AGILE and Terrestrial Gamma-Ray Flashes

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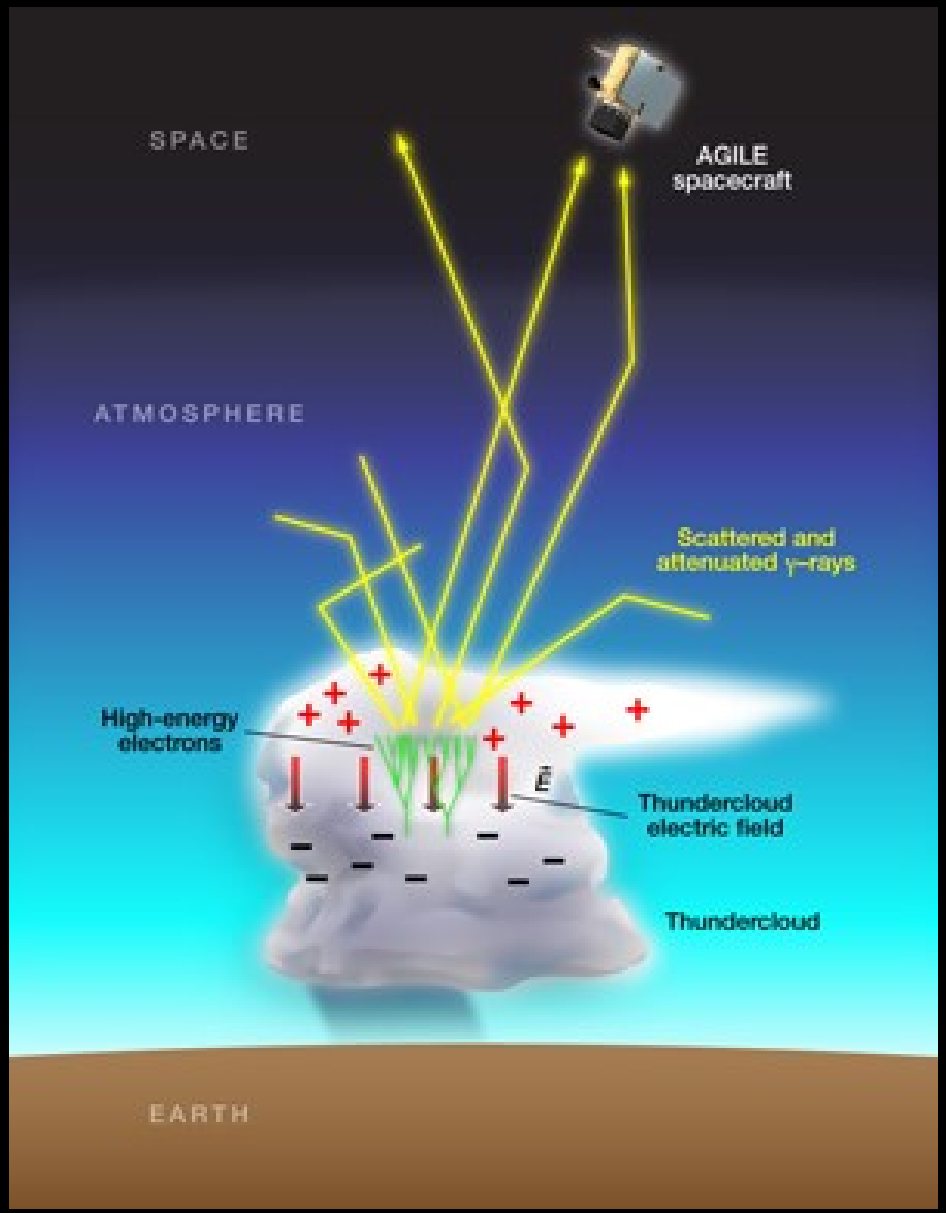
Joint MTG LI & GOES-R GLM Workshop, May 29, 2015

Thunderstorms are powerful and energetic natural particle accelerators on Earth

Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2015 February 4


SPACE
AGILE
spacecraft
ATMOSPHERE
Scattered and
attenuated γ-rays
High-energy
electrons
Thundercloud
electric field
Thundercloud
EARTH

