

IASF Bologna

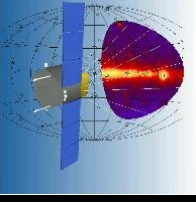
AGILE Observation of Terrestrial gamma-Ray Flashes

Martino Marisaldi (INAF-IASF Bologna)

on behalf of the AGILE Team

SciNeGHE 2010

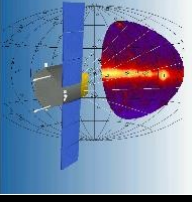
September 8-10 2010, Trieste



Outline

- TGF science: an overview
- AGILE-MCAL instrument and detection capabilities
- Characteristics of the AGILE TGF sample
- **NEW!** Localization of TGFs in space
- Conclusions

AGILE



Terrestrial Gamma-ray Flashes (TGF)

INAF



IASF Bologna

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)

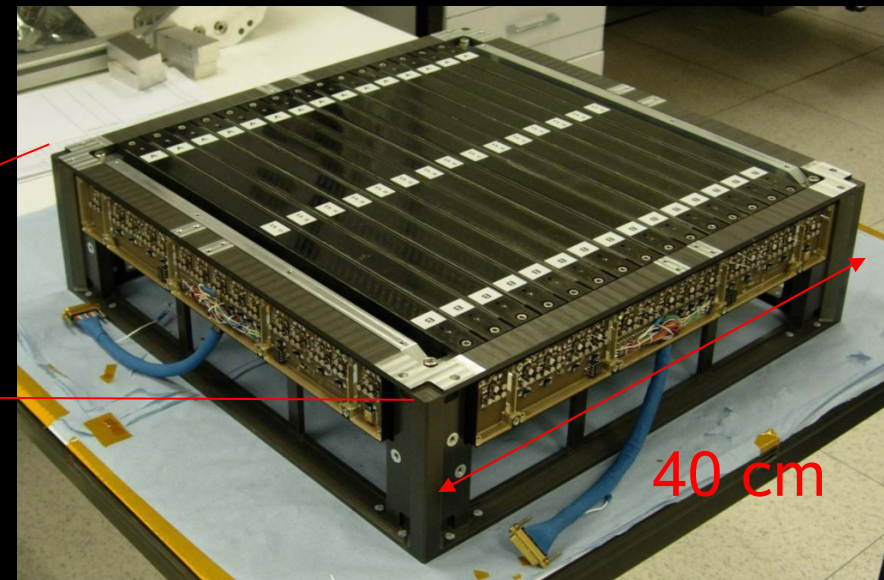
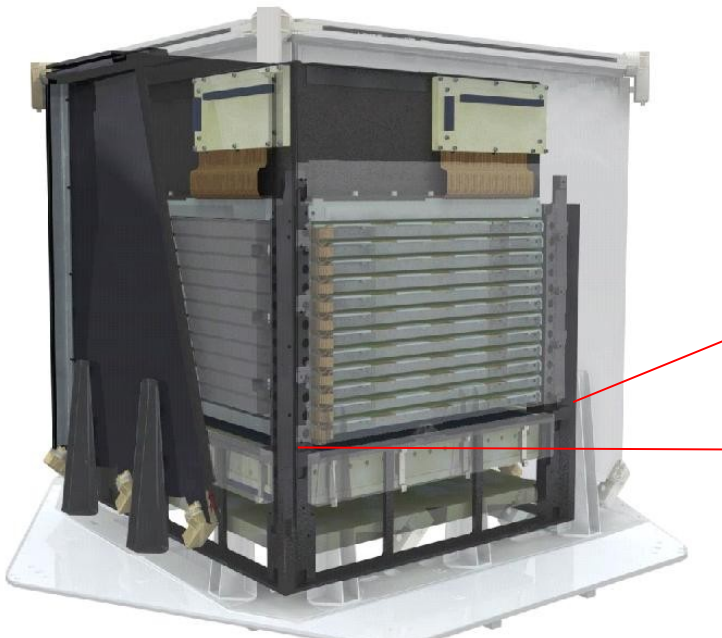
Clearly associated to lightning discharges during thunderstorms by means of correlation with VLF spheric waves detection on ground (Inan et al., GRL, 1996; Cummer et al., GRL, 2005)

>2008: Observed by AGILE and Fermi-GBM

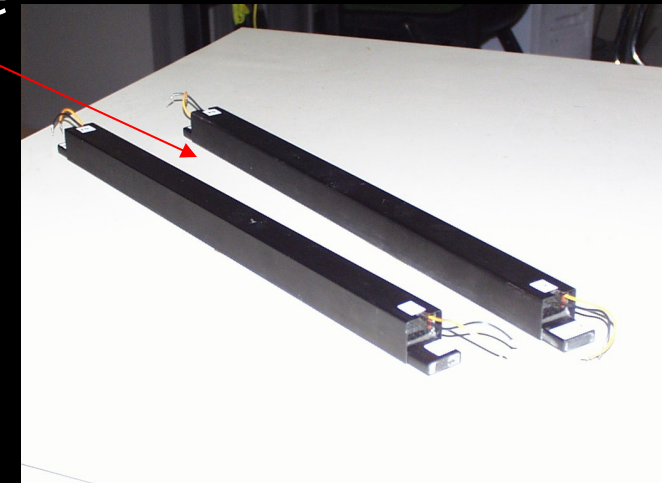
2009: AGILE reports energy up to 40MeV (Marisaldi et al., JGR 2010)

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

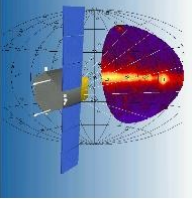
Challenging detection: timing and energy range are key issues



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



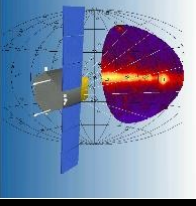
Labanti et al., NIM A (2009): instrument paper
 Fuschino et al., NIM A (2008): trigger logic
 Marisaldi et al., A&A (2008): GRB detections
 Marisaldi et al., JGR (2010): TGF detections



Why AGILE is good for TGF science?



- 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?

