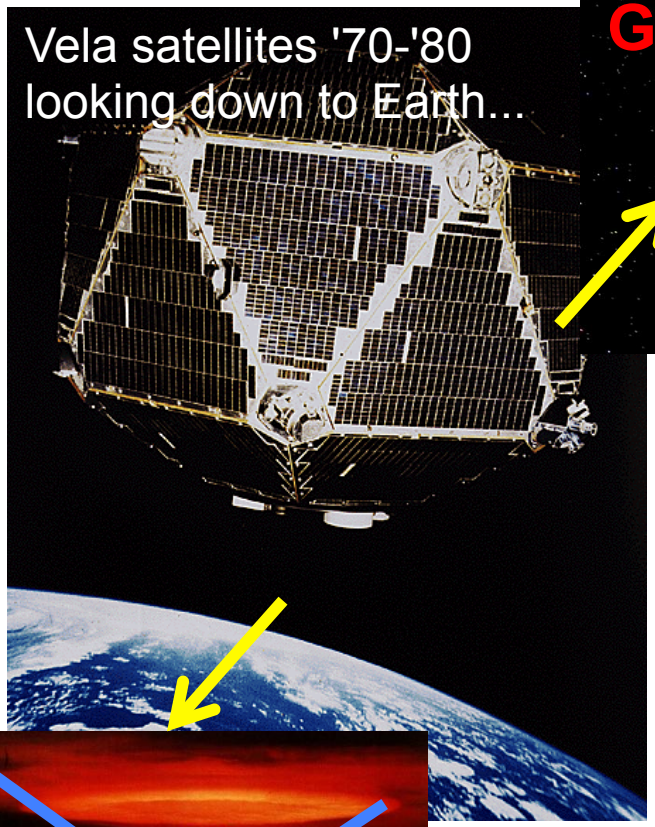
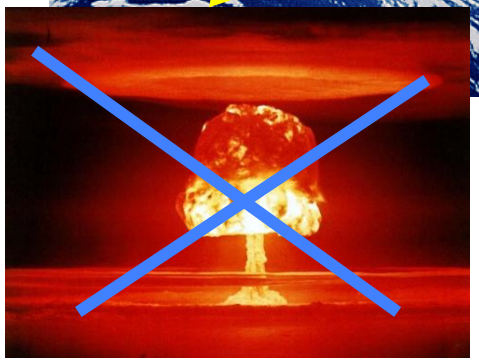
Terrestrial Gamma-ray Flashes Studies with AGILE

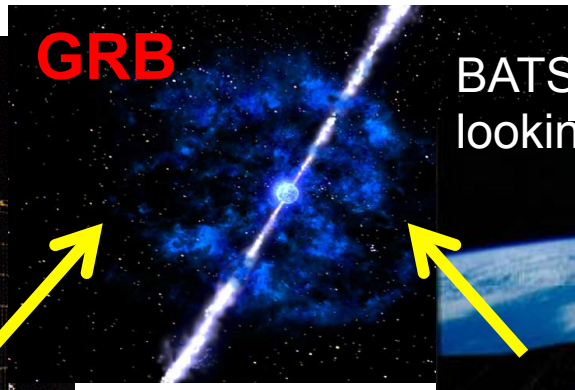
Martino Marisaldi (INAF – IASF Bologna)
on behalf of the AGILE Team

Serendipity at play

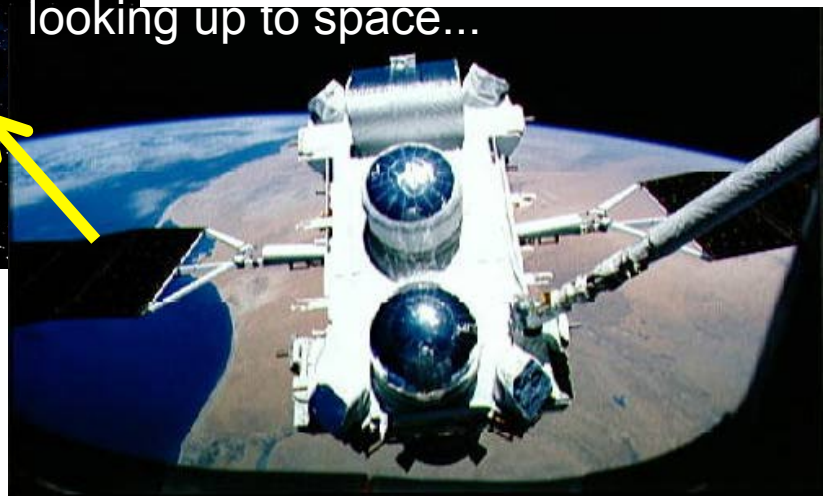
Vela satellites '70-'80
looking down to Earth...

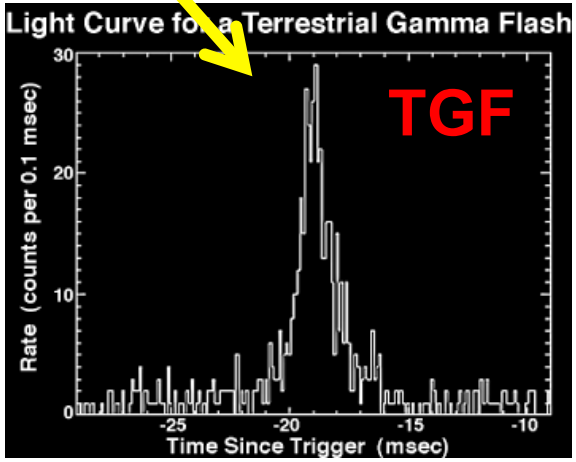




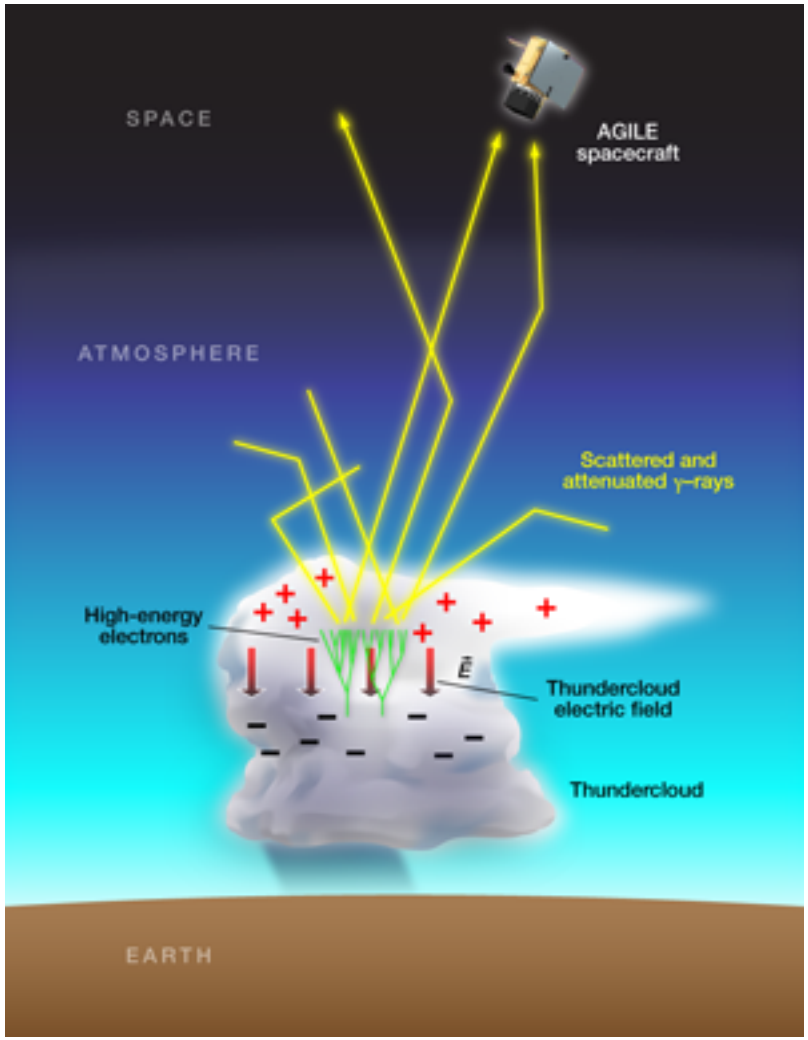


BATS
looking up to space...



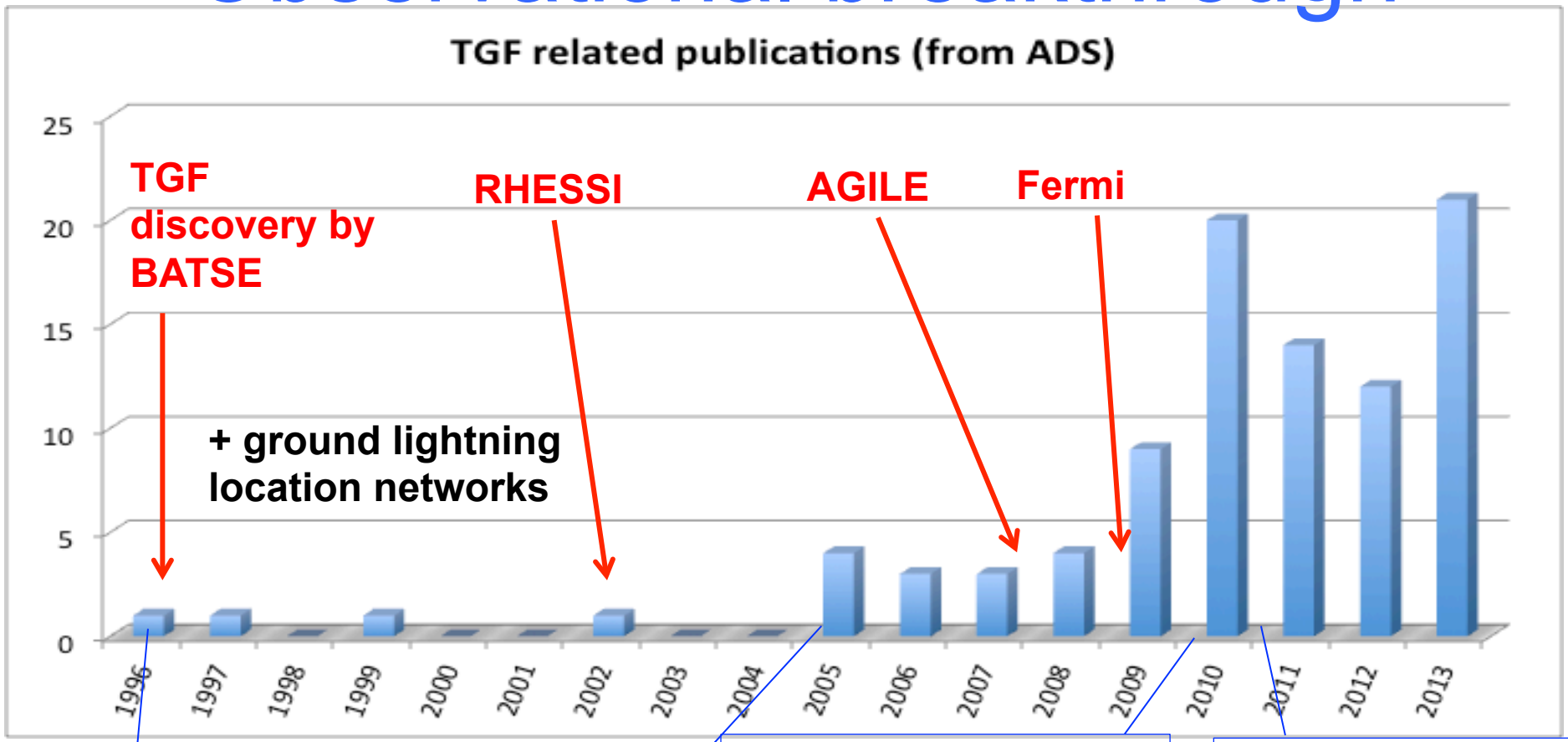


Terrestrial Gamma-ray Flashes



Credit: Alan Stonebraker

Observational breakthrough



Association to lightning

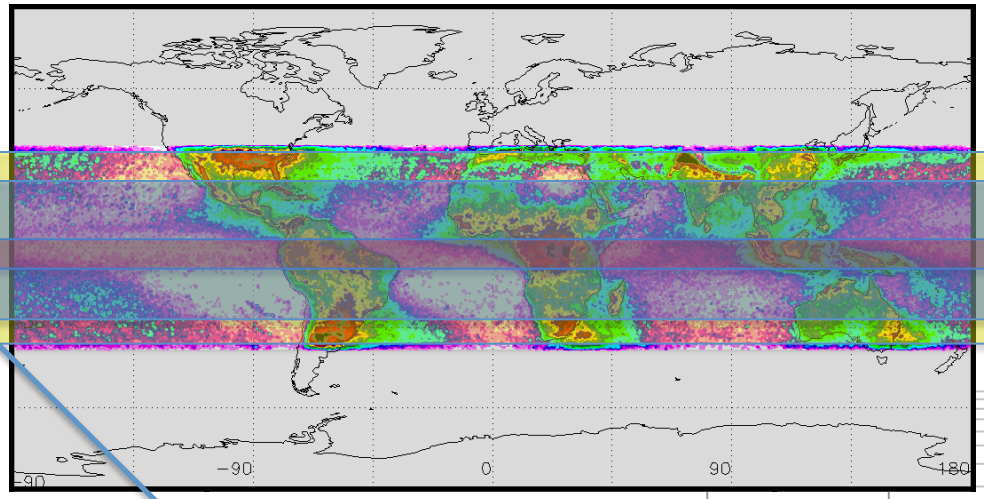
- Cumulative spectrum
- Energy up to 20 MeV
- production altitude < 20km

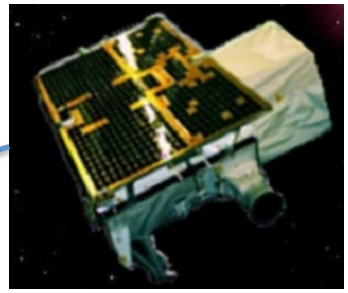
- Energy > 40 MeV up to ~ 100 MeV
- First localization in γ-rays from space
- TGF & global lightning activity
- 1st AGILE catalog

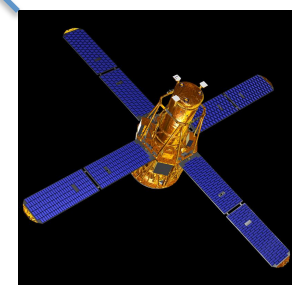
New!