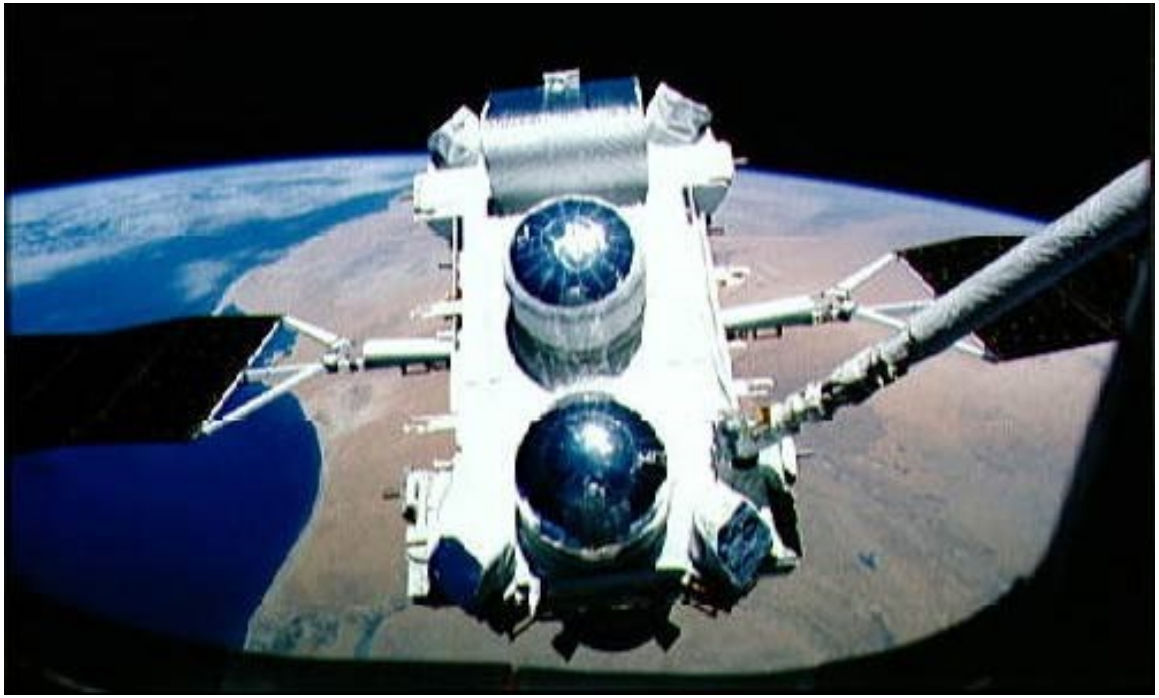
500-600 km

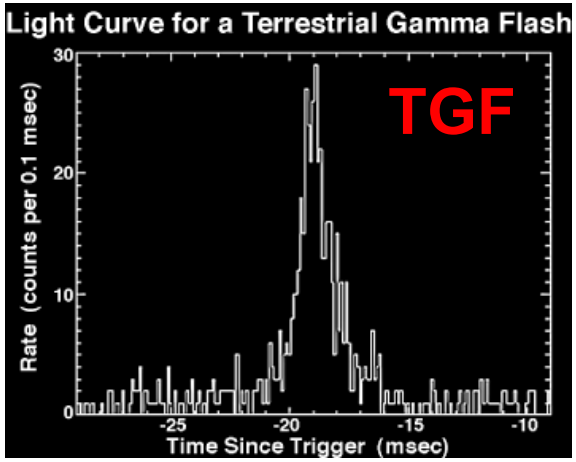
TGFs: very energetic gamma-ray flashes from the Earth

- in general associated with powerful thunderstorms and convective cells (but also exceptions)
- much more energetic than normal lightning
- very hard spectrum
- pulses ranging from 100 microsec to milliseconds
- not the usual type of lightning (?) ($1/10^4$)

Discovery of TGFs by CGRO (1994)

Seminal paper by **G.J. Fishman et al.**,
"Discovery of Intense Gamma-Ray Flashes of Atmospheric Origin", Science (1994)





Discovery of terrestrial gamma-ray flashes

Seminal paper by **G.J. Fishman et al.**,
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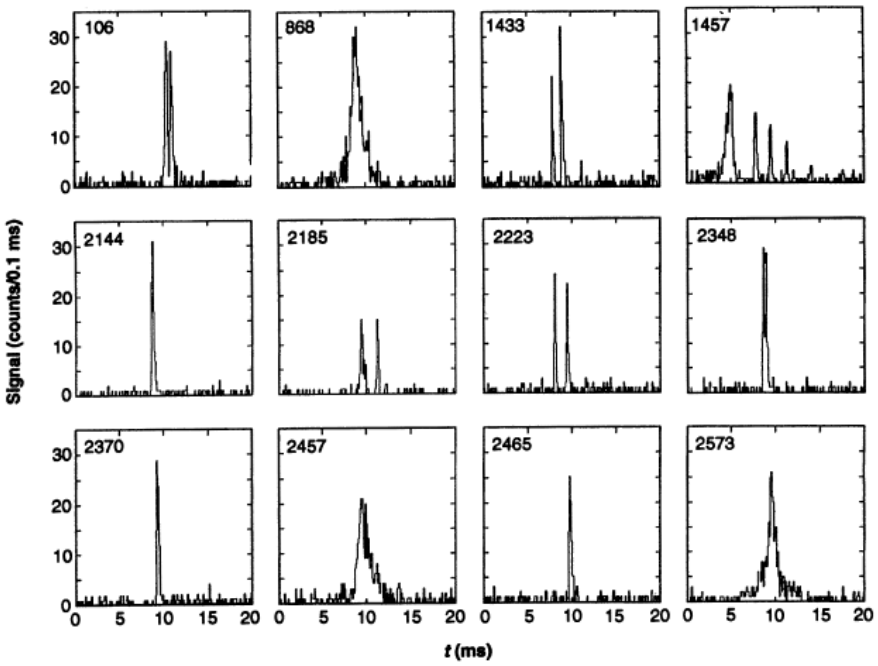
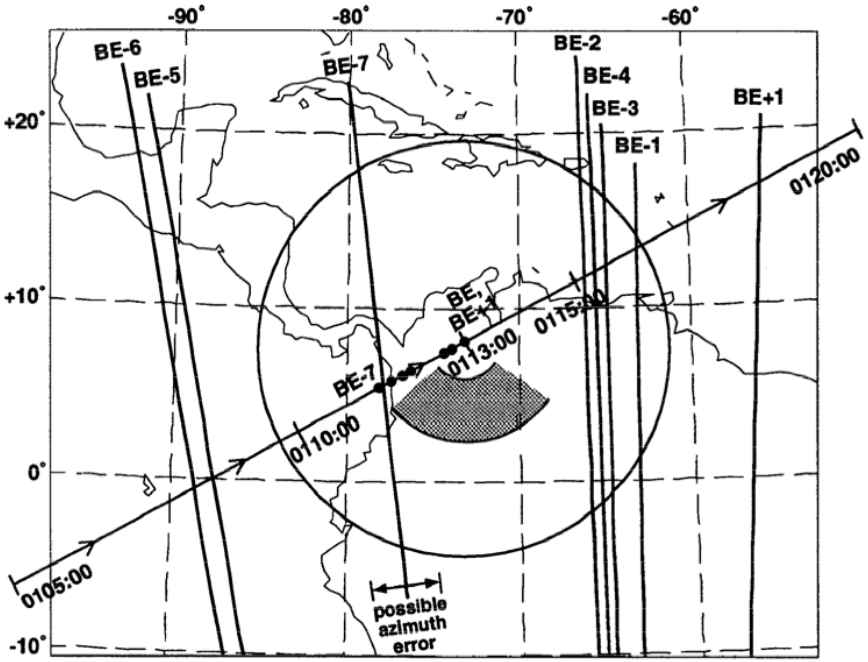