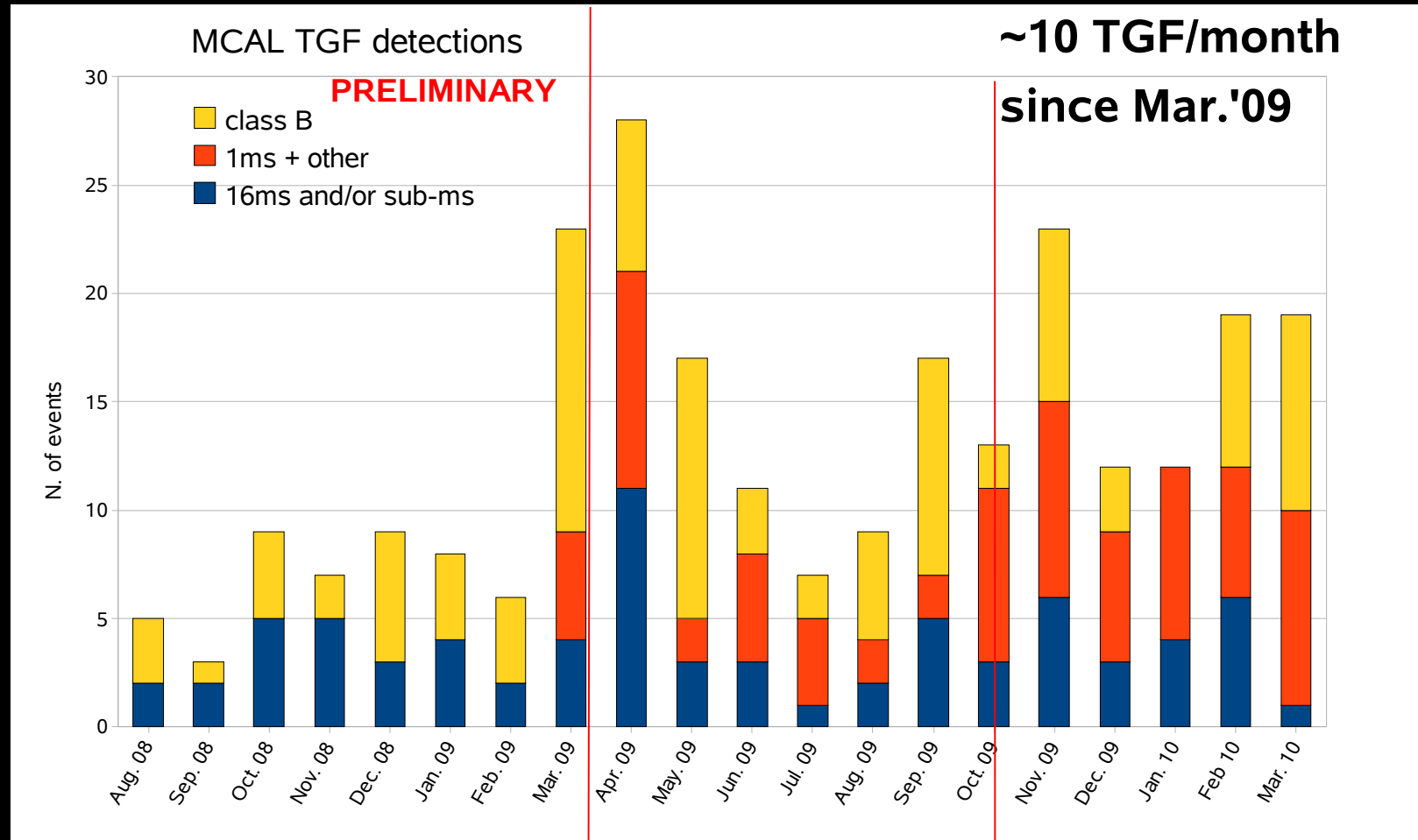


- **photon-by-photon data** download for triggered events with $2\mu\text{s}$ time resolution
- **$<100\mu\text{s}$ absolute timing accuracy**: mandatory for sferics correlation
- **AGILE orbit at 2.5° inclination** is optimal for mapping the equatorial region, where most of the events take place, with unprecedented exposure

MCAL TGF detection rate



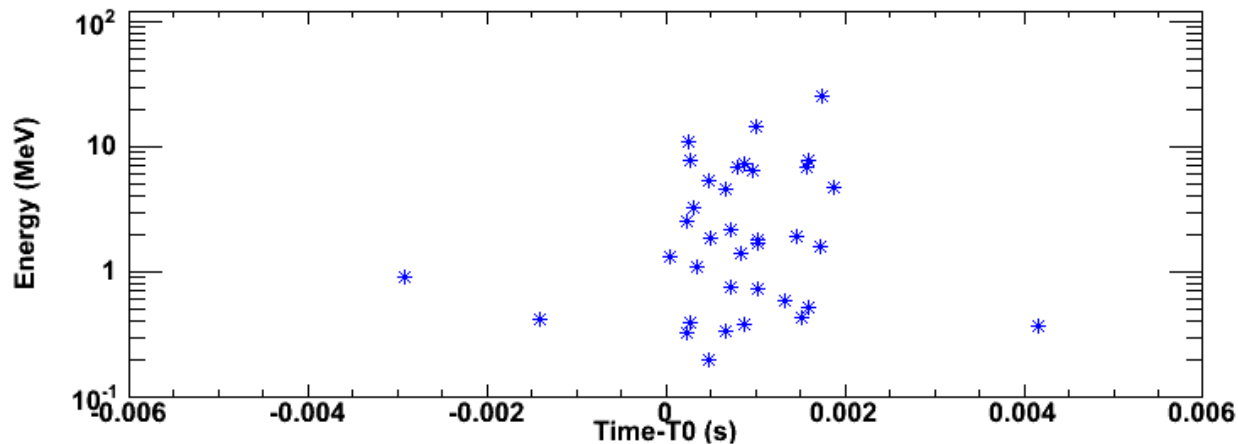
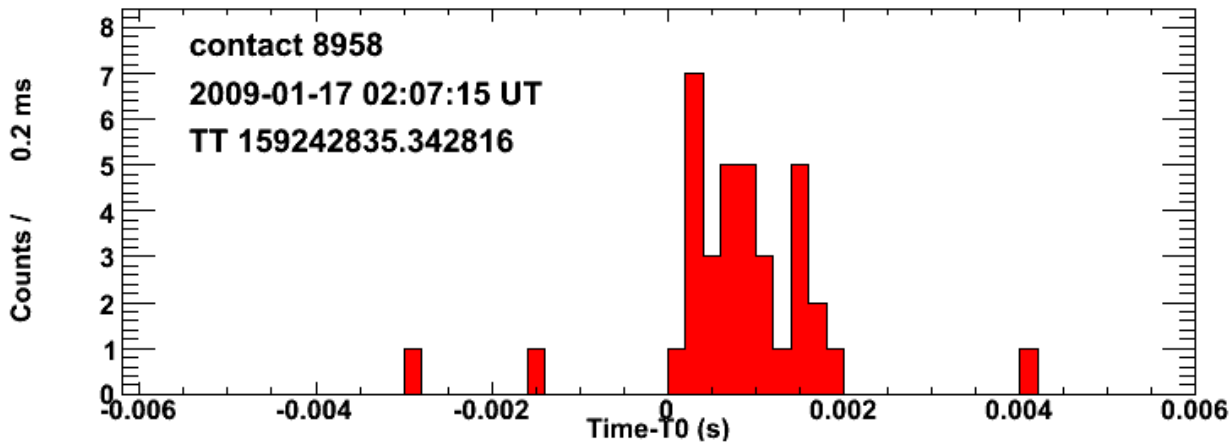
> 190 class A TGFs + ~130 class B TGFs since June 2008



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

After entering
Spinning mode

The AGILE TGF sample



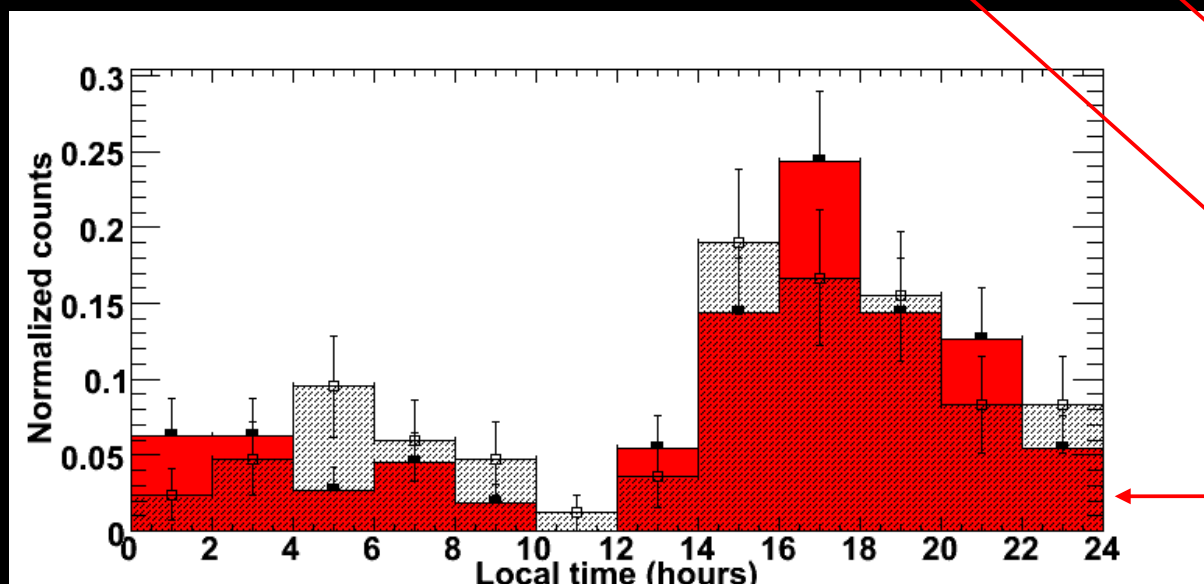
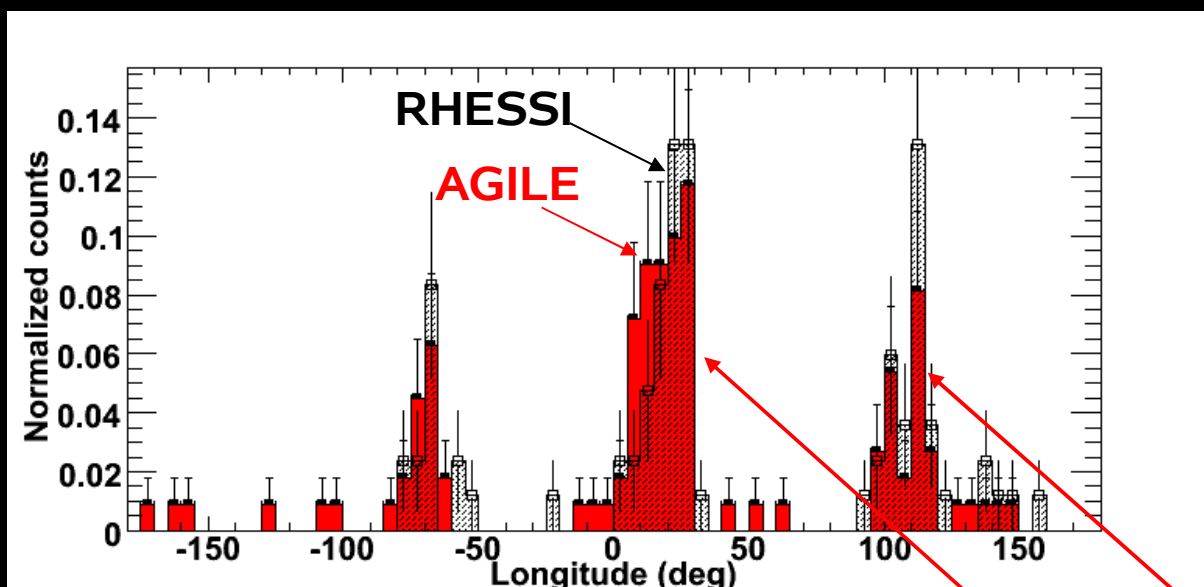
Average properties:

Number of counts =
17.3 +/- 6.4

Duration =
(1.7 +/- 0.9) ms

Energy =
(4.0 +/- 1.7) MeV

AGILE vs RHESSI: longitude and local time



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

selected RHESSI TGFs in
a $\pm 2.5^\circ$ latitude belt
(like AGILE orbit) $T_0 < 1^{\text{st}}$
Jan. 2006: 84 TGFs

**Longitude and local time
distributions are
compatible**

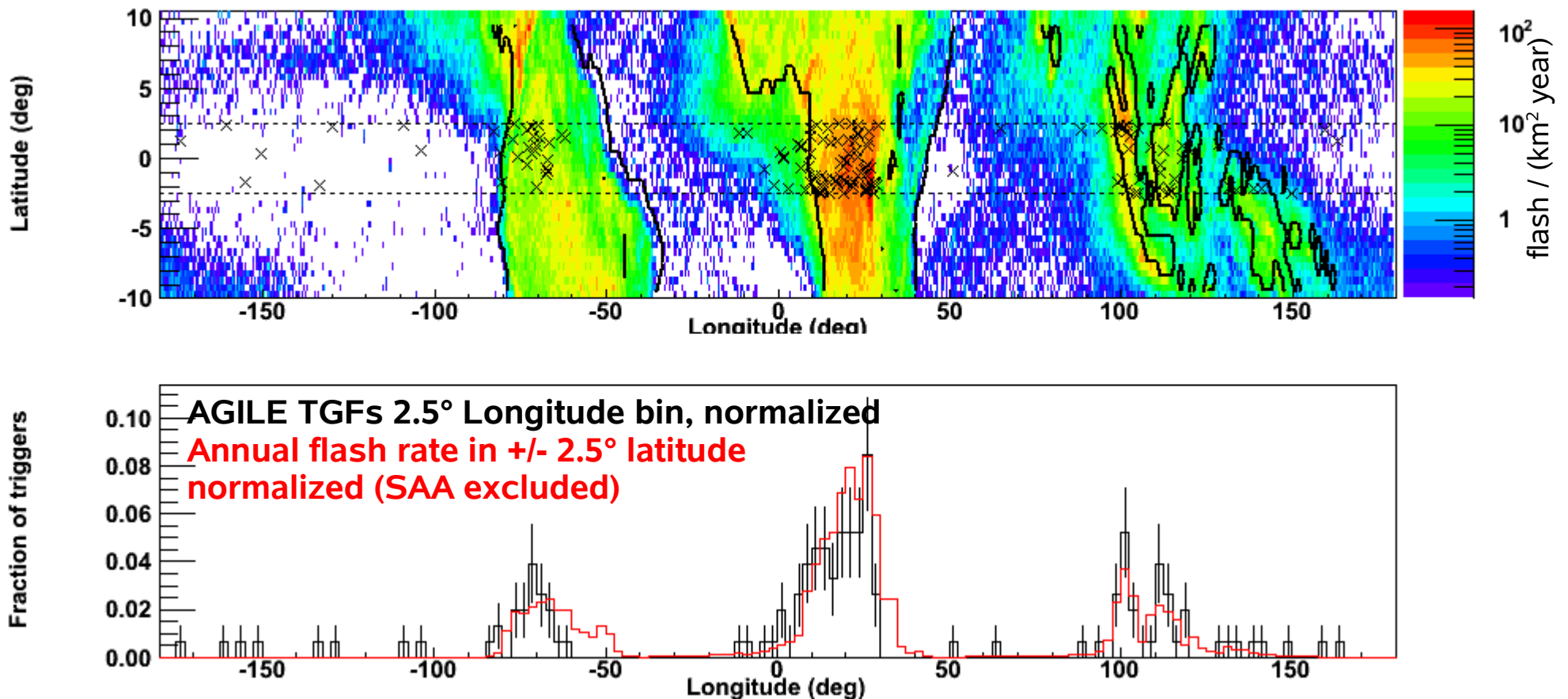
**double peaked feature
on South East Asia**