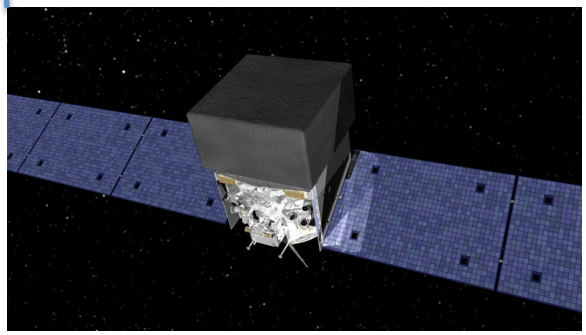
- Discovery of e^+/e^- flashes
- Radio emission from TGFs
- Improved selection

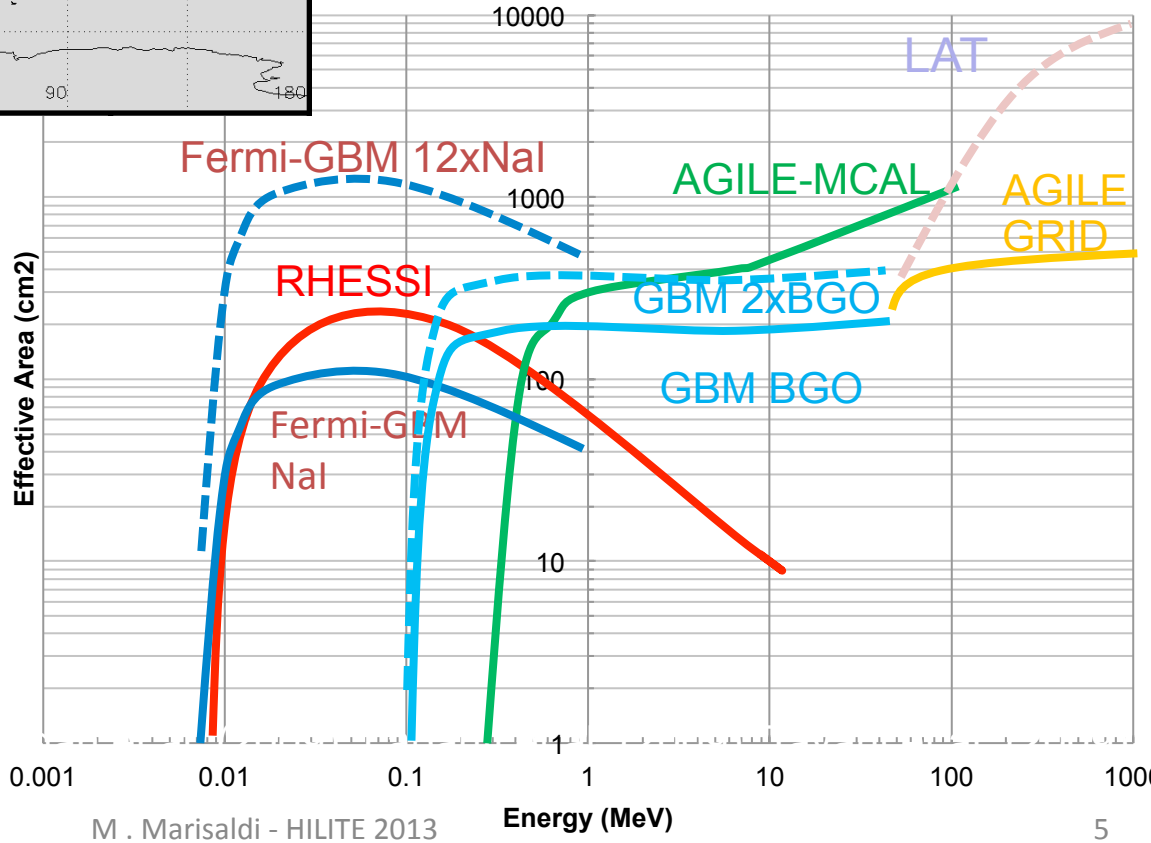
Operating TGF detectors



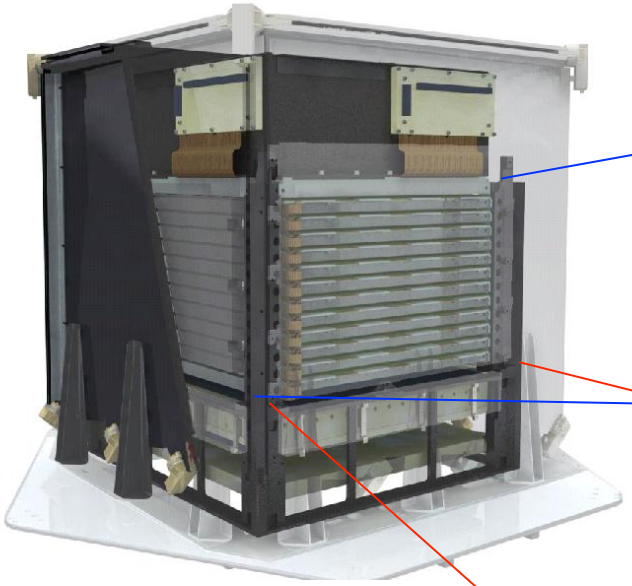


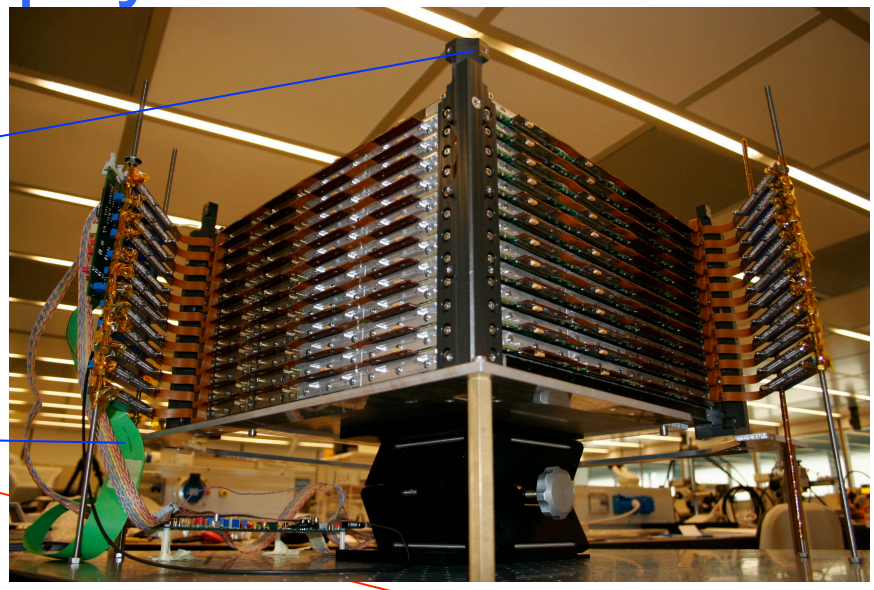






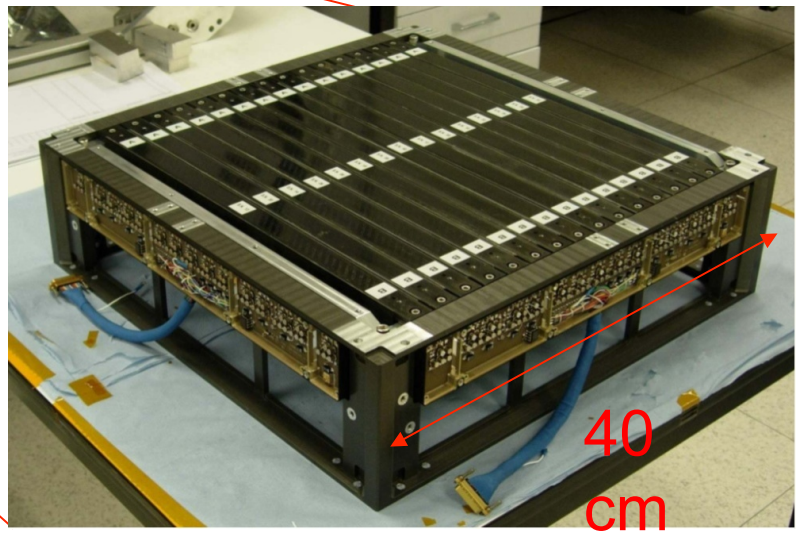
The AGILE payload



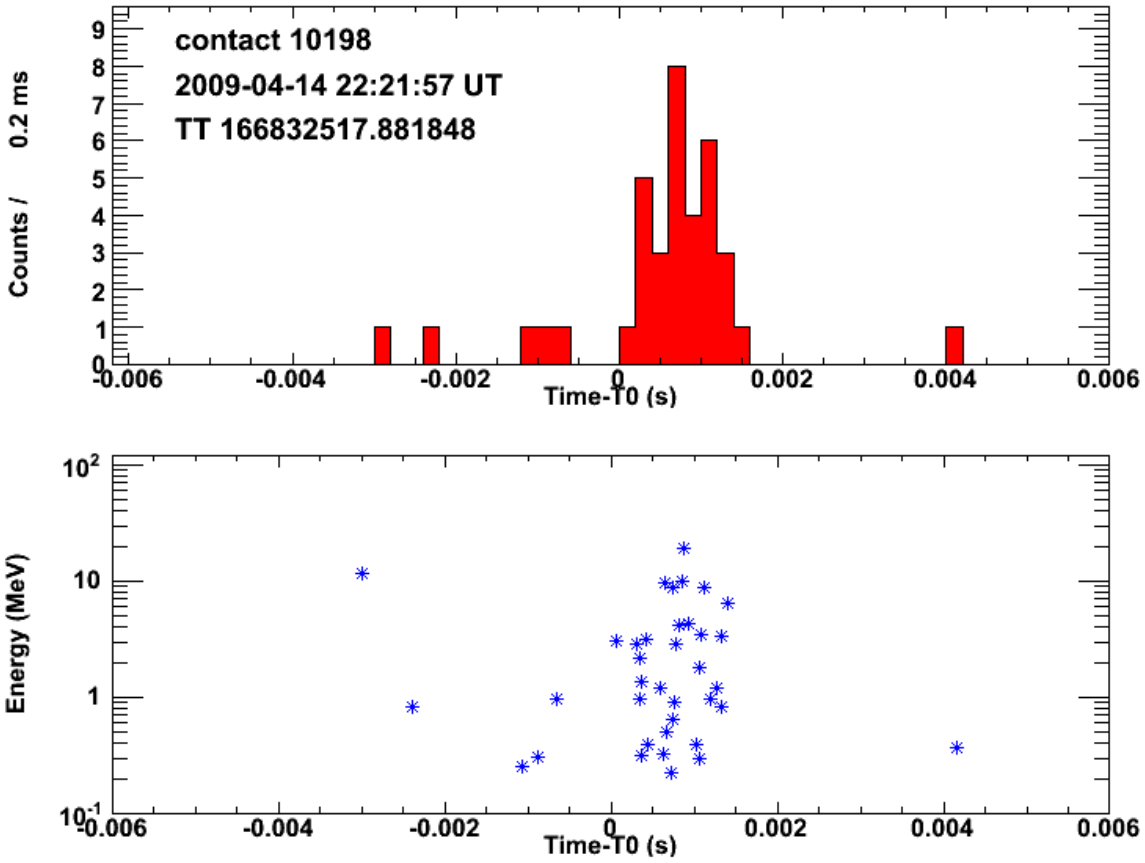


MCAL:

- 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 16ms, 1ms and 300μs**



The 2009 AGILE TGF sample



Average properties:

Number of counts =

17 +/- 5

Duration =

(1.5 +/- 0.8) ms

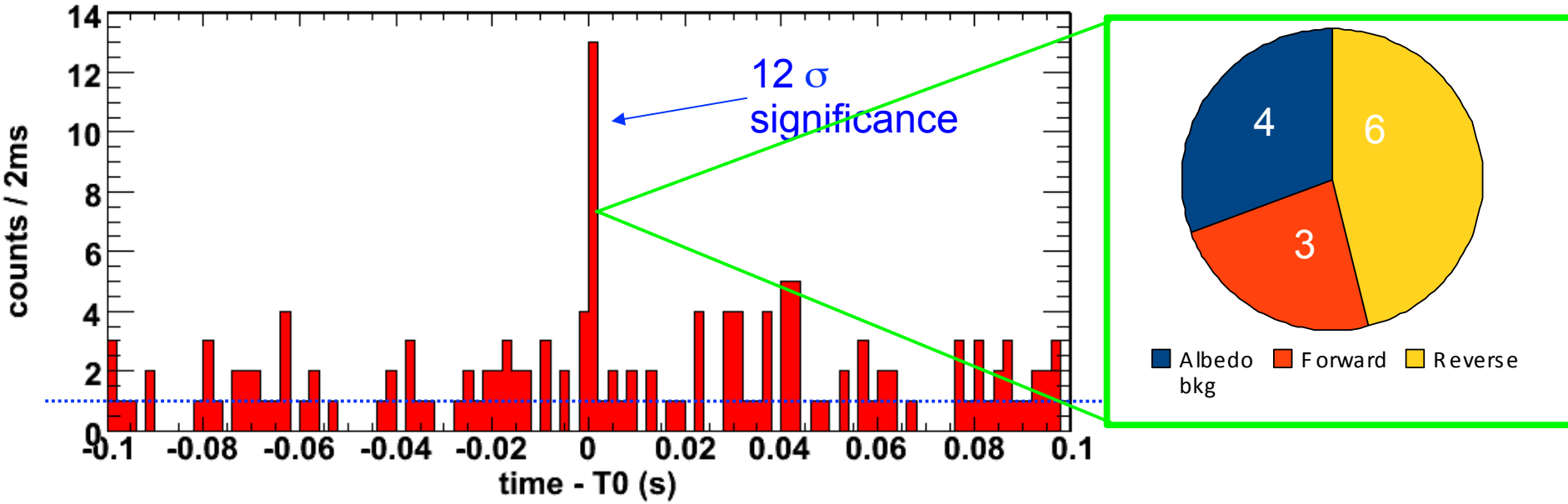
Energy =

(4.0 +/- 1.4) MeV

Marisaldi et al., JGR, 2010

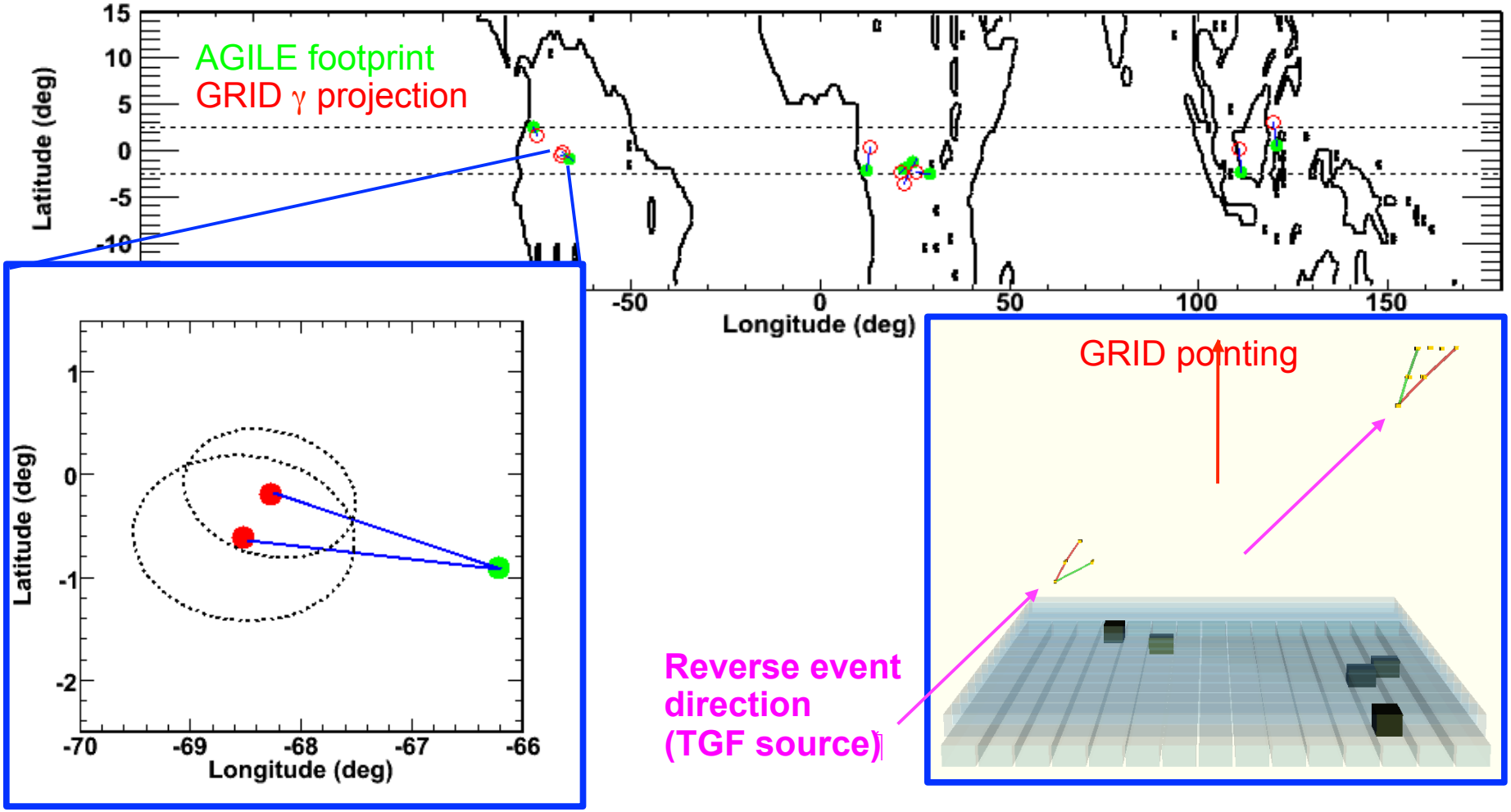
Imaging TGFs in gamma rays

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

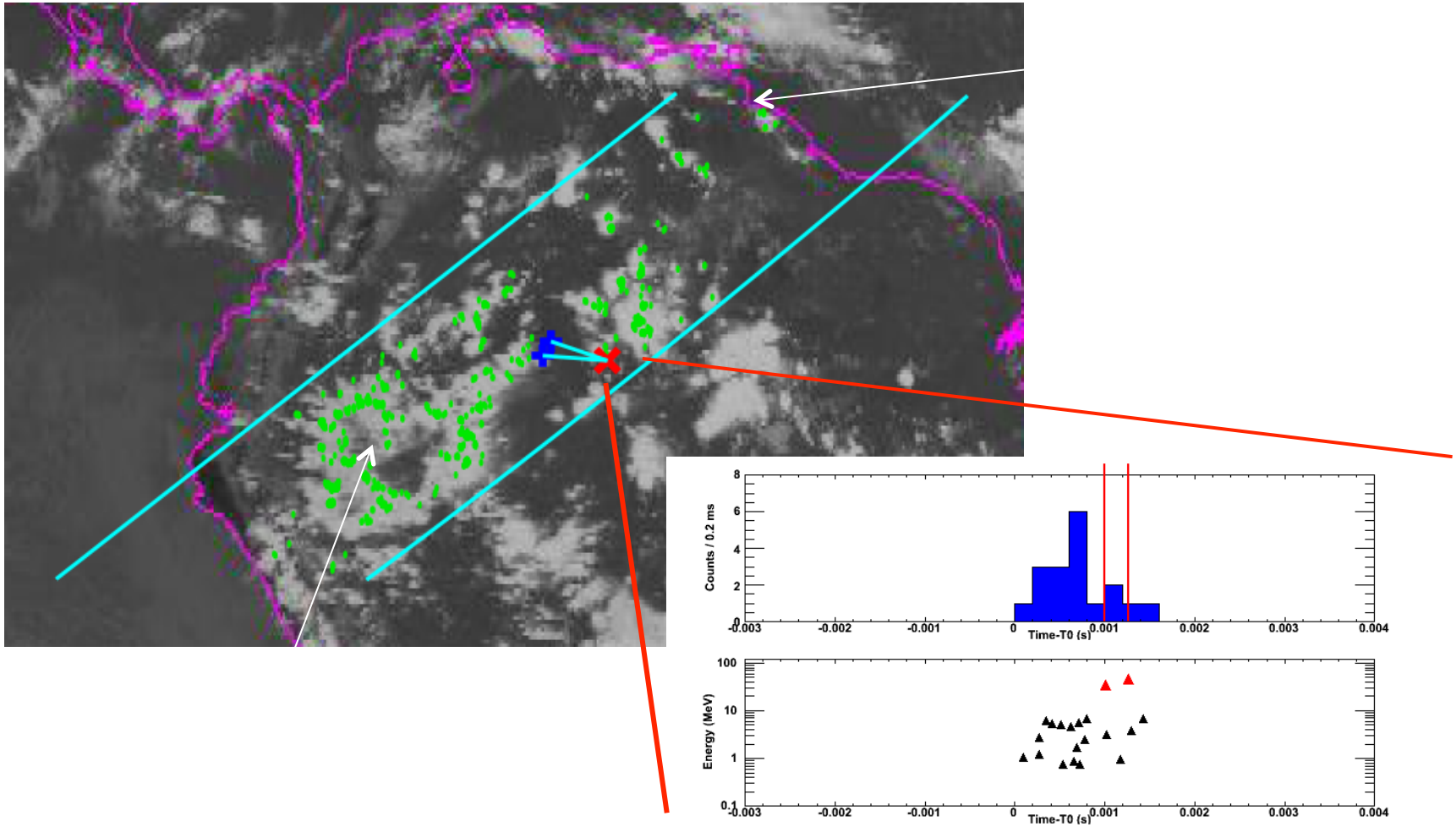


13 GRID events within 2 ms from TGFs T0!

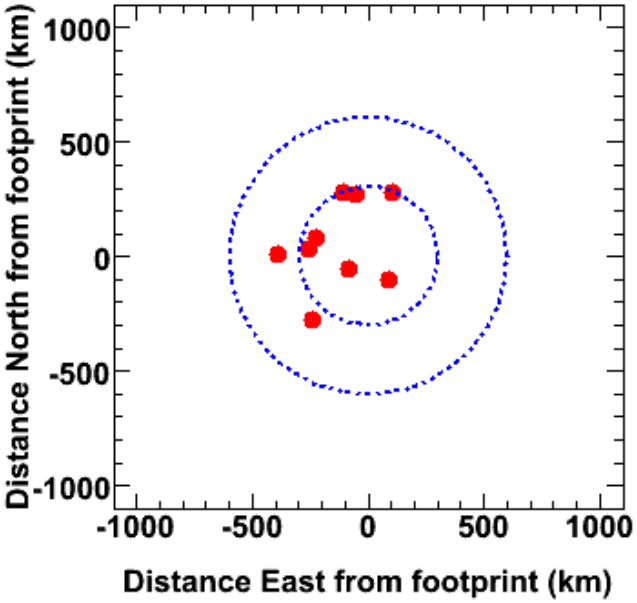
Beaming angle: TGF localization from space in γ-rays by AGILE GRID

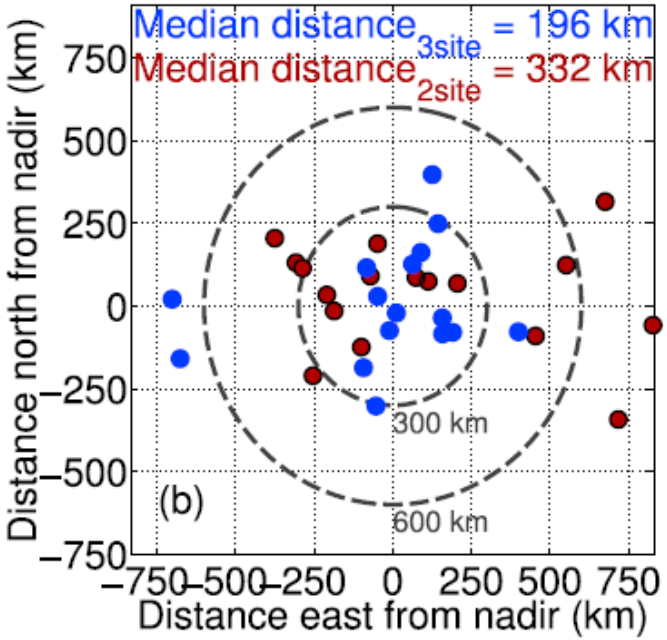


TGF 12809-19 in details (2010 Oct. 16 20:44:55 UT)



Geographical distribution

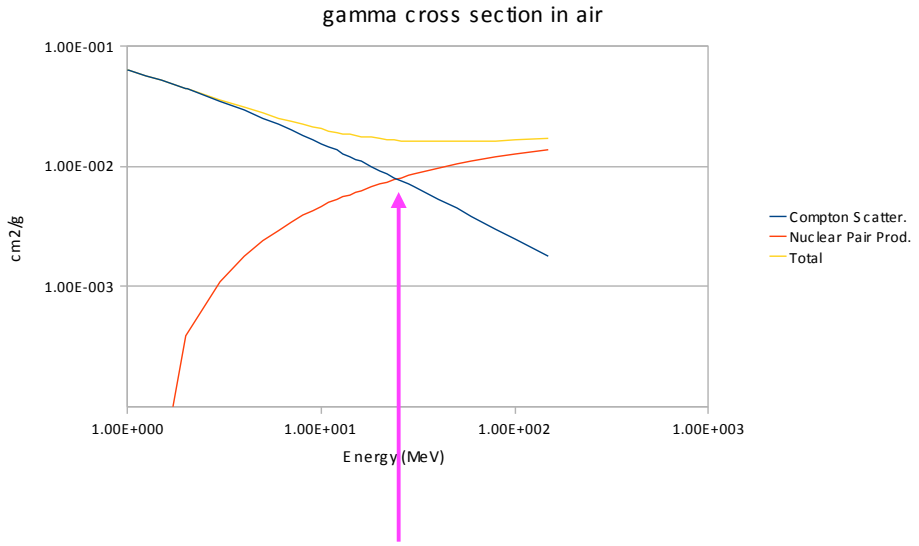




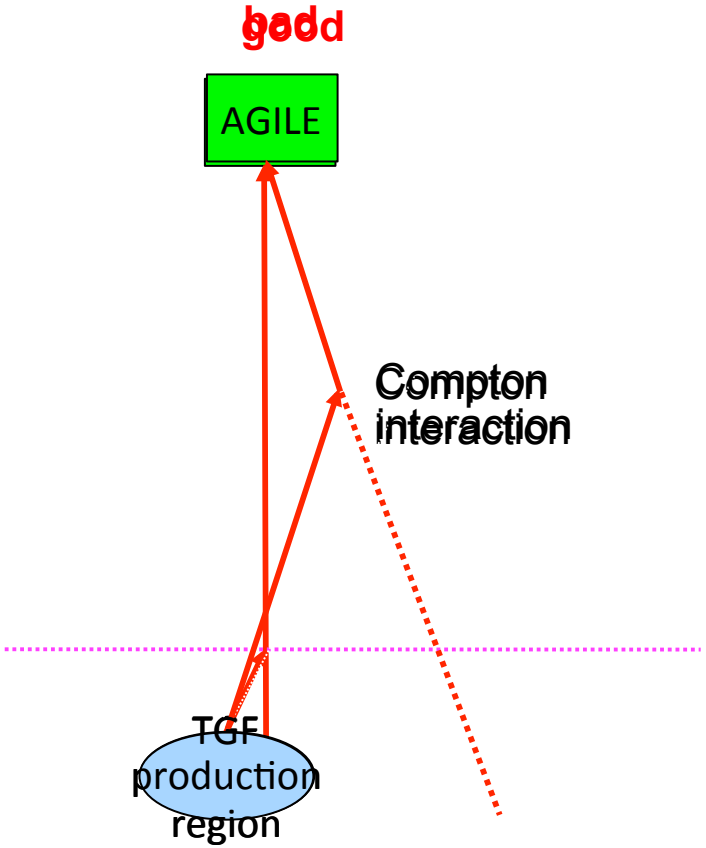
Cohen et al., GRL 2010

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

Do GRID photons come directly from the production region?

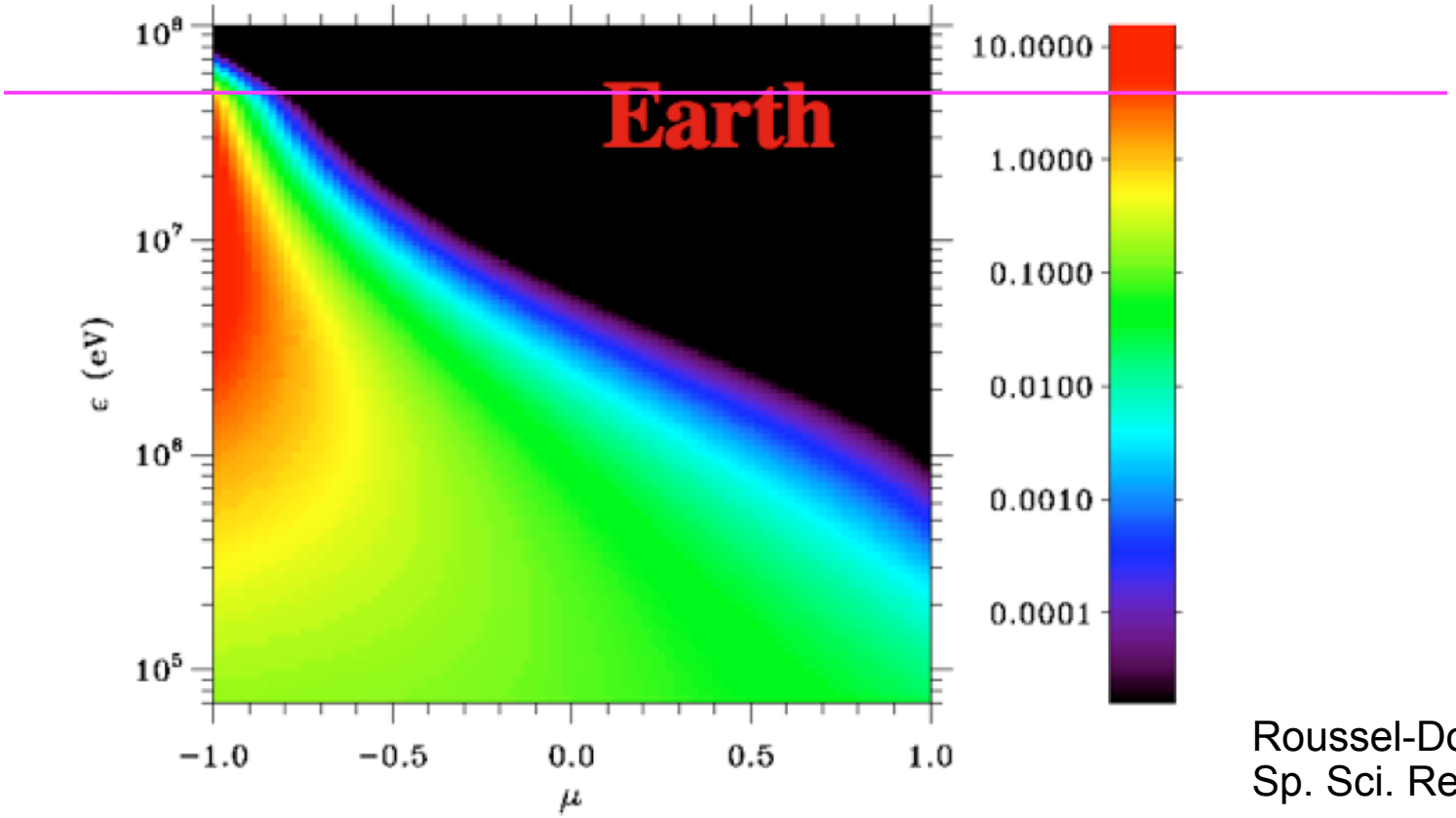


Compton and pair production cross section in air become equivalent at ~25MeV:
Compton interaction for low-energy GRID events cannot be ignored