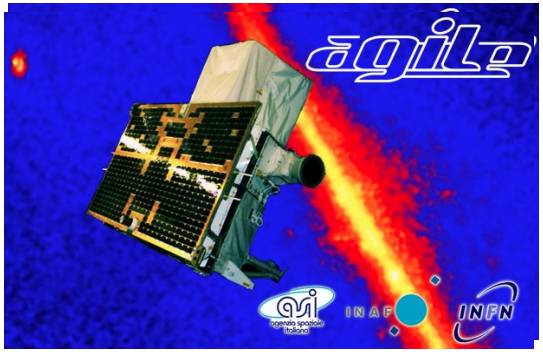


- Energy > 1 MeV, harder than GRBs
- Very bright, ~1ms duration
- Associated to lightning

19 April 2015.
Happy 21st birthday TGFs !

TGF observations from space

Italy
Tavani, Marisaldi,
Fuschino et al., INAF
AGILE (ASI), since 2007
800+ TGFs



- More than 800 events recorded
- **Discovery of very hard component**
- Detection up to 100 MeV
- TGF imaging with Silicon Tracker
- Match with lightning pattern, but with geographical differences

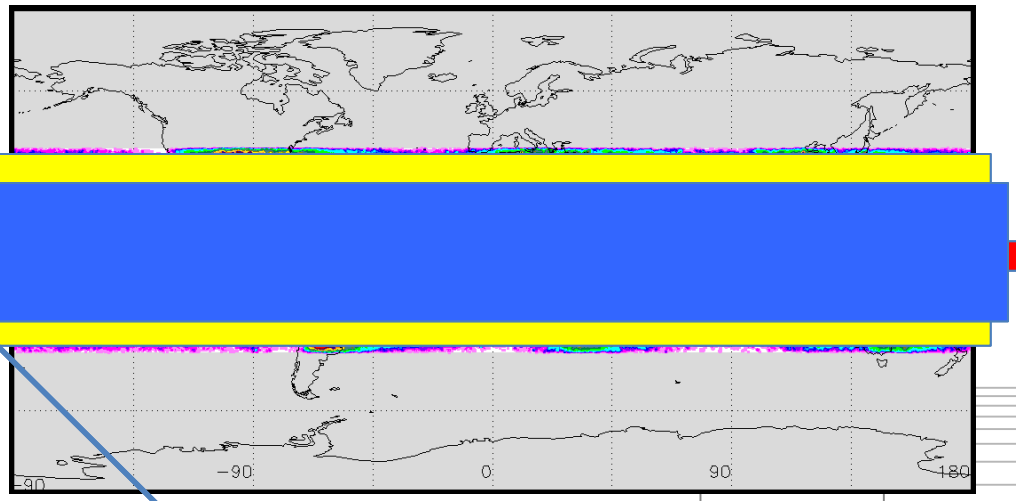
USA
Smith et al., UC Santa Cruz
RHESSI (NASA), since 2002
1000+ TGFs

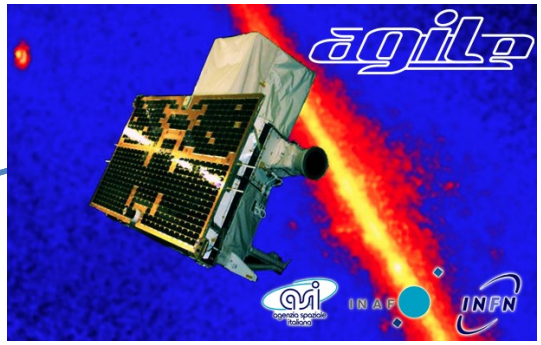
- More than 1000 events recorded
- Production depths 15-20 km close to cloud tops