sharp cut on western Africa

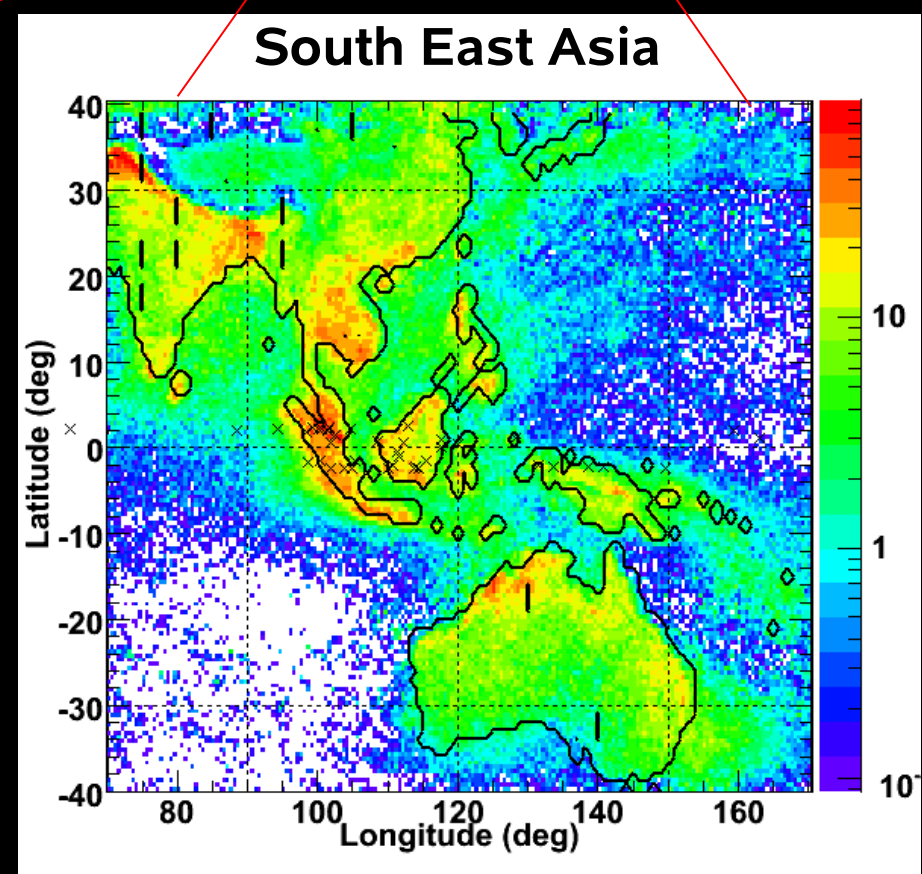
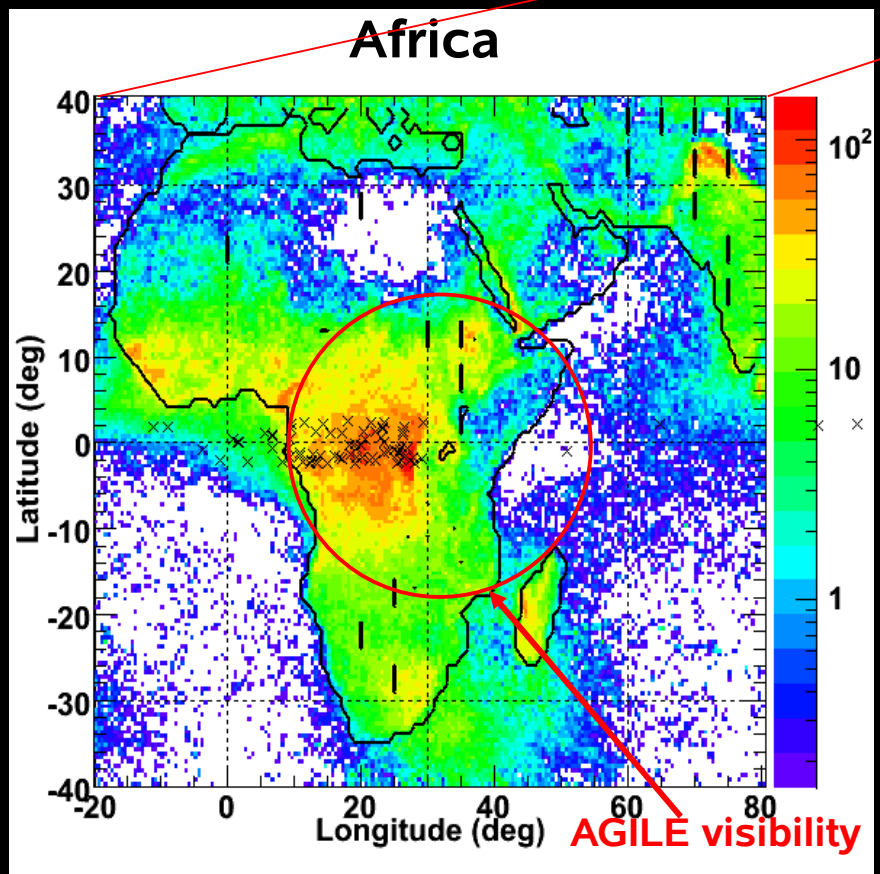
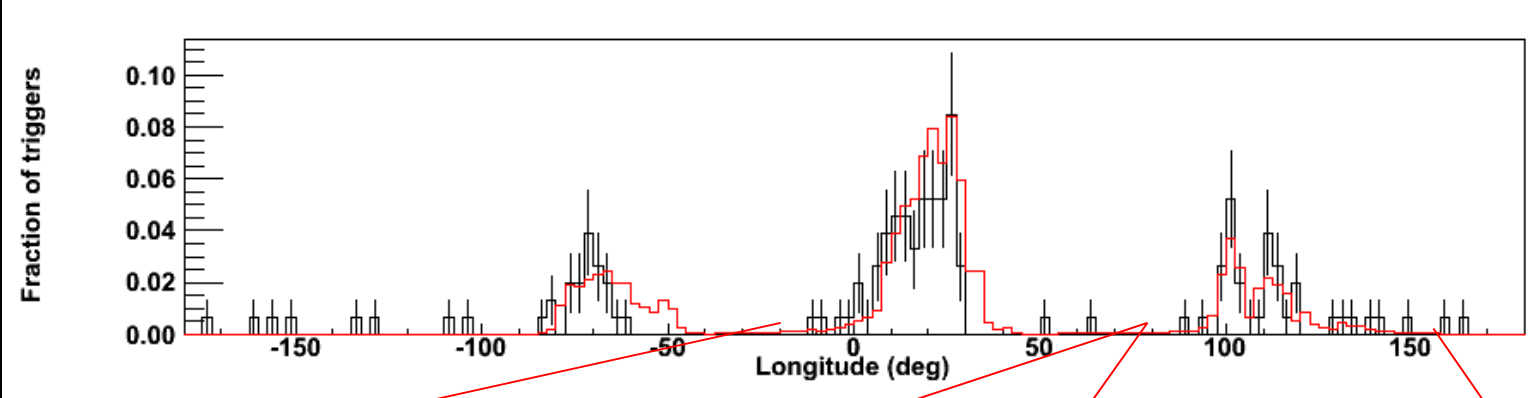
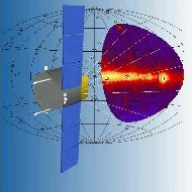
**late afternoon
occurrence peak**