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

Implications for beaming angle and electric field orientation at the source

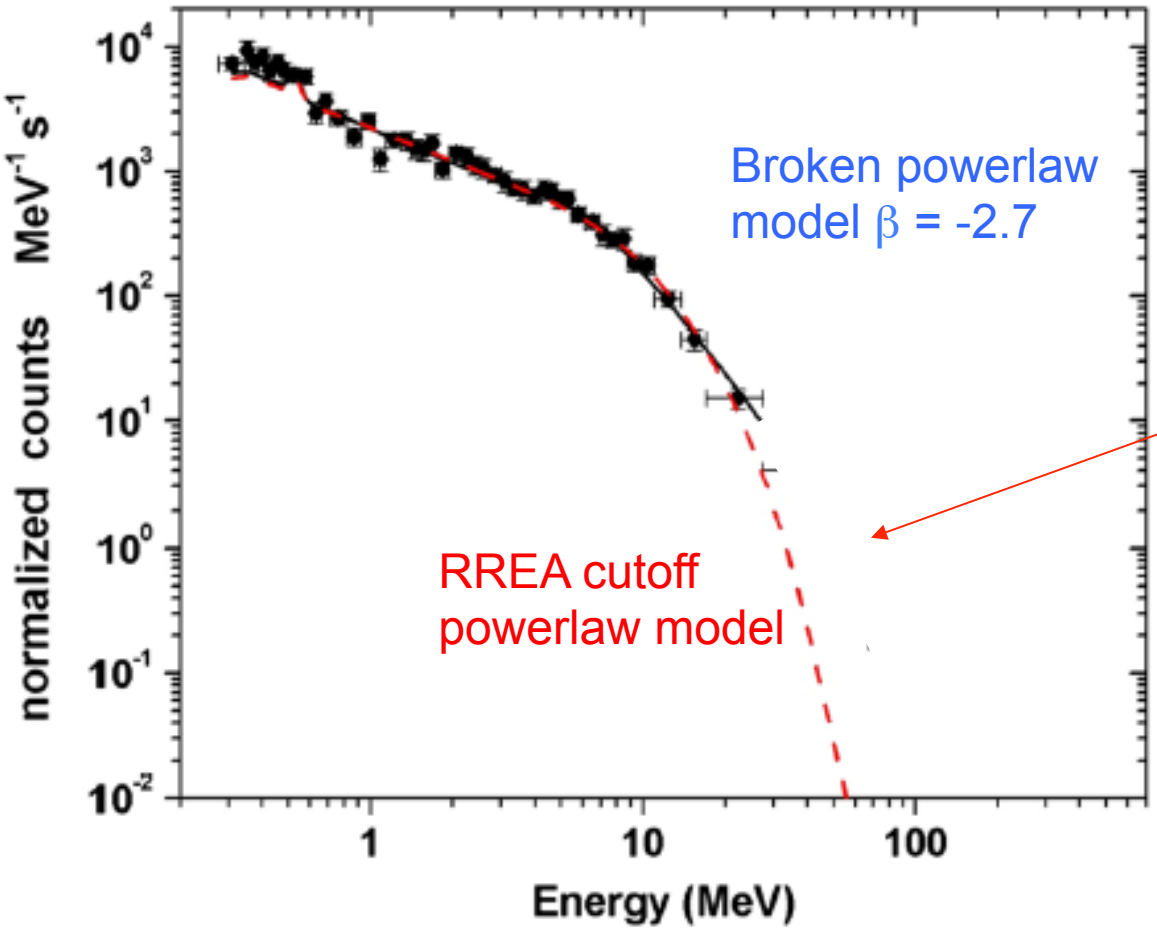


Roussel-Doupre et al.
Sp. Sci. Rev. 2009

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

A new tool to probe remotely the production site electric field

Cumulative spectrum

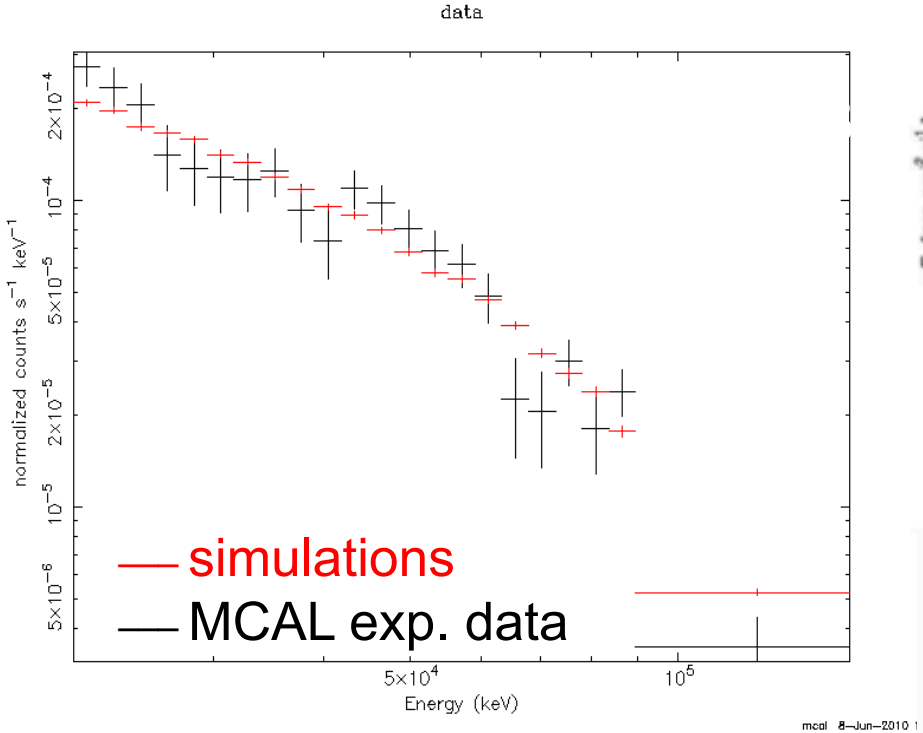


significant detection of γ >40 MeV uneplained by standard RREA model: challenge for emission models

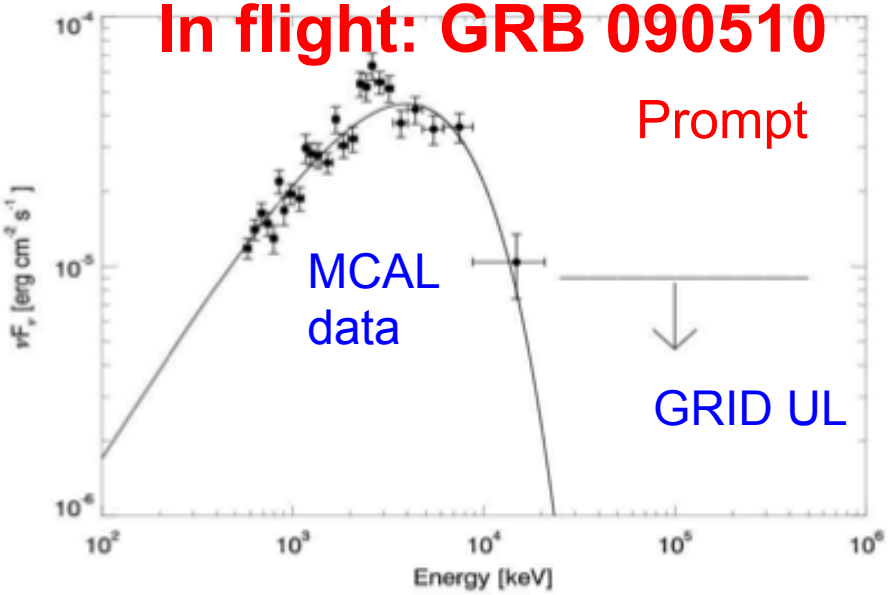
Results published in Tavani et al., Phys. Rev. Letters 106, 018501 (2011)

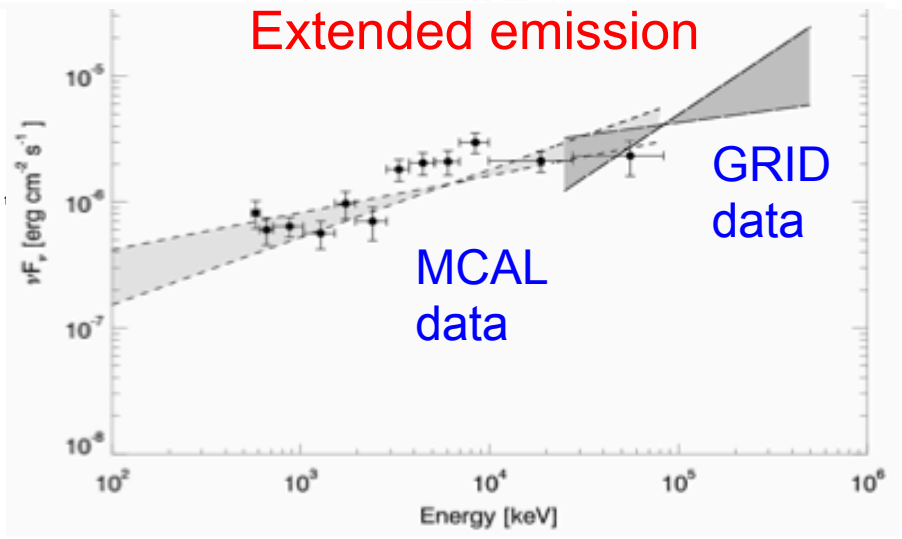
MCAL high energy calibration

On ground



In flight: GRB 090510

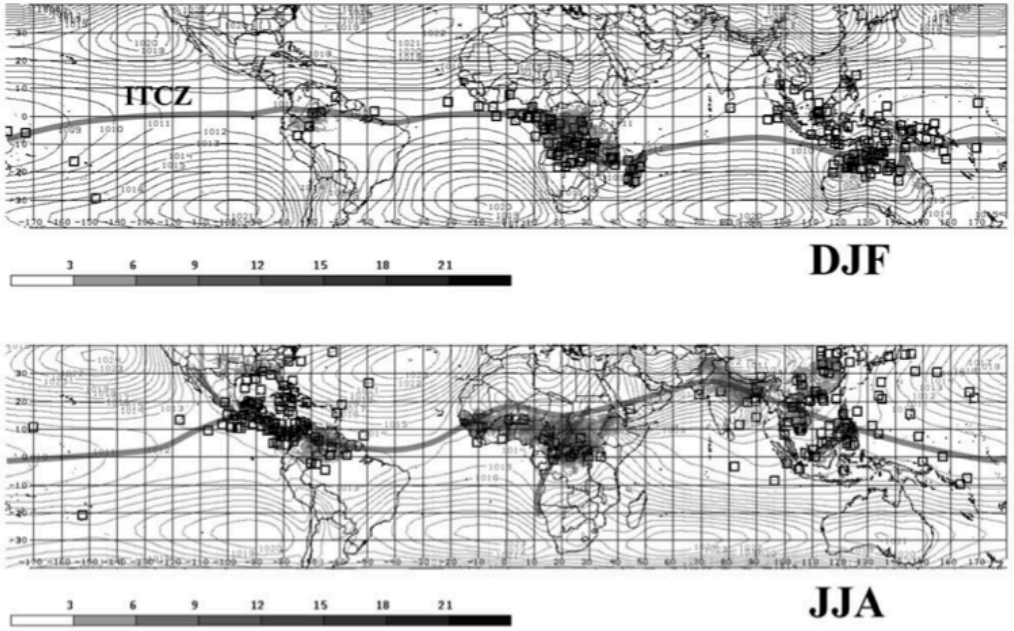




AGILE on-ground calibration performed at INFN Beam Test Facility, Frascati, with Bremsstrahlung γ-rays by 460 MeV e^- on Si target

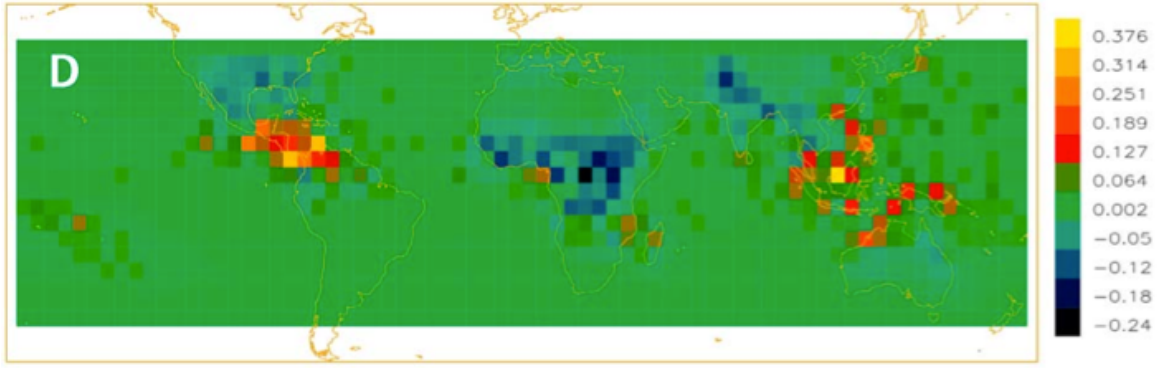
Giuliani et al., ApJL 708 (2010) L84

Toward a climatology of TGFs



Splitt+2010, JGR

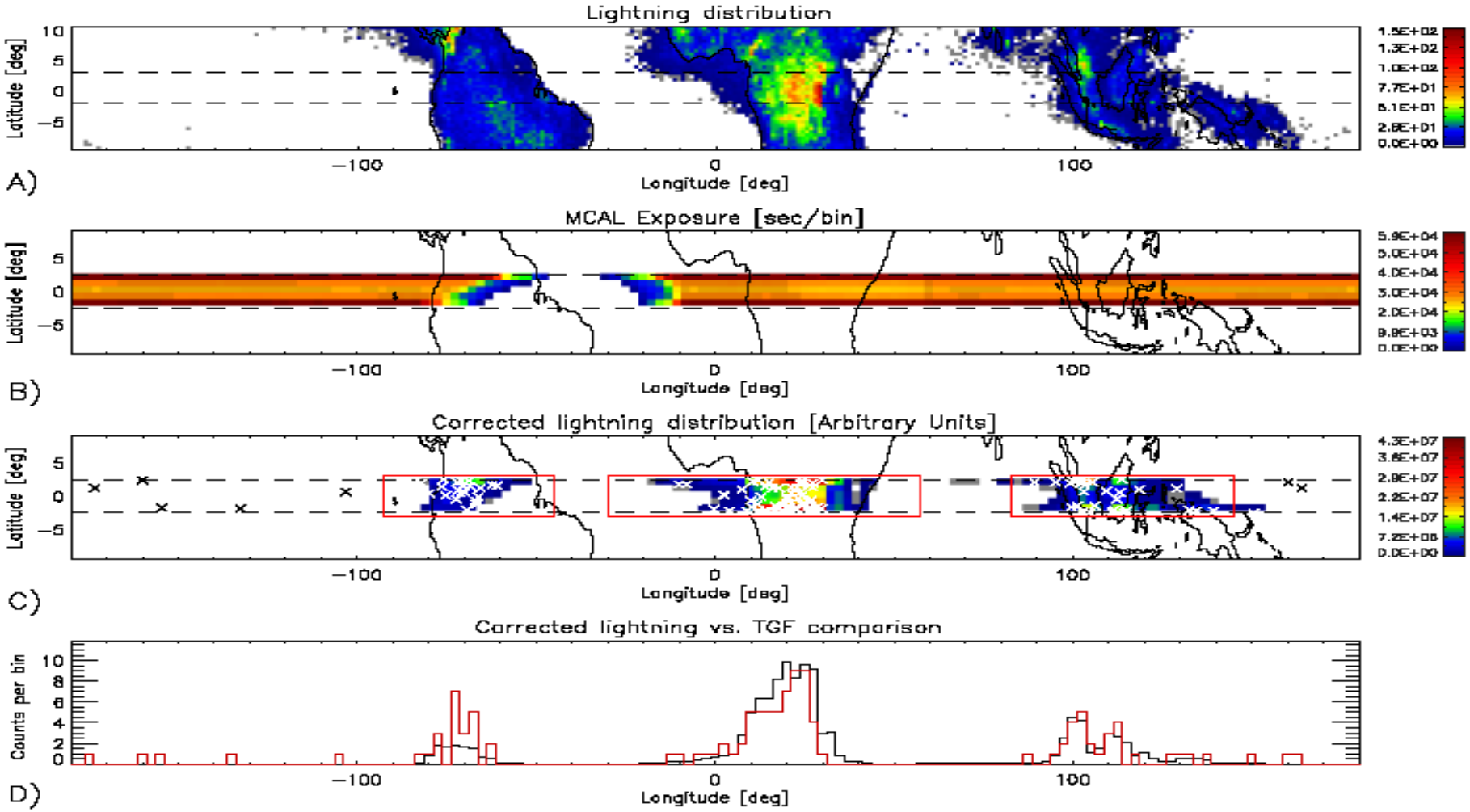
- TGFs follow lightning distribution and ITCZ movement
- BUT with significant differences: TGF tend to peak at later storm phase (while lcs don't) and there is a geographical asymmetry.
- Peculiar subset of lightning?