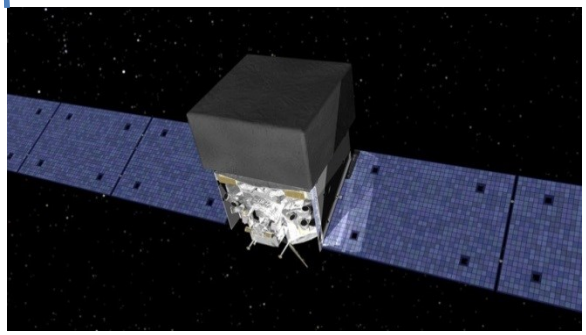
USA
Fishman, Briggs et al., NASA MSFC / UAH,
Fermi-GBM (NASA), since 2008
2000+ TGFs

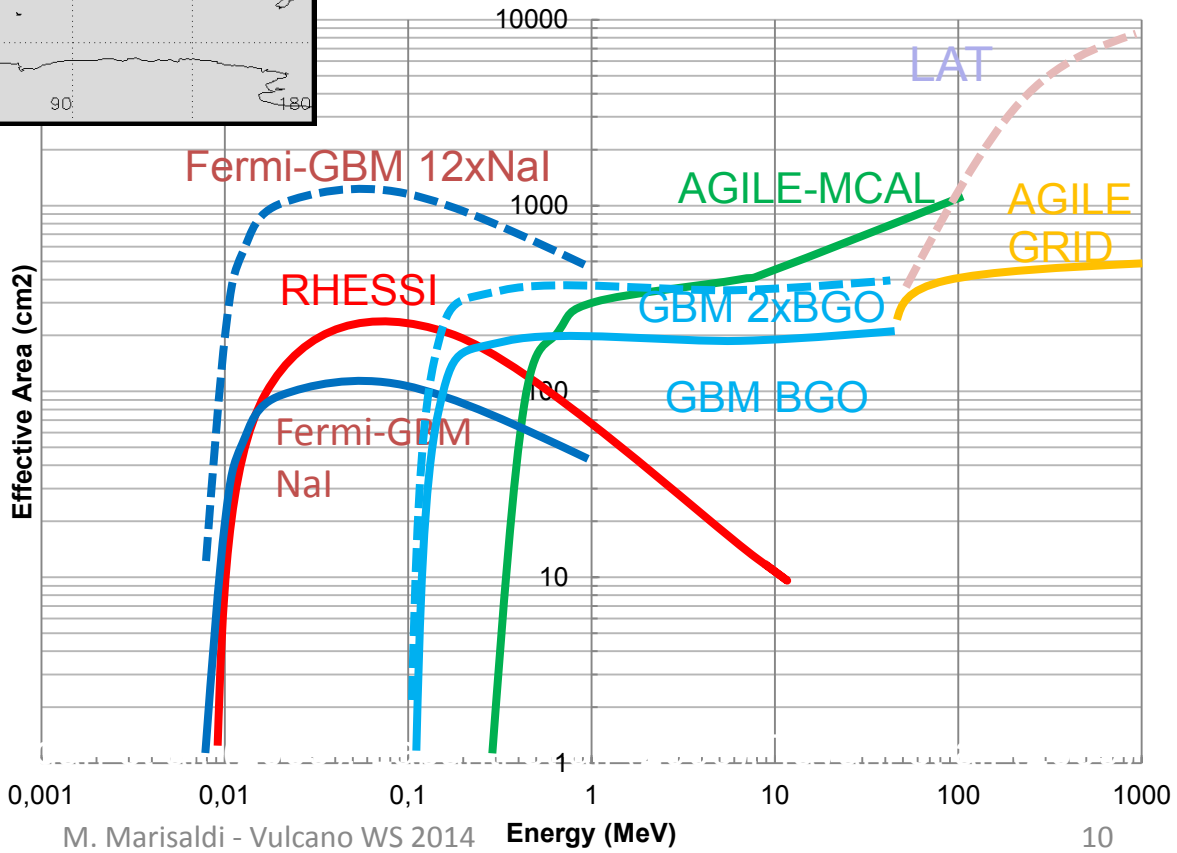
- Detection up to 40 MeV
- TGFs can produce positrons
- Electron and positron bursts can travel the geomagnetic field lines
- Gamma-ray pulses are ~100 μsec long