TGFs and Lightnings



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

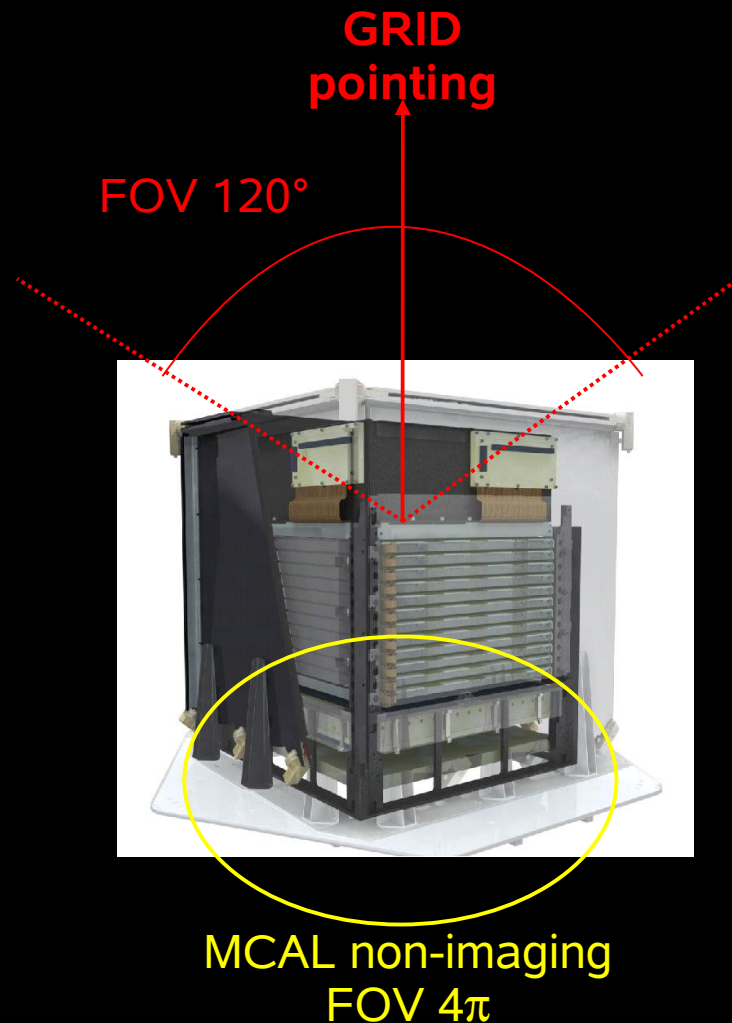


cluster over western Africa

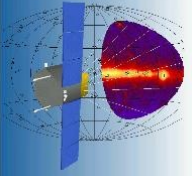
cluster over Sumatra and the Borneo

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

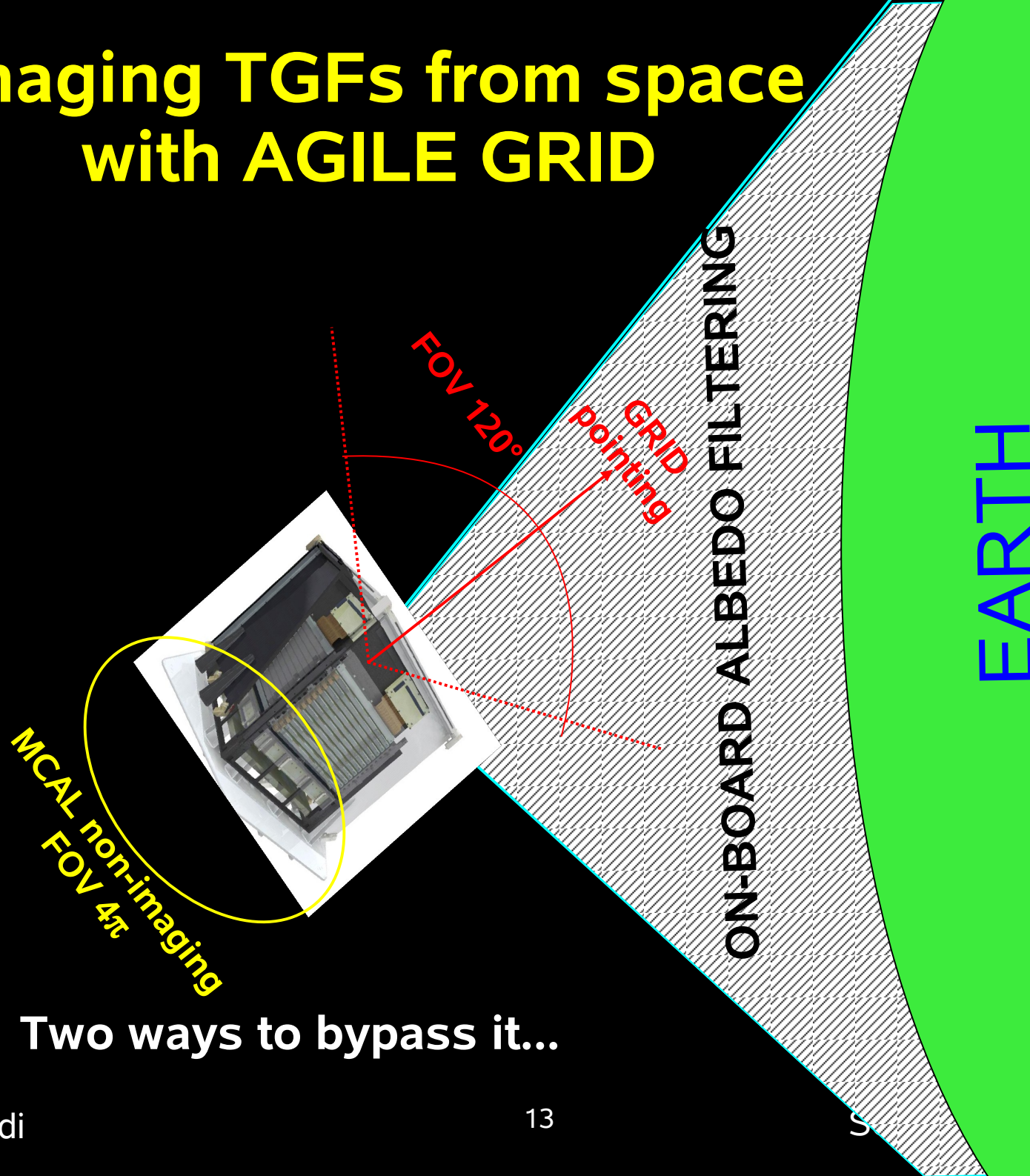
Imaging TGFs from space?



- 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



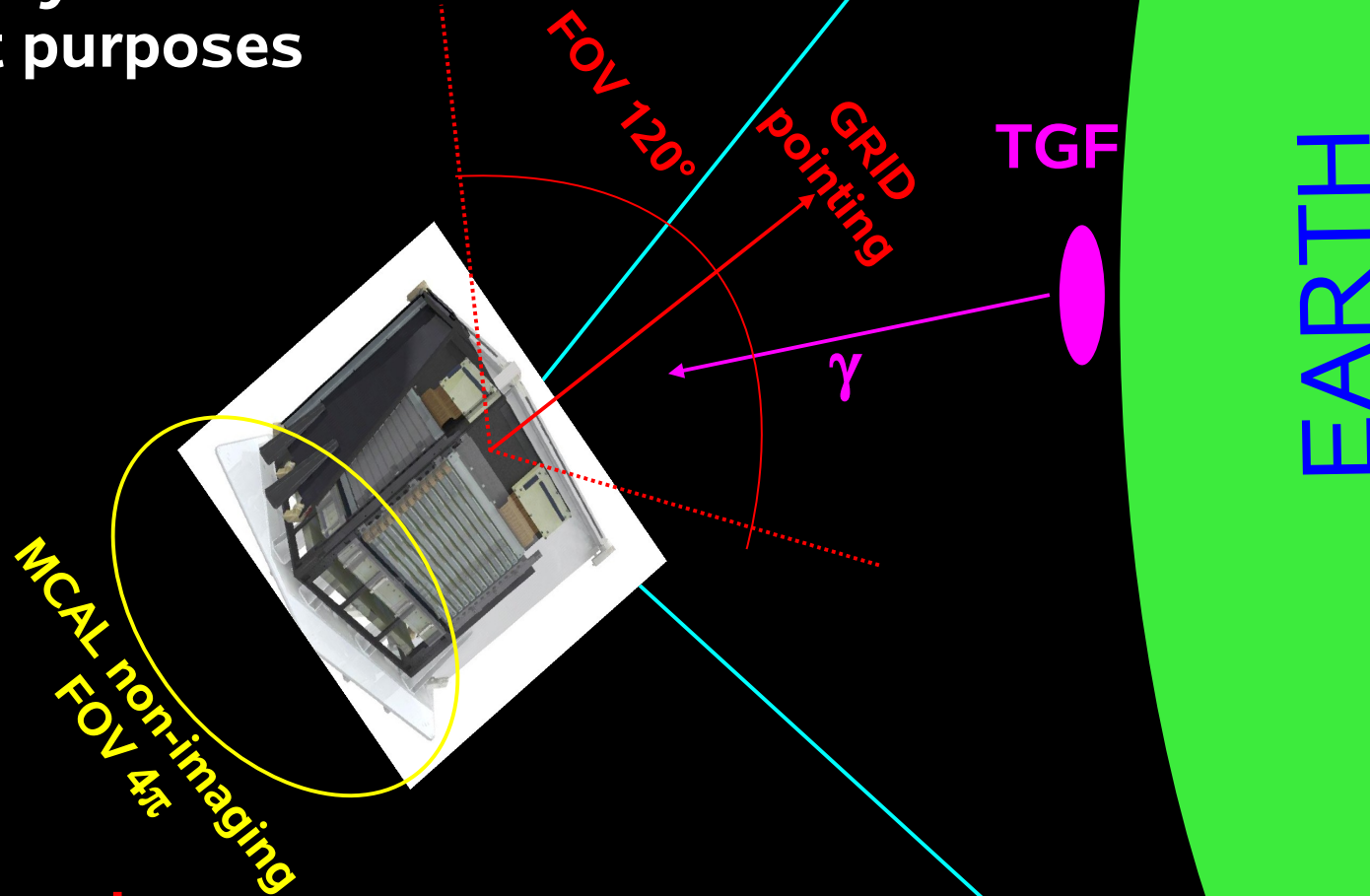
Imaging TGFs from space with AGILE GRID



Two ways to bypass it...