Smith+2010, JGR

- Hint: water/ice mixed phase plays a role
- **Few climatology studies yet**

TGF-lightning correlation



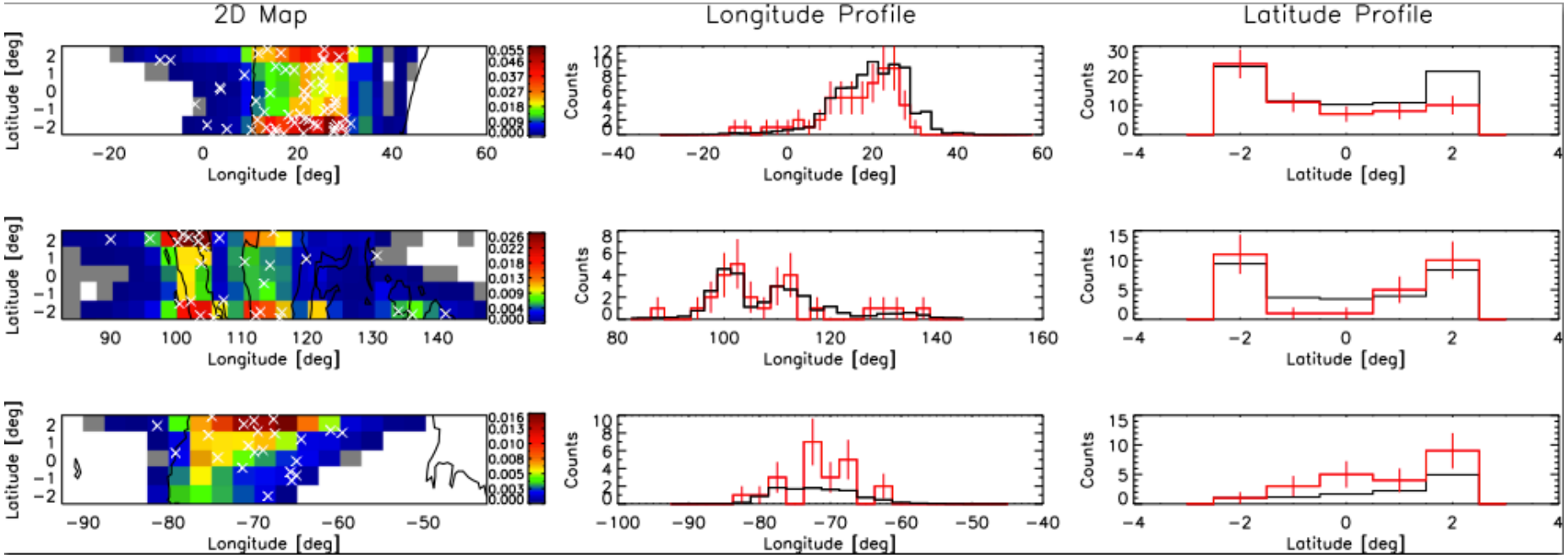
0.68 correlation coefficient for global case BUT…

2D Kolmogorov Smirnov probability = 0.002 for TGFs to be drawn from the same distribution of lightning!

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

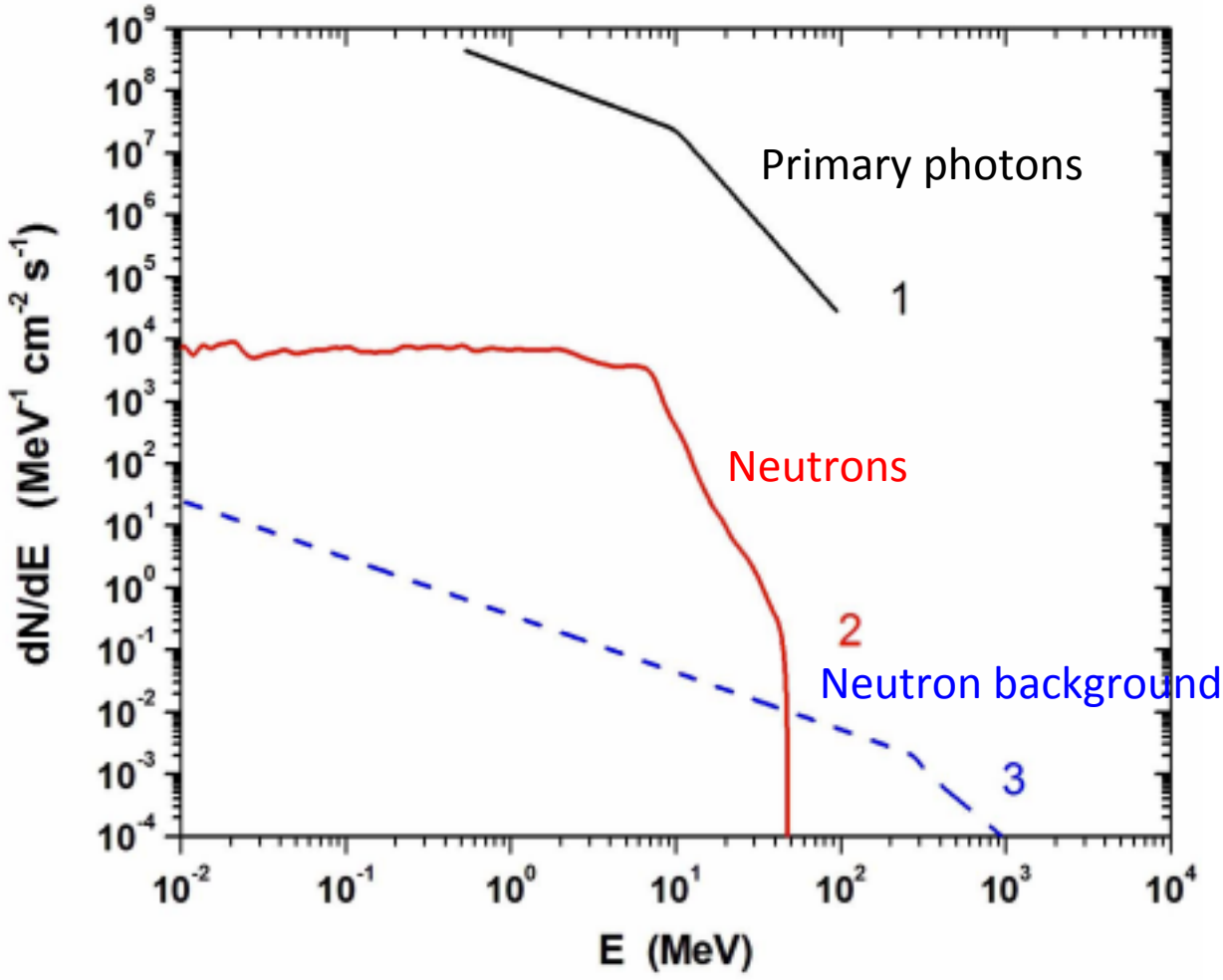
TGF / lightning flash ratio

Fuschino+2011 GRL, confirmed by Briggs+2013 JGR



Continental region	1D KS Longitude P	1D KS Latitude P	2D KS P	TGF / flash ratio
America	0.34	0.45	0.13	$1.5\ 10^{-4}$
Africa	0.17	0.14	0.03	$6.0\ 10^{-5}$
South East Asia	0.95	0.78	0.87	$7.5\ 10^{-5}$
All	0.002		0.002	$7.8\ 10^{-5}$