Operating TGF detectors

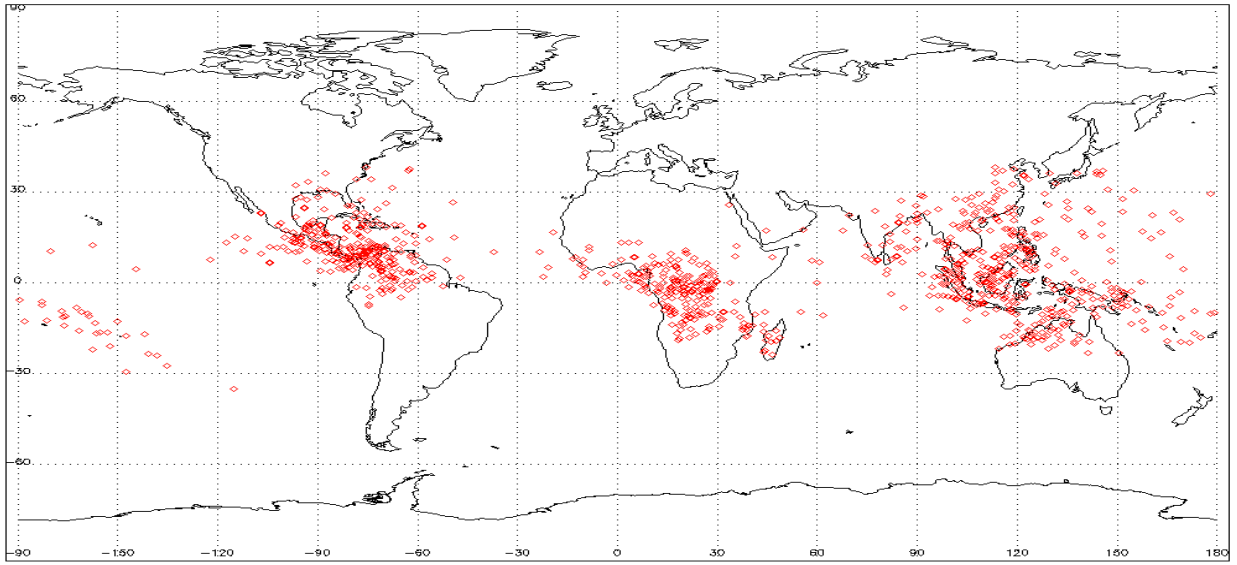


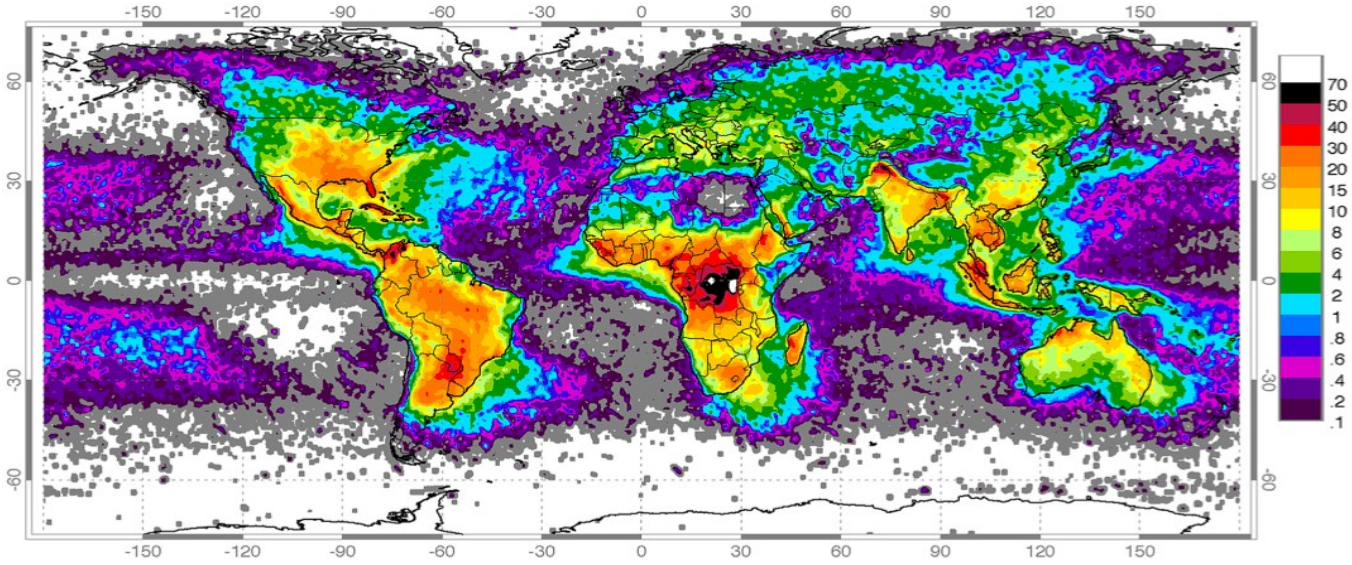






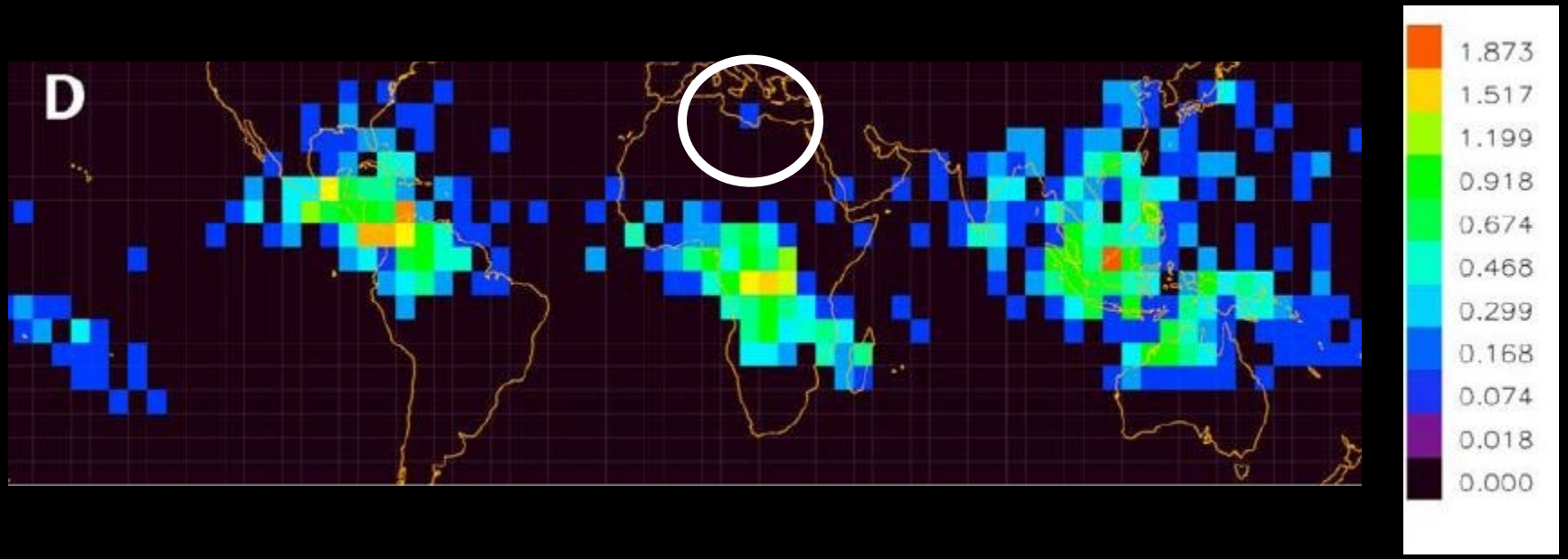
~ 1000 TGFs detected by RHESSI