Imaging TGFs from space with AGILE GRID

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

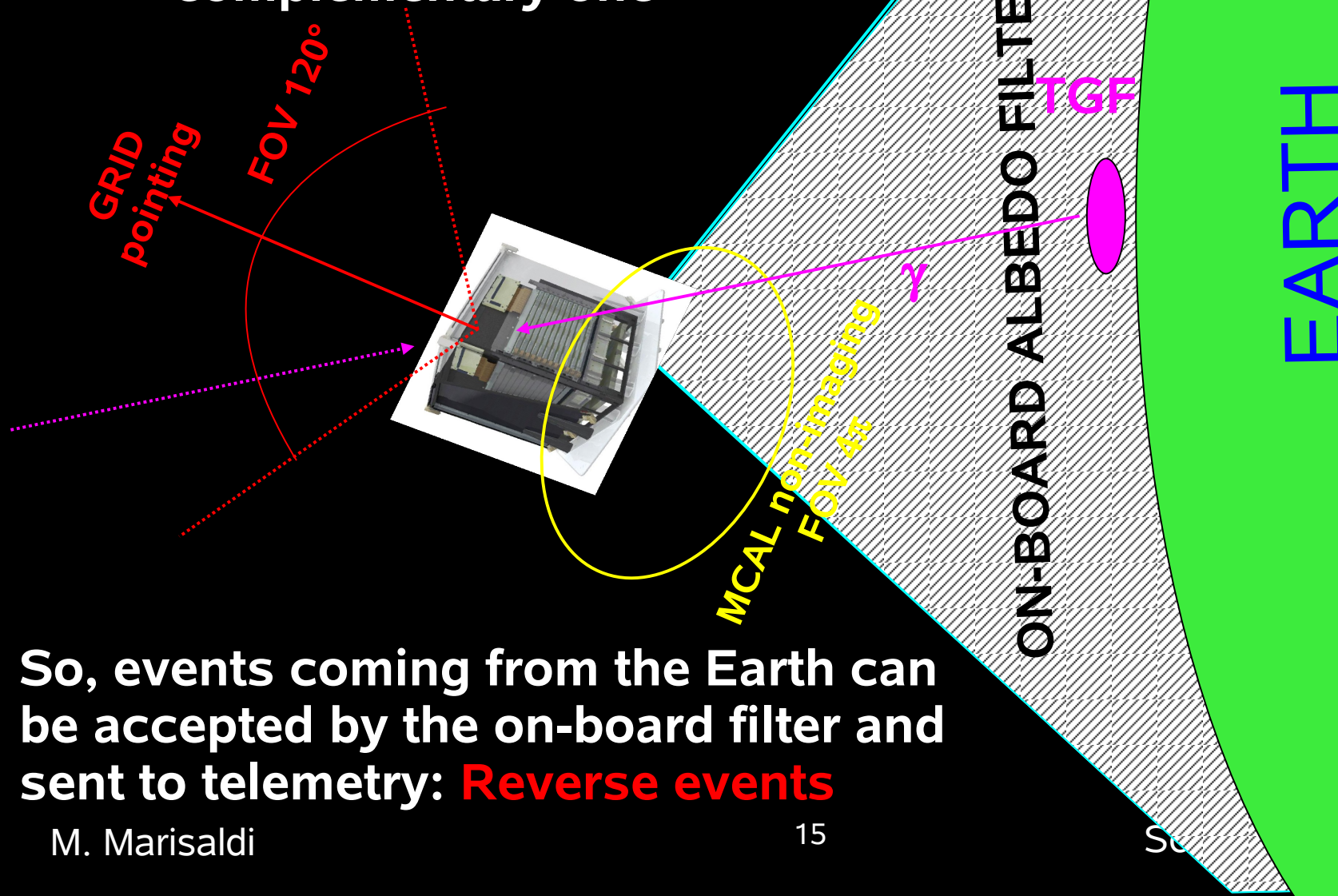


Forward events.

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

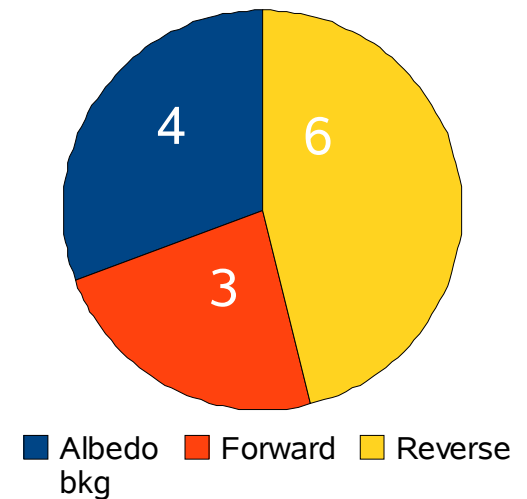
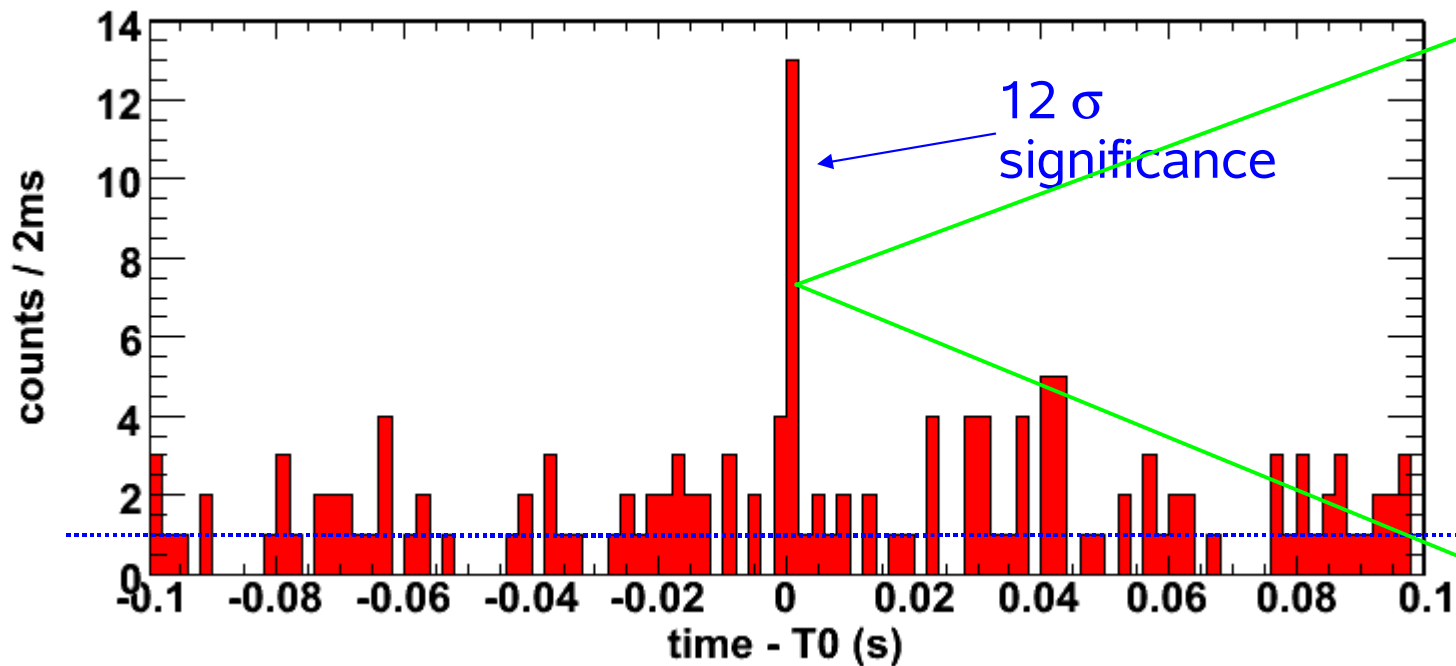


So, events coming from the Earth can be accepted by the on-board filter and sent to telemetry: **Reverse events**

GRID events vs MCAL TGFs

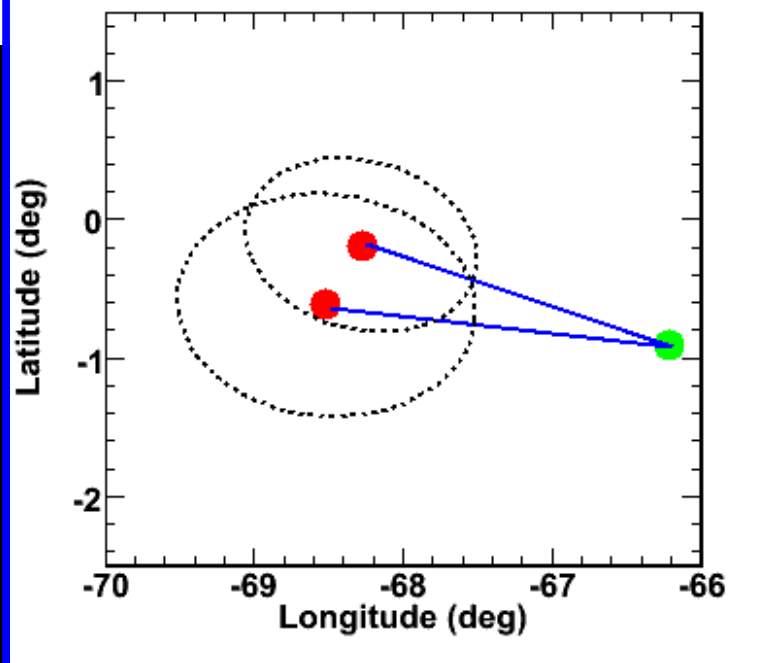
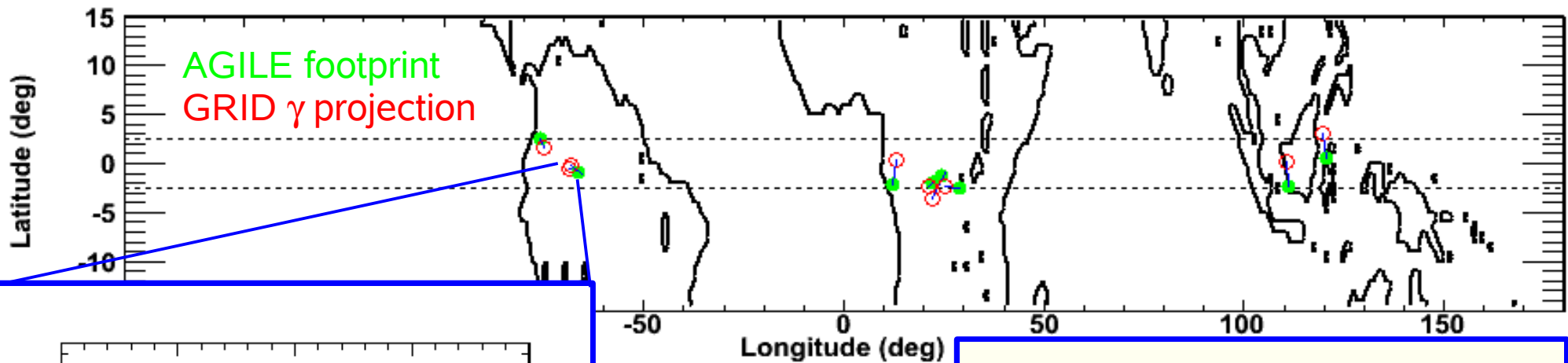