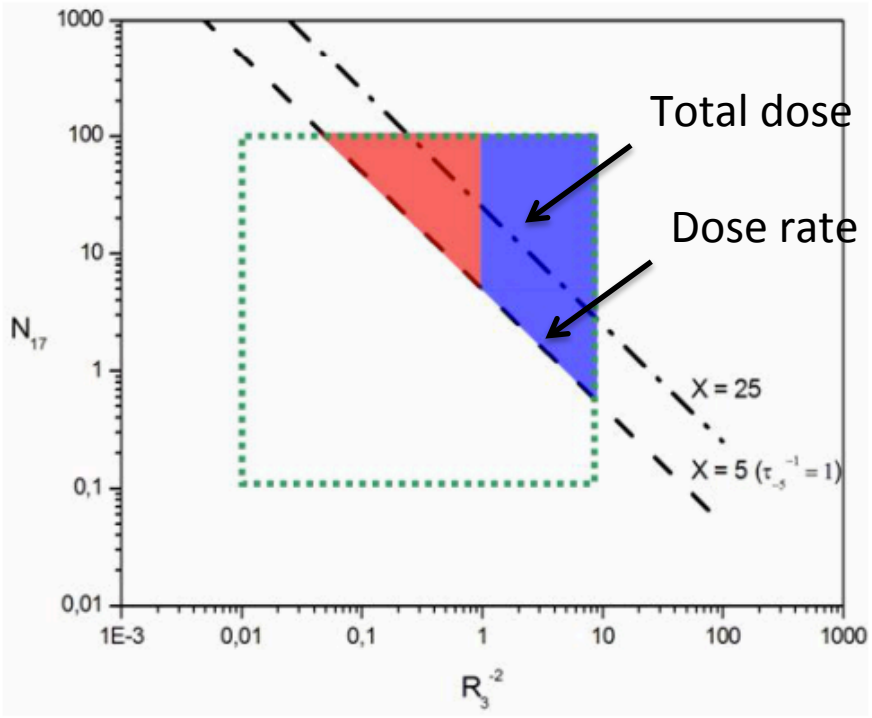
Possible effects on avionics



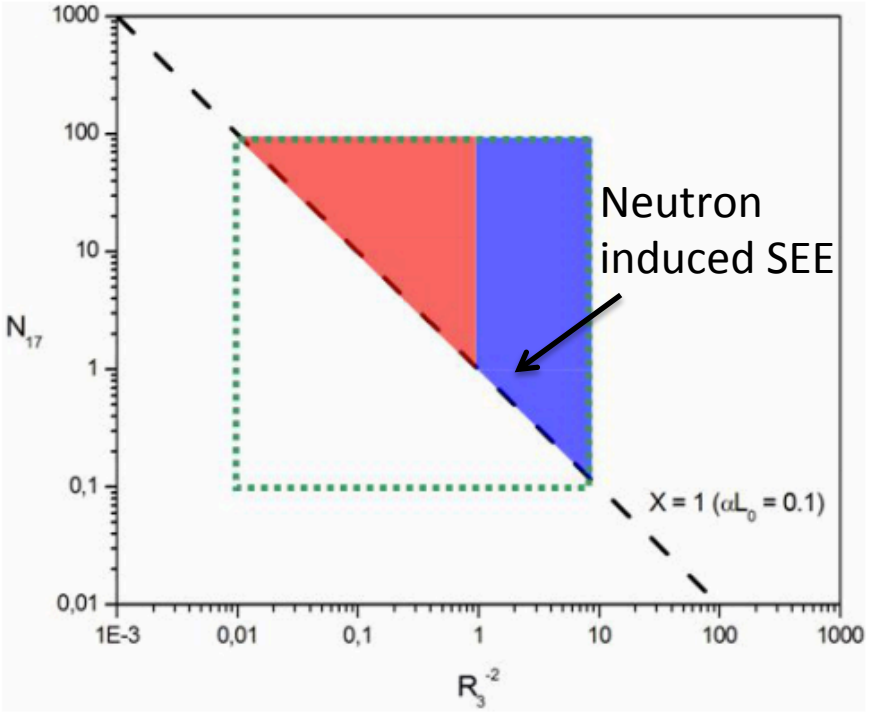
Tavani et al., NHESS 2013

Possible effects on avionics

Electromagnetic component



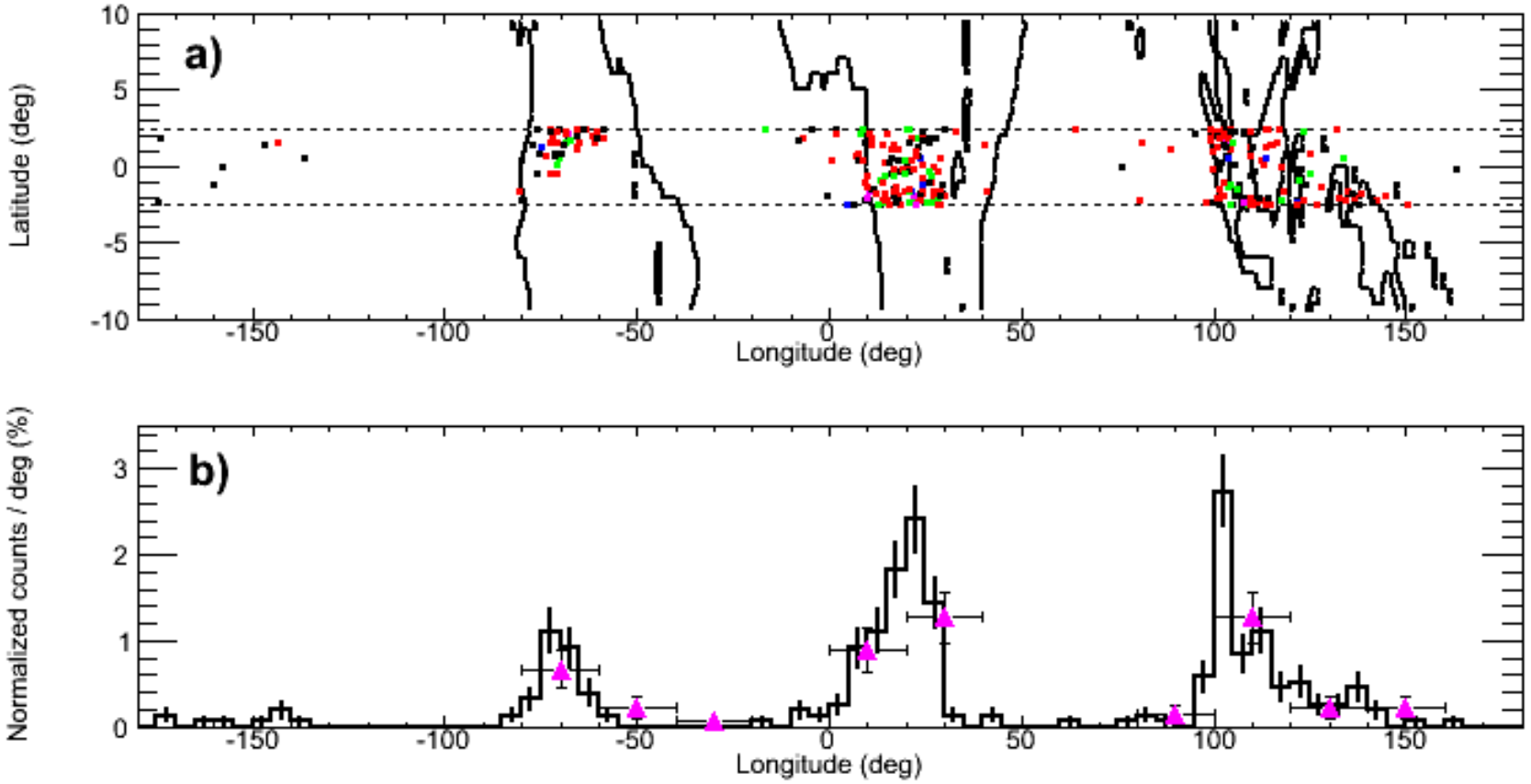
Neutron component



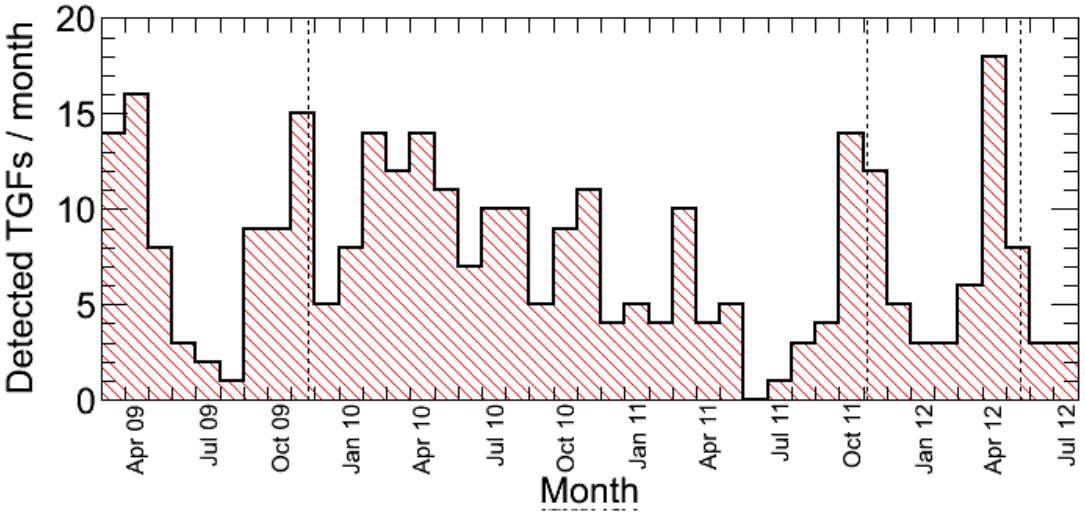
Tavani et al., NHESS 2013

The AGILE 1st TGF catalog

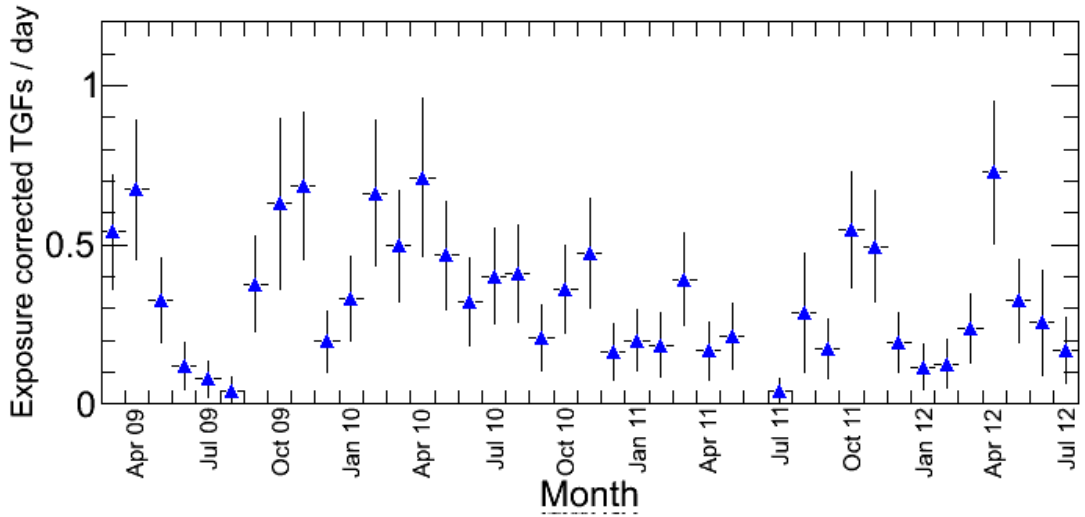
308 TGFs with max energy <30 MeV in 3.5 years (Marisaldi+2013 JGR submitted)

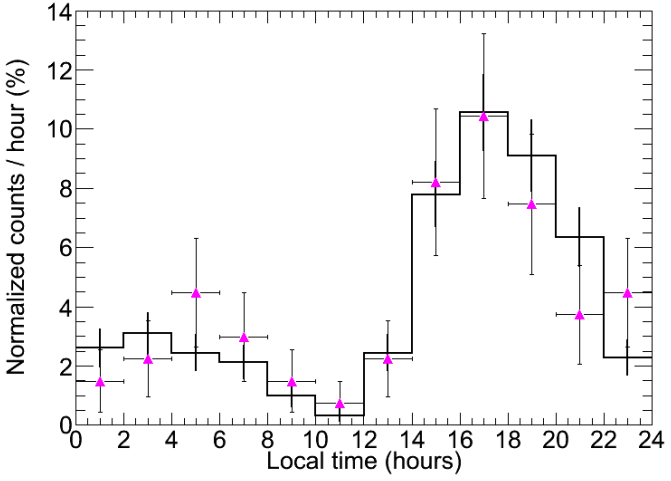


Detection rate

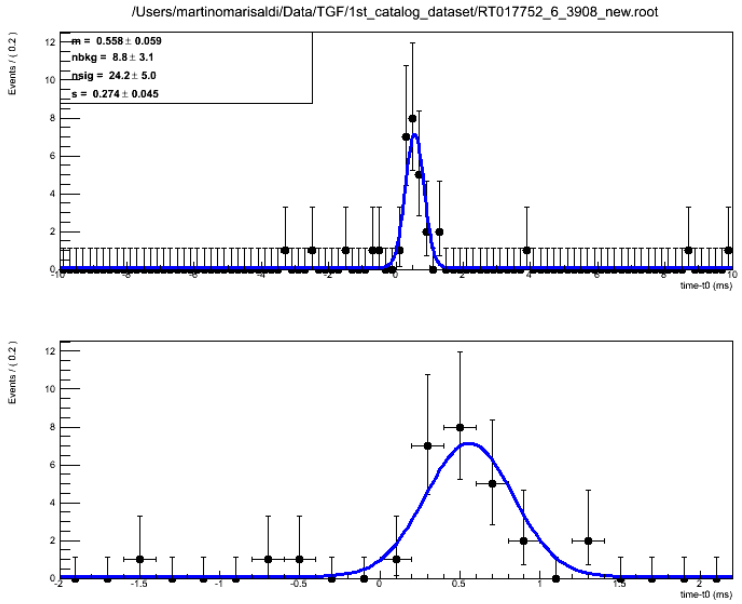


Onboard trigger required +
>9 counts
HR > 0.5
All MCAL segments involved
E_{MAX} < 30 MeV

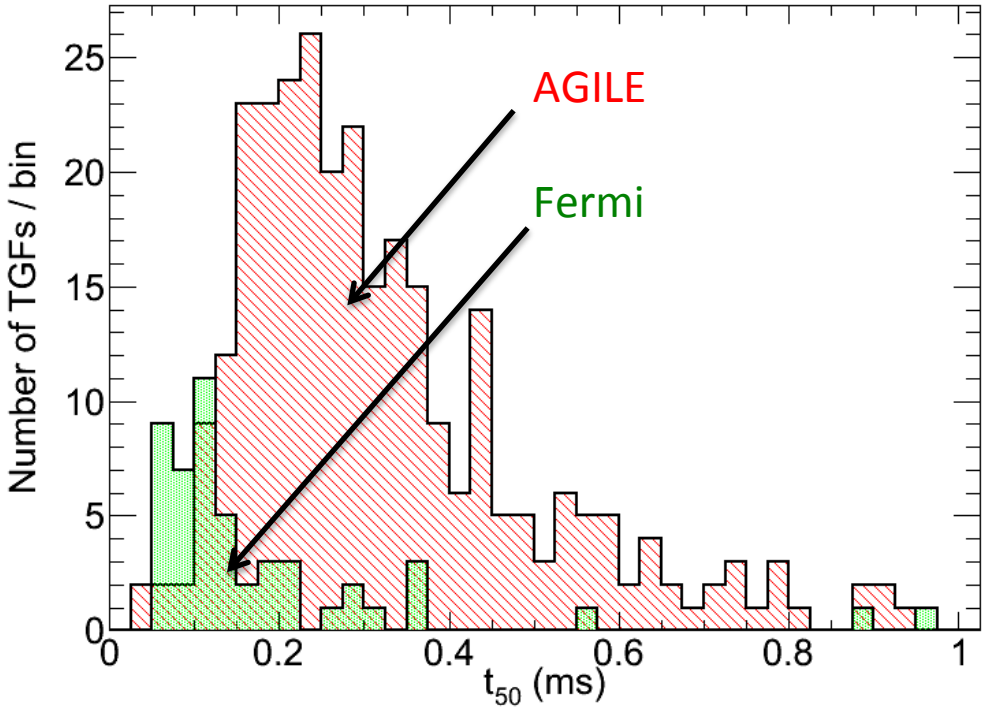




Duration distribution



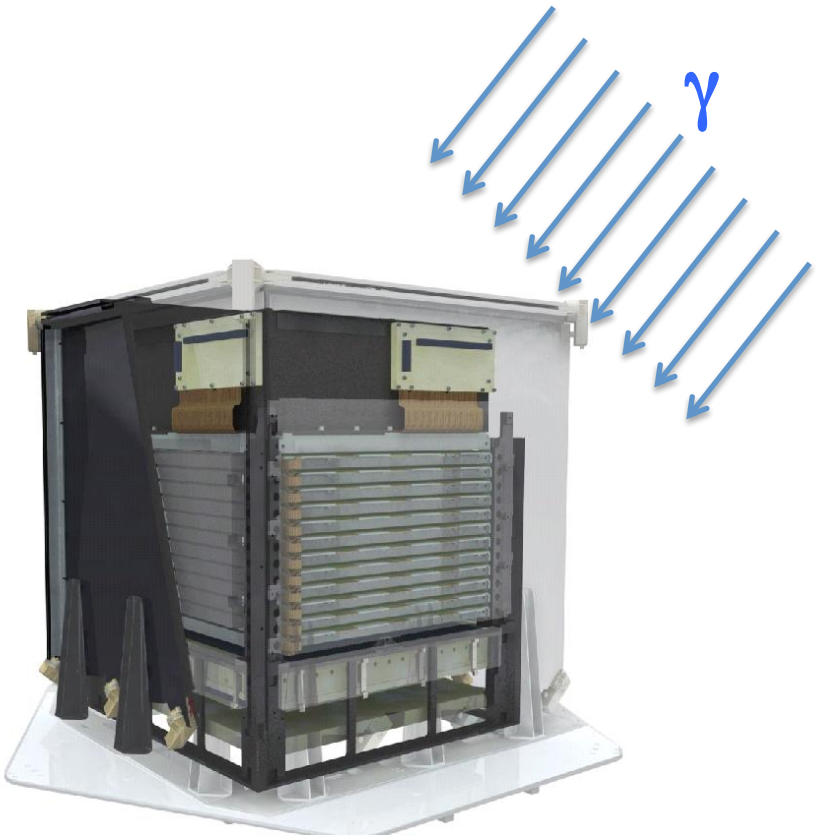
$T_{50} = 1.35\ \sigma$



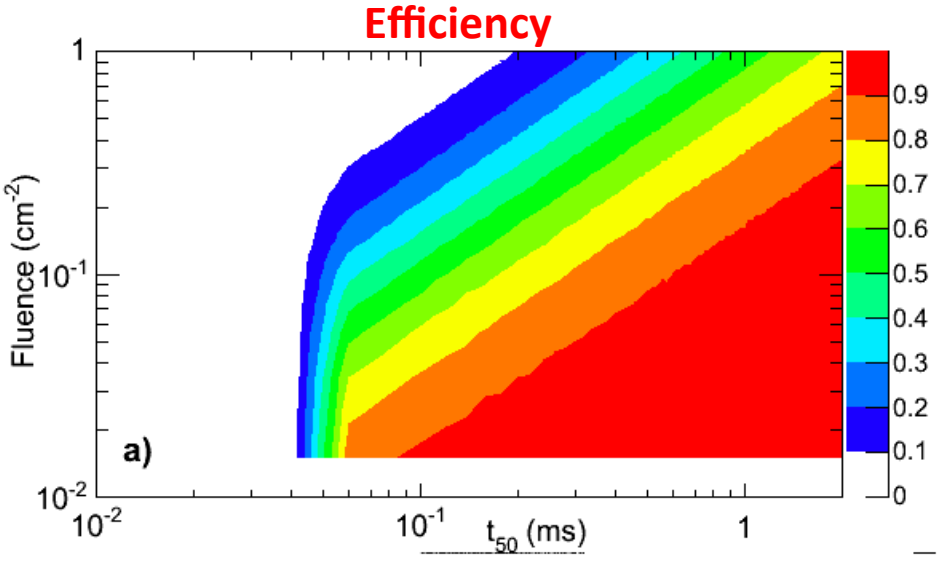
$T_{50,\ AGILE} \sim 2.5\ T_{50,\ Fermi}$

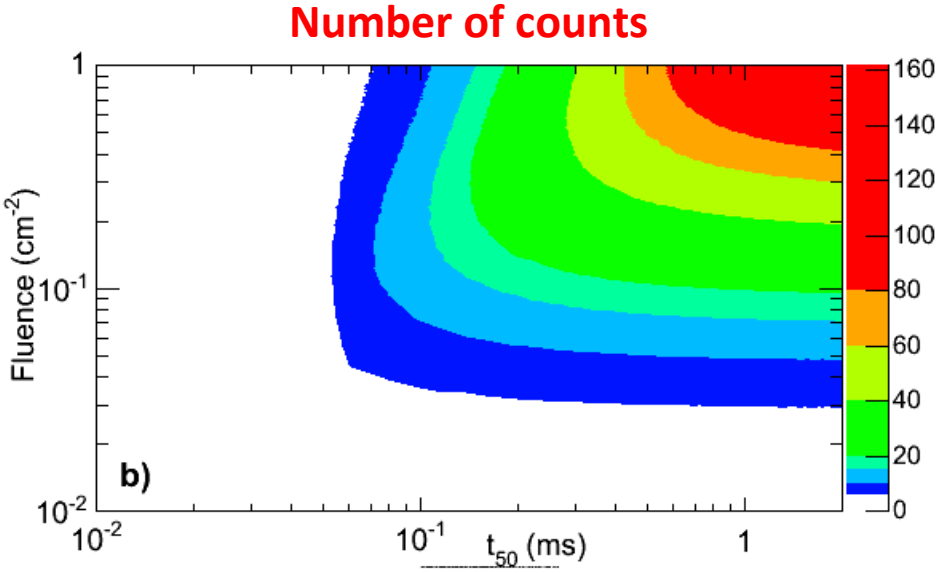
?