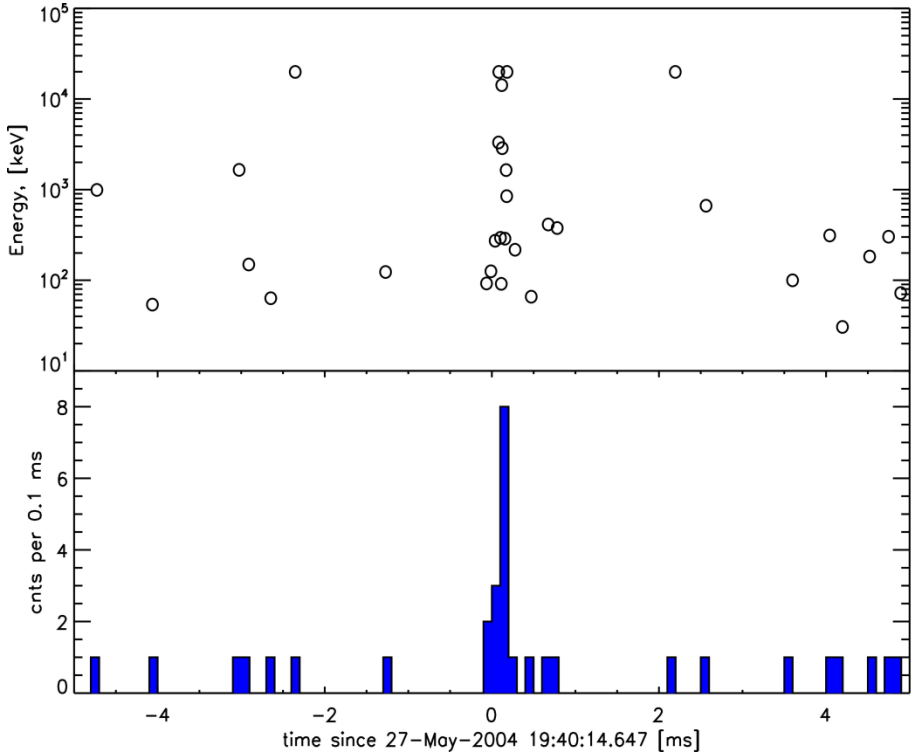


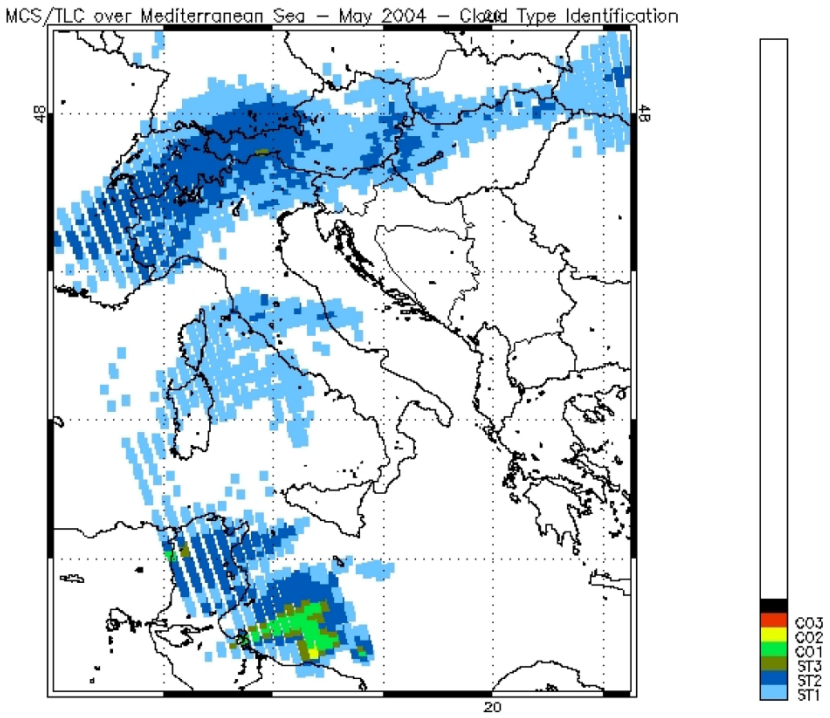
global lightning distribution [strokes · km^{-2} · year^{-1}]

TGF_RHESSI_distribution



