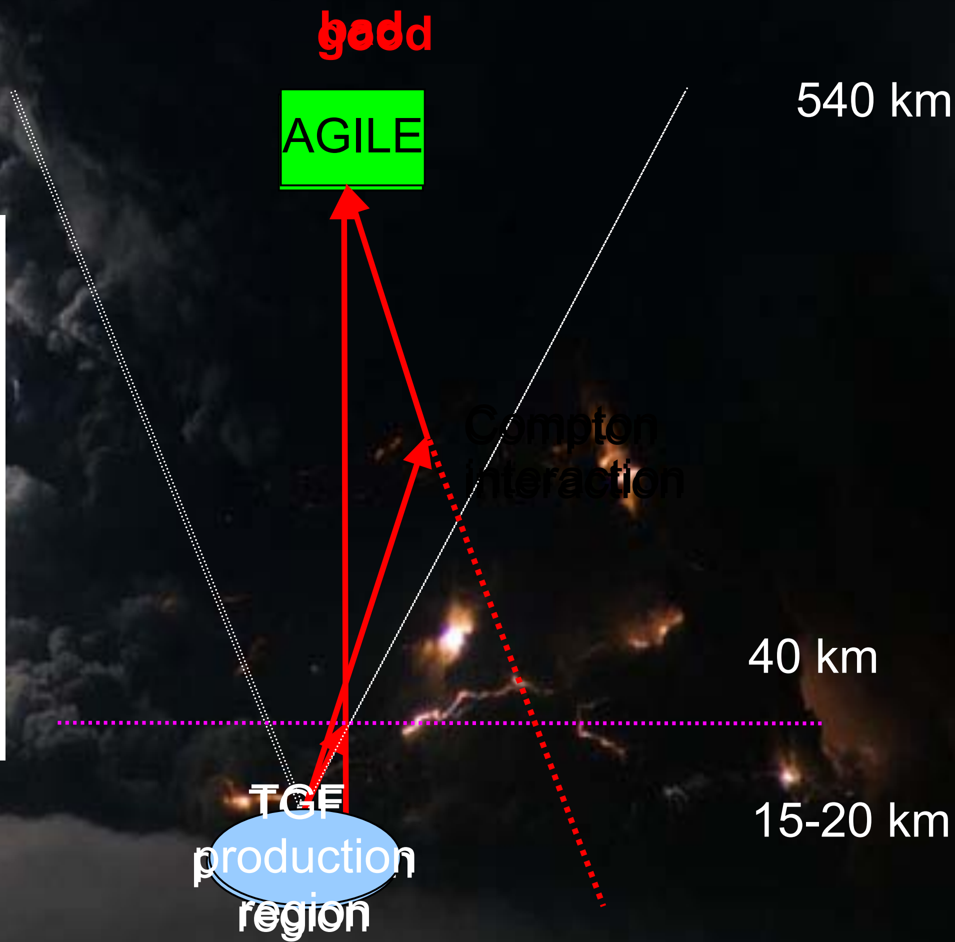


Compton and pair production cross section in air become equivalent at ~25MeV:
<u>Compton interaction for low-energy GRID events cannot be ignored</u>



<3% probability to scatter above 40 km: the GRID photon tracks the source within the angular resolution

Implications for production models

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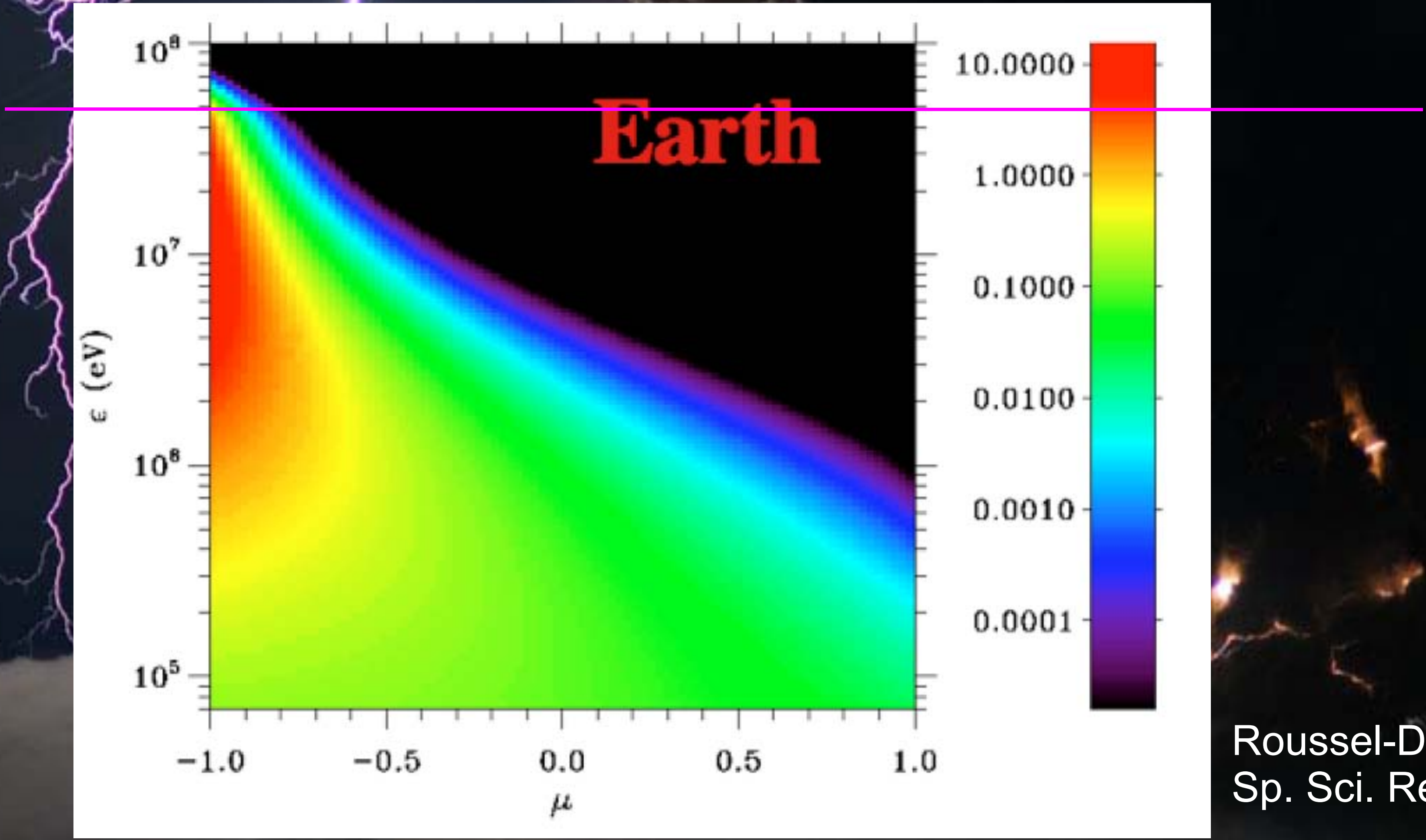

Roussel-Doupre et al.
Sp. Sci. Rev. 2009

High energy photons track well the electric field orientation at the source

A new tool to probe remotely the production site electric field