Search for GRID events in temporal coincidence with 119 MCAL TGFs detected between Jun. 2008 – Dec. 2009

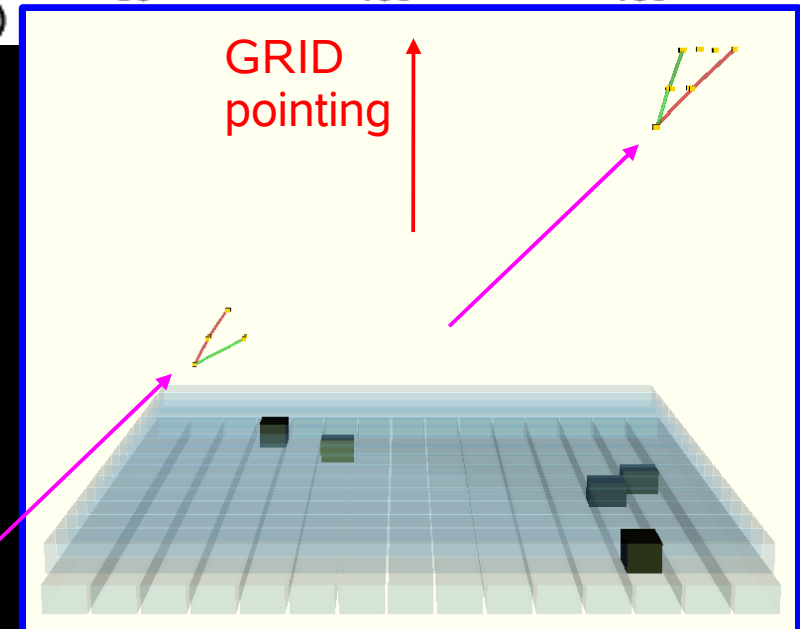


13 GRID events within 2 ms from TGFs T0!

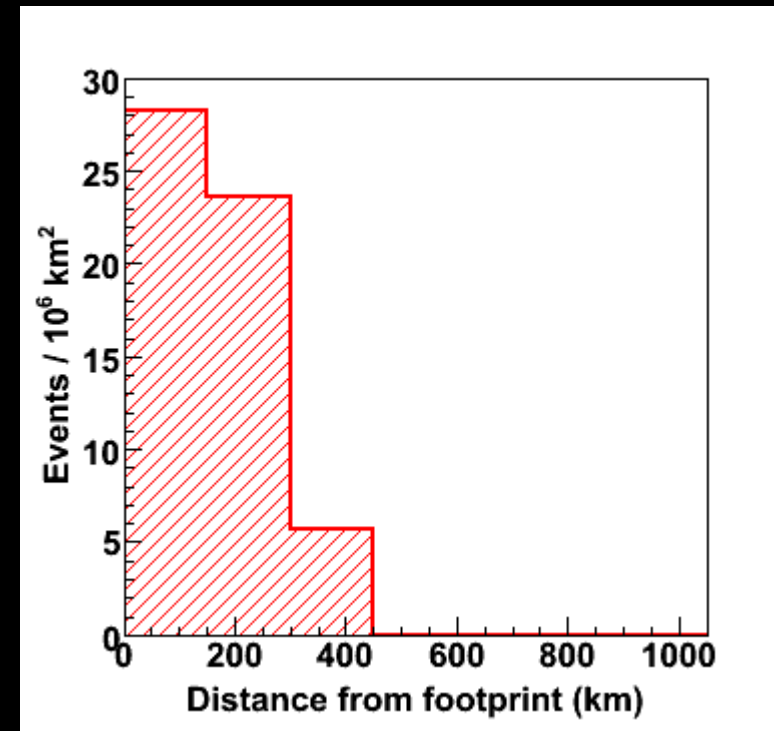
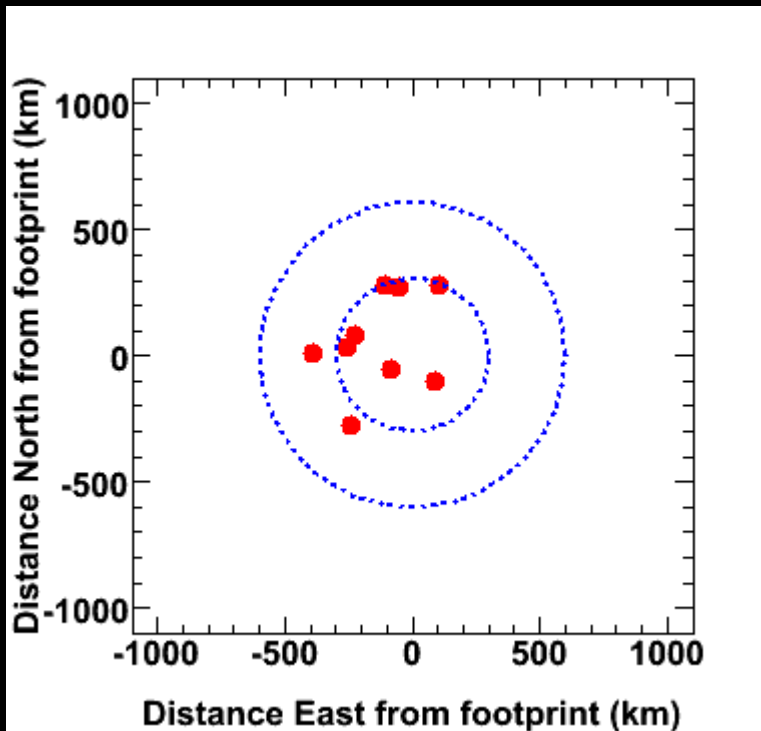
Geographical distribution



Reverse event
direction
(TGF source)



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 accepted for publication by Phys. Rev. Letters, in press



Do GRID photons come directly from the production region?

good

540 km

AGILE

15-20 km

TGF
production
region

the incoming photon direction tracks the production region.