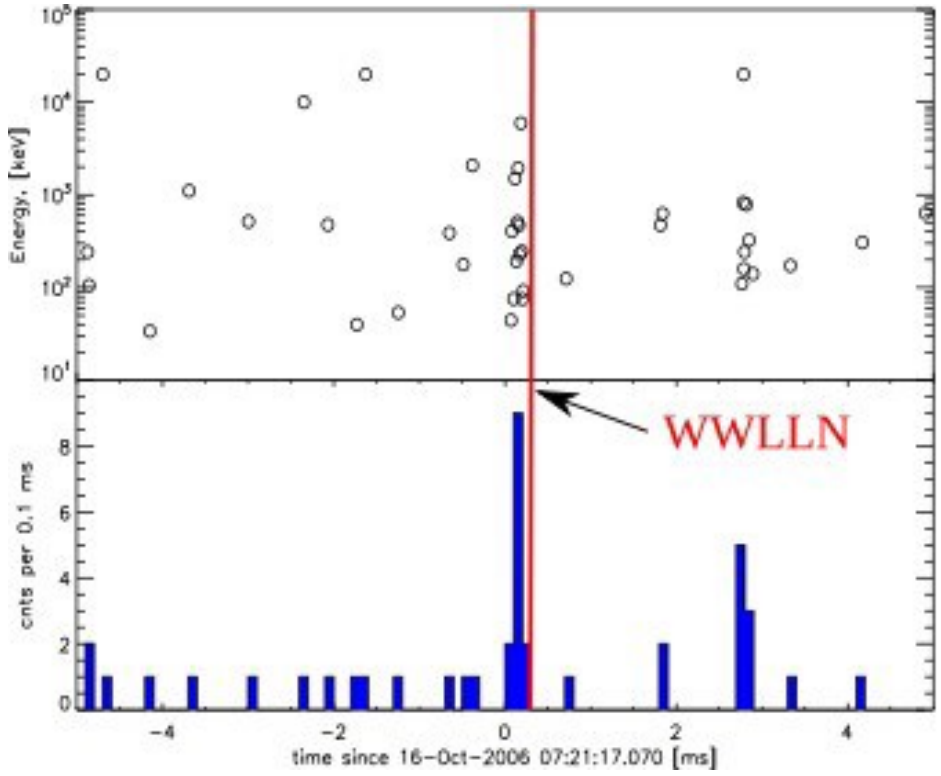
RHESSI TGF on the Mediterranean sea: May 27, 2004

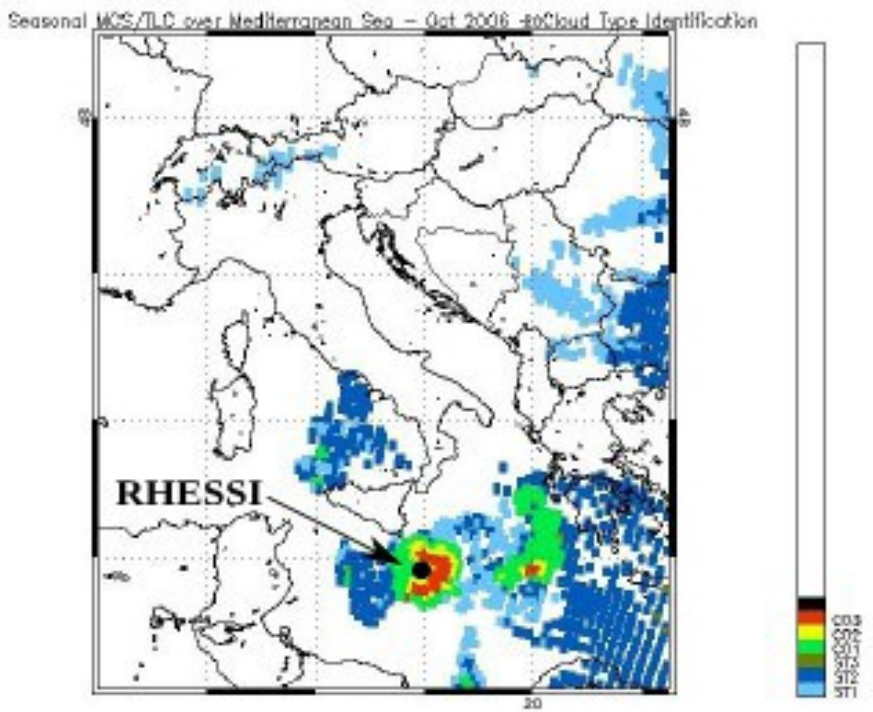




(Gjesteland at al., EGU-2013)