Dead time model

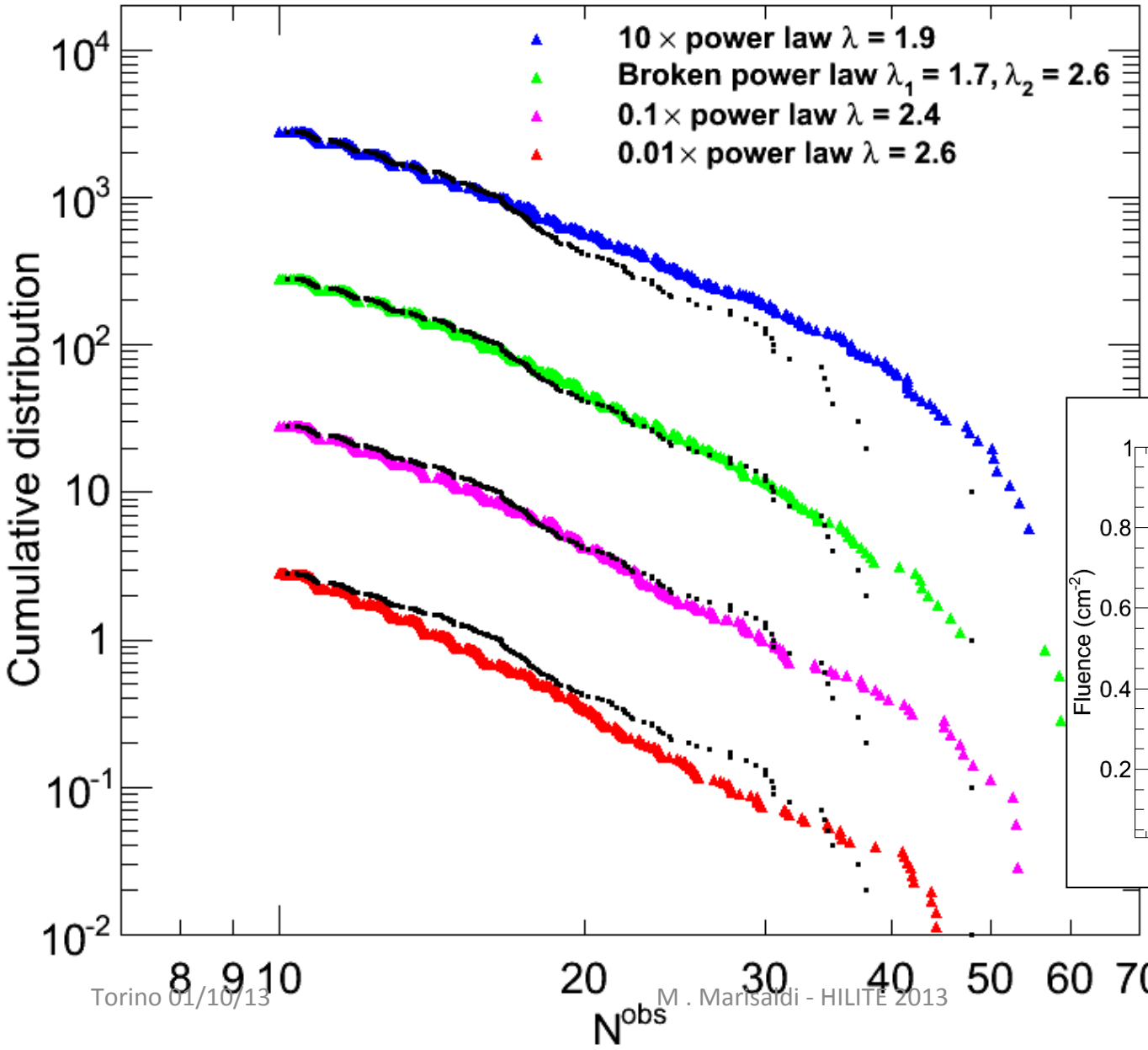


AC shield is a paralizable detector!