bad

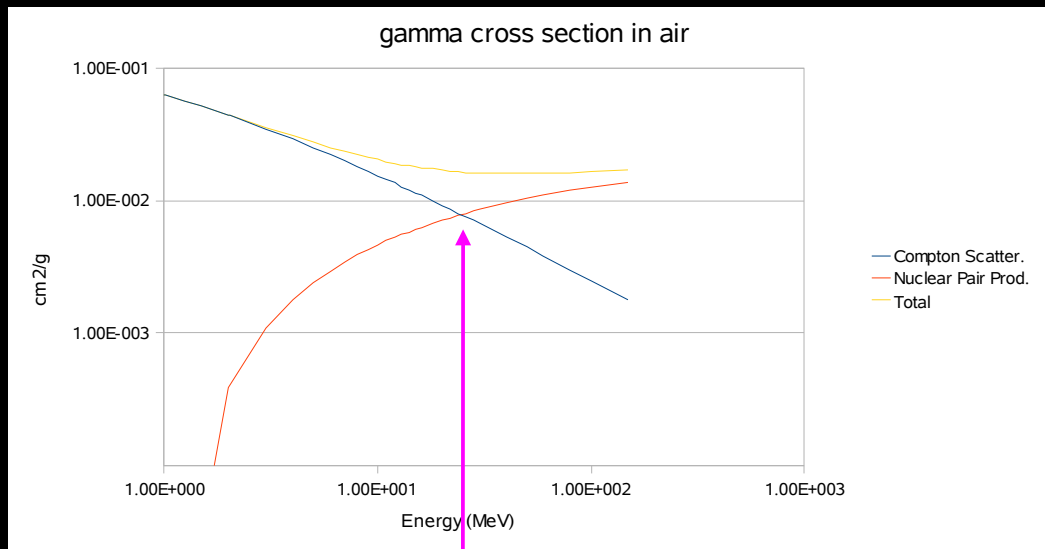
AGILE

TGF
production
region

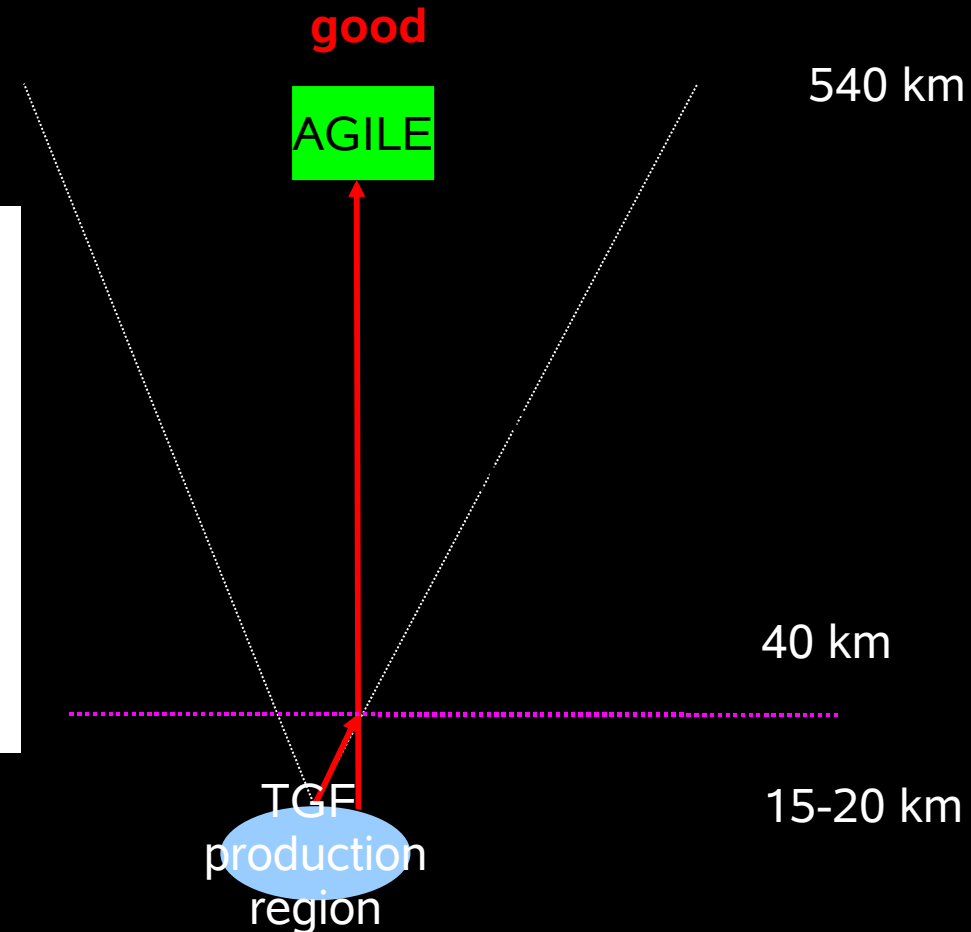
the incoming photon direction DOES NOT track the production region. No way to be aware of it. Is it probable???



Do GRID photons come directly from the production region?

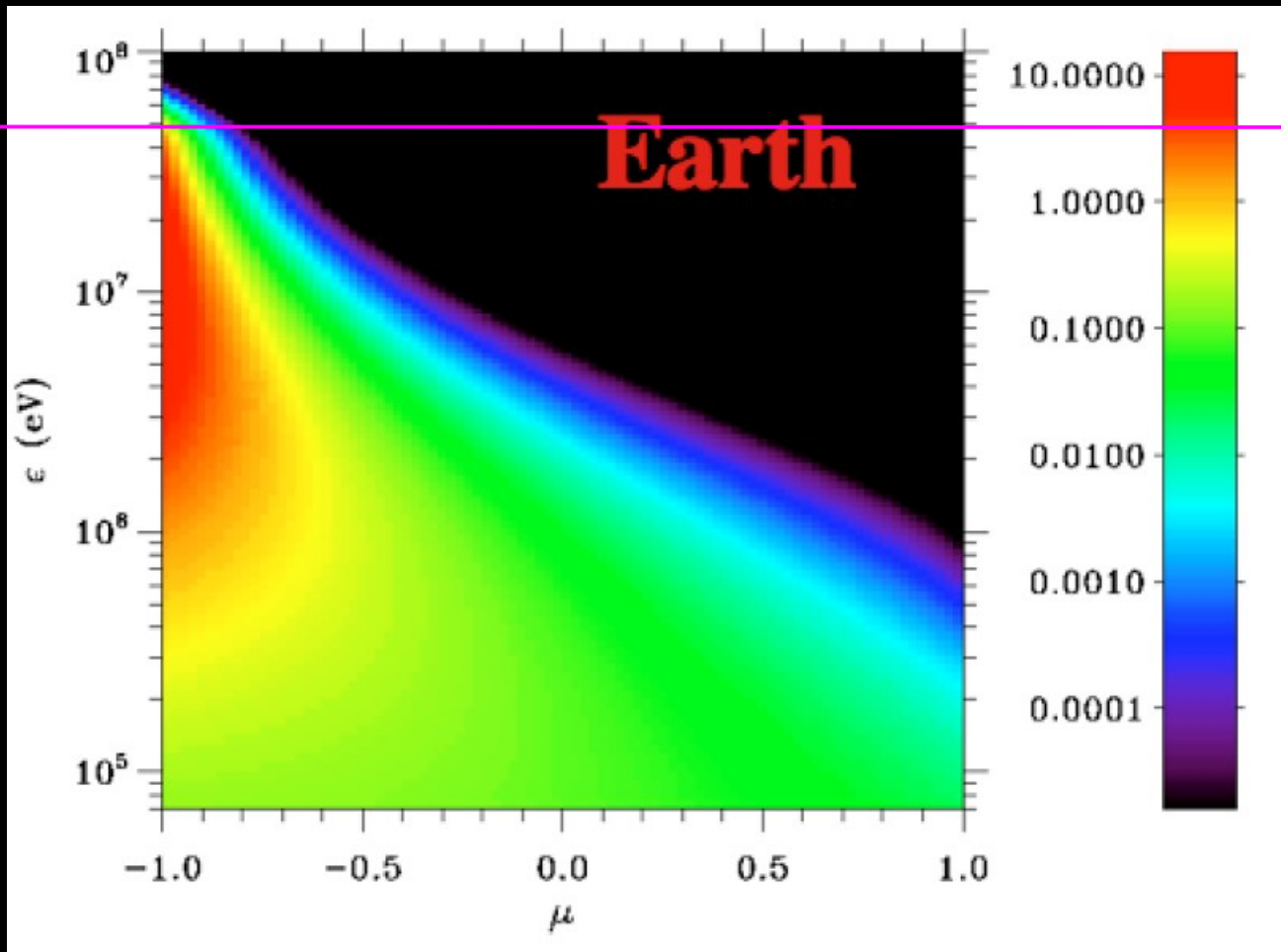
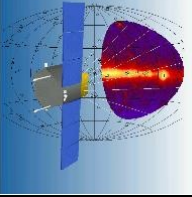


Compton and pair production cross section in air become equivalent at ~25MeV:
Compton interaction for low-energy GRID events cannot be ignored



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

Implications for production models



50 MeV

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



Conclusions

- **AGILE is an important instrument for TGF science:**
 - the only one with energy range extended up to 100 MeV
 - the only one with <1 ms trigger logic
 - photon-by-photon with μ s timing
 - \sim equatorial orbit
- **AGILE detects ~ 10 TGFs / month with current selection criteria. Rate can be almost doubled with improved selections**
- **Cumulative spectrum with significant detection above 40 MeV: challenge for production models**
- **First TGFs localized in space by means of the AGILE gamma-ray imager. Work in progress: improve the detections, implications for production models**