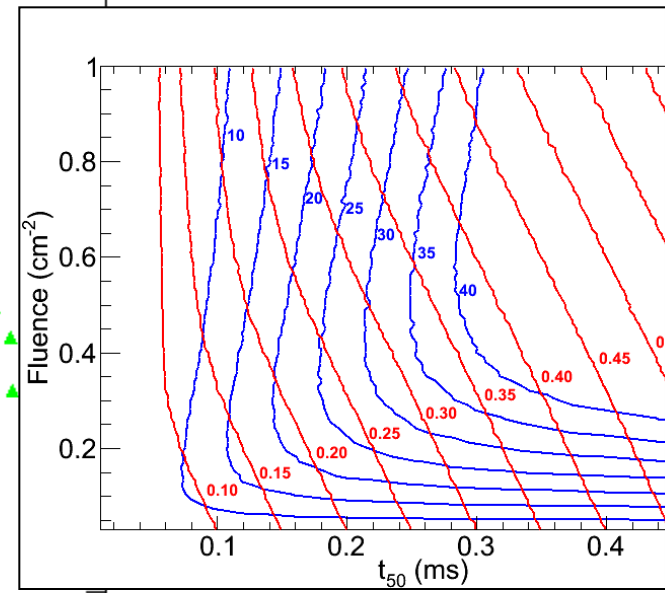




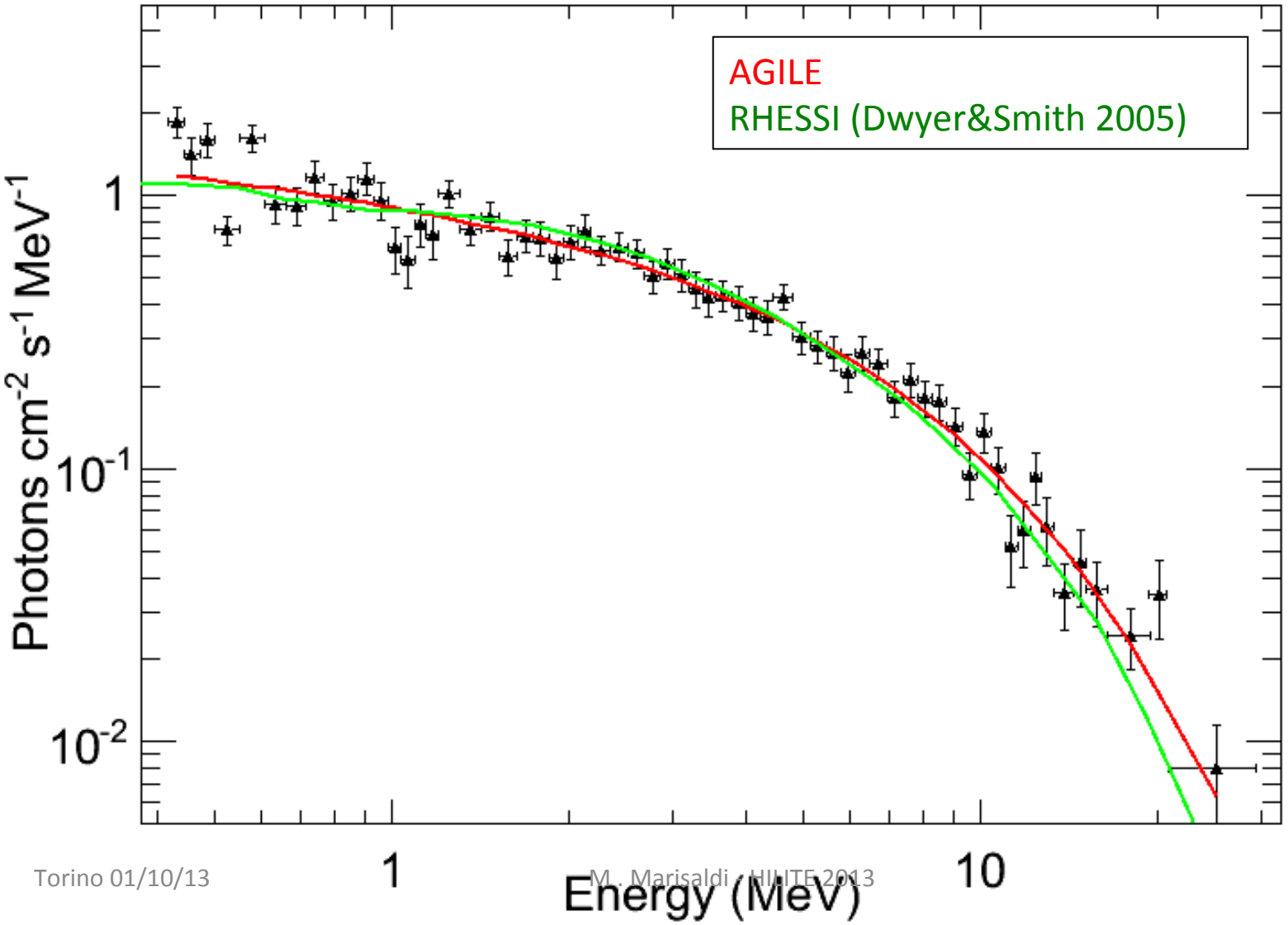
Intensity distribution



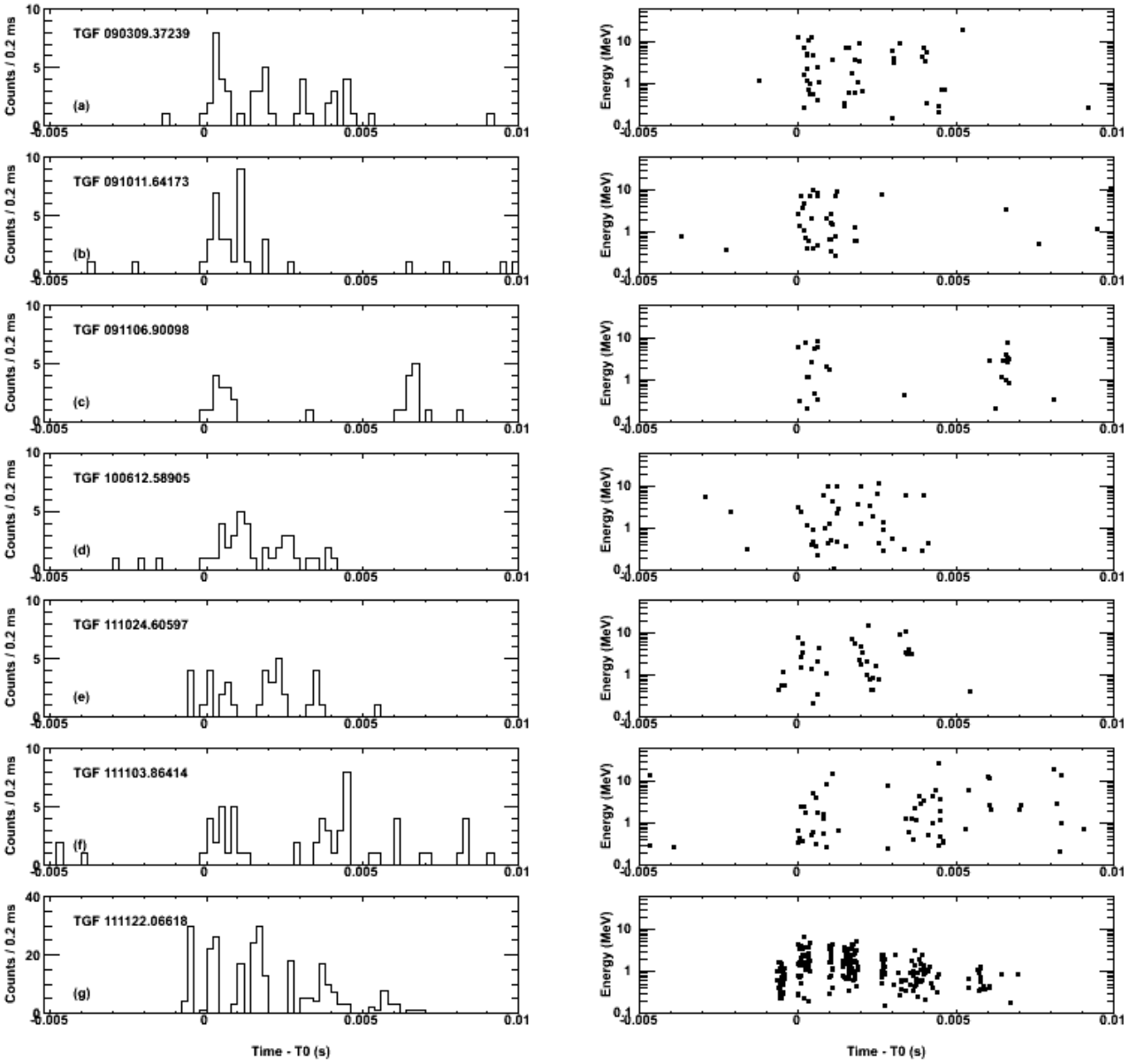
Dead time model



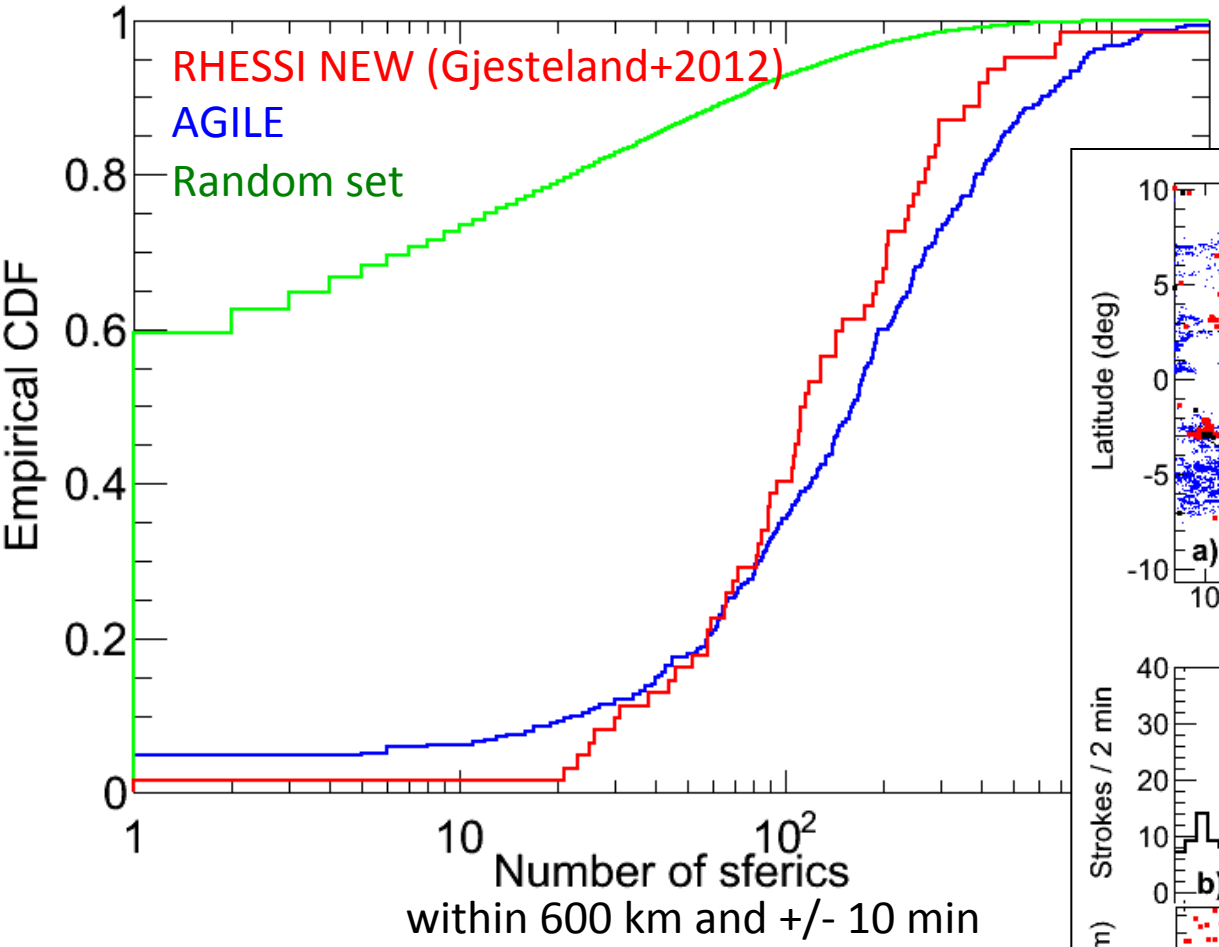
Cumulative energy spectrum

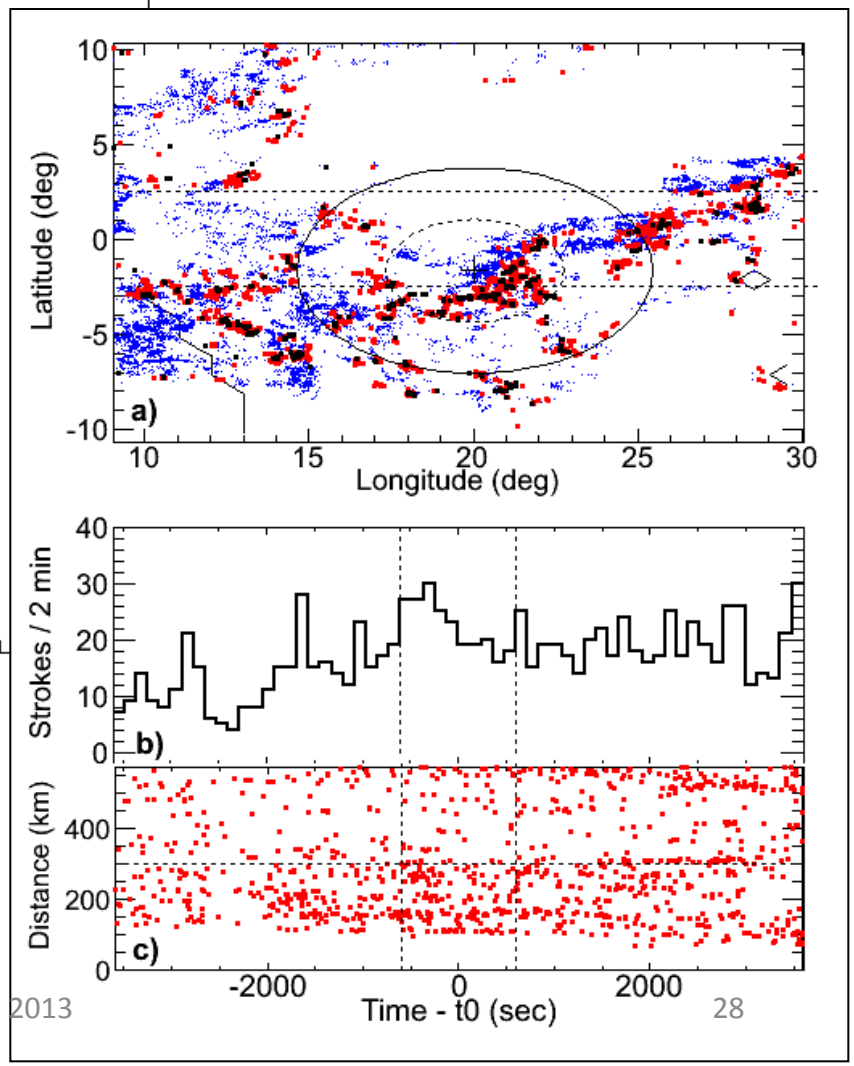


Multiple peaks

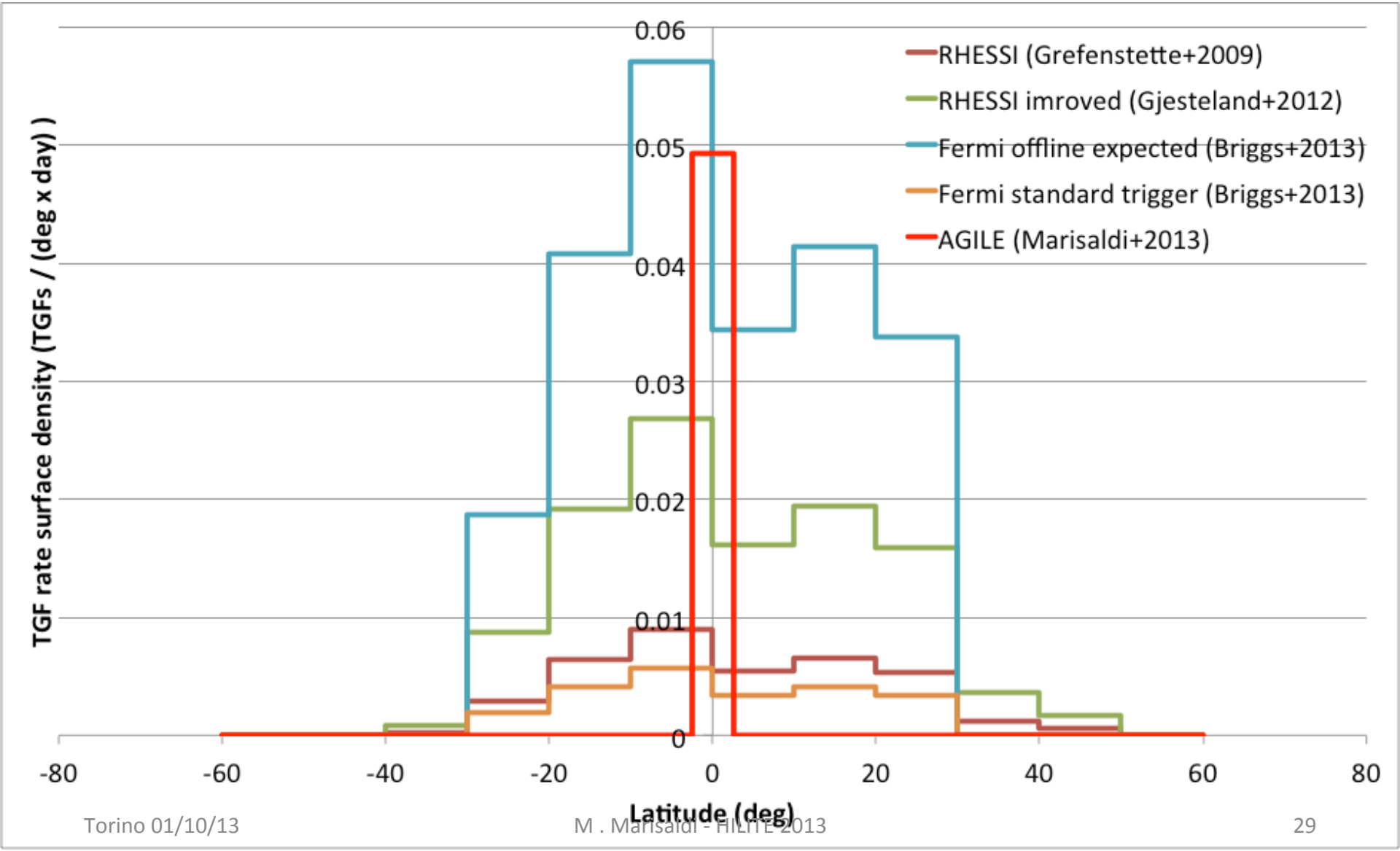


Correlation with WWLLN sferic waves

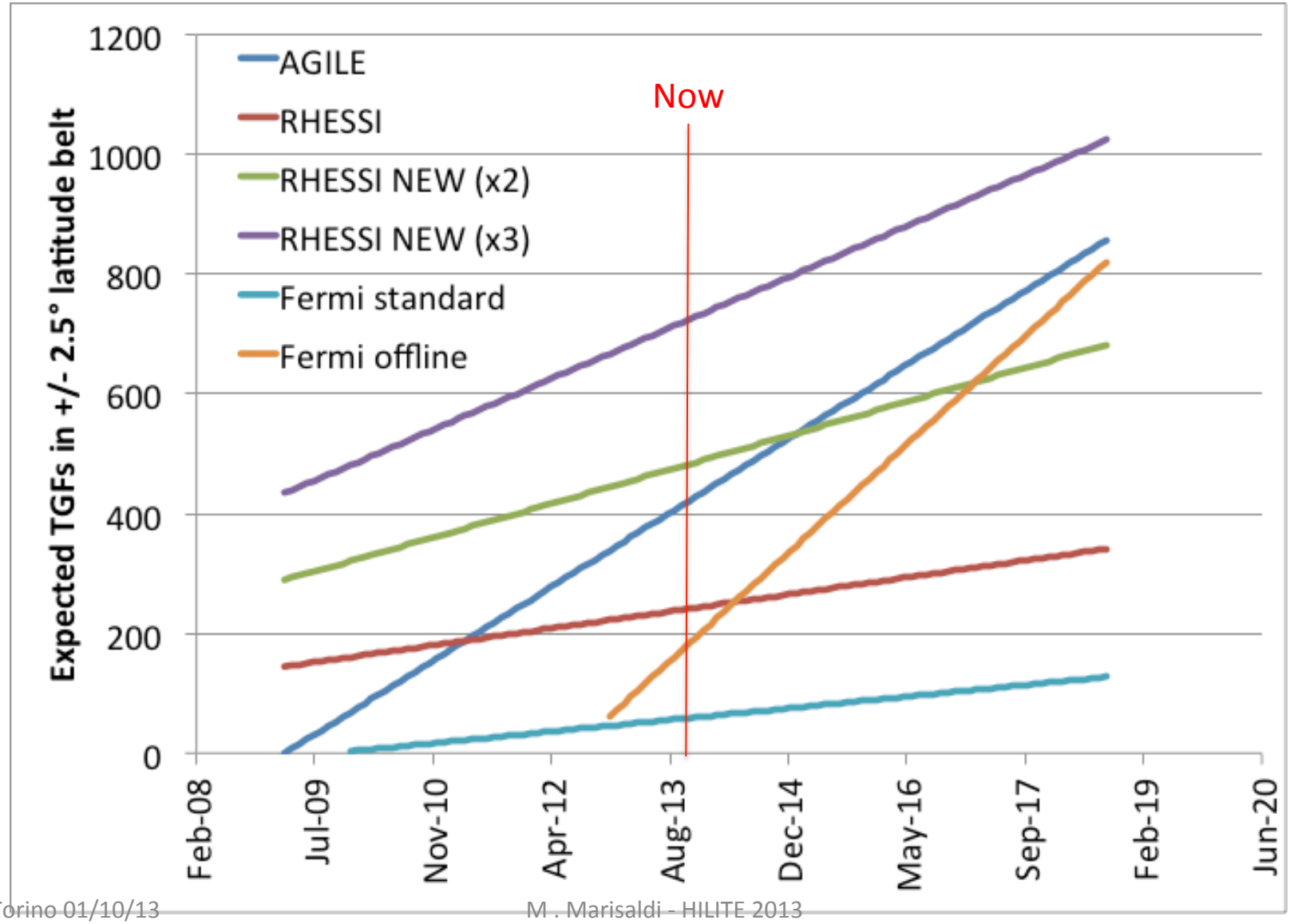




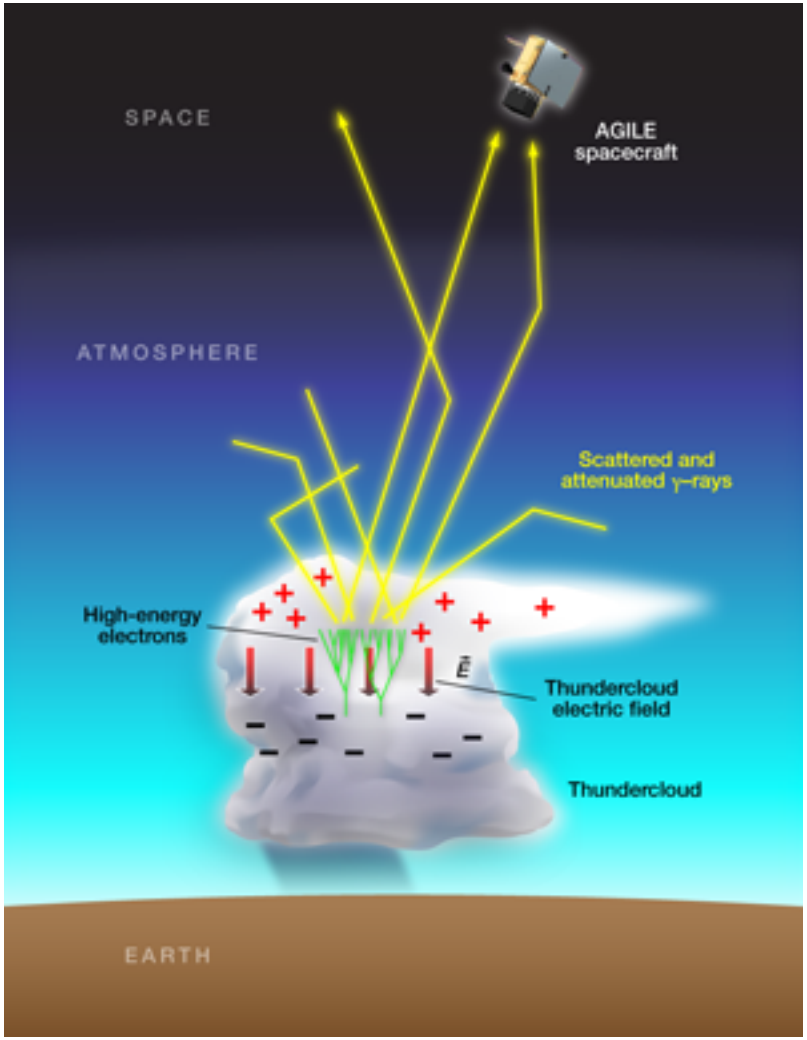
TGF rate surface density



TGFs above the equator



THANK YOU!



Credit: Alan Stonebraker

First AGILE TGF detections:
Marisaldi et al., JGR 115, A00E13 (2010)

TGF γ-ray localization:
Marisaldi et al., Phys Rev Lett 105, (2010)

TGF high-energy spectrum:
Tavani et al., Phys Rev Lett 106, (2011)

AGILE TGFs & lightning activity:
Fuschino et al., GRL 38, L14806(2011)

Possible TGF effects on avionics:
Tavani et al., NHESS 13, (2013)

1st AGILE TGF catalog:
Marisaldi et al., JGR submitted

Coming soon!