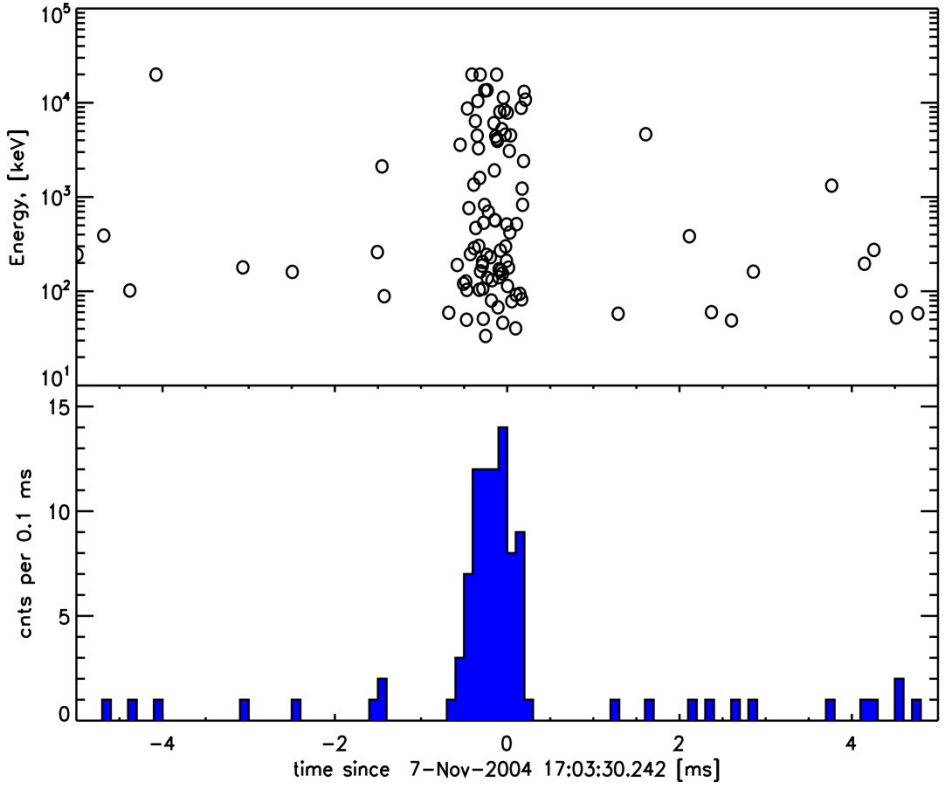
RHESSI TGF on the Mediterranean sea: October 16, 2007

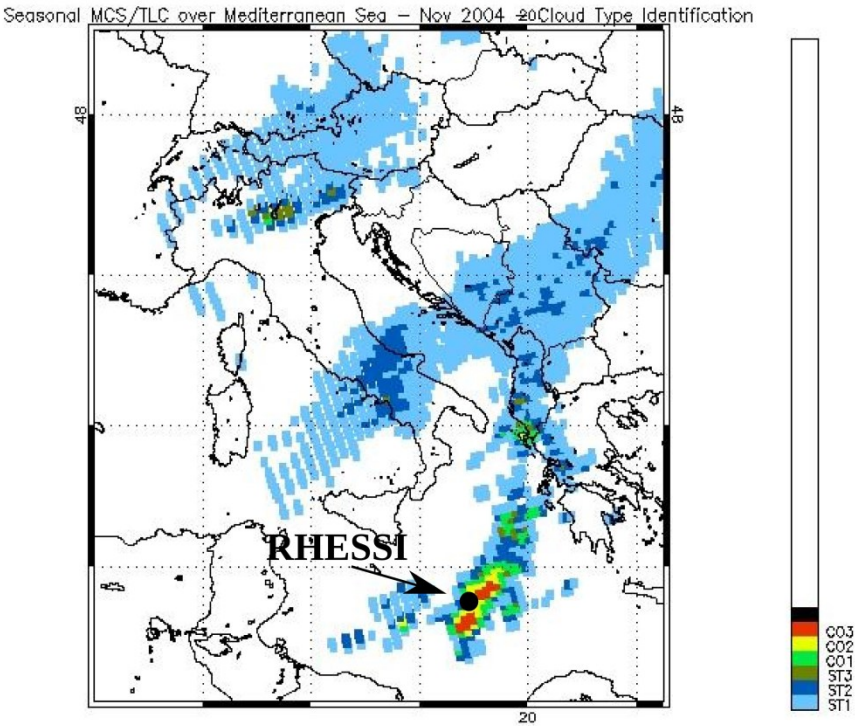




(Gjesteland at al., EGU-2013)

RHESSI TGF on the Mediterranean sea: November 7, 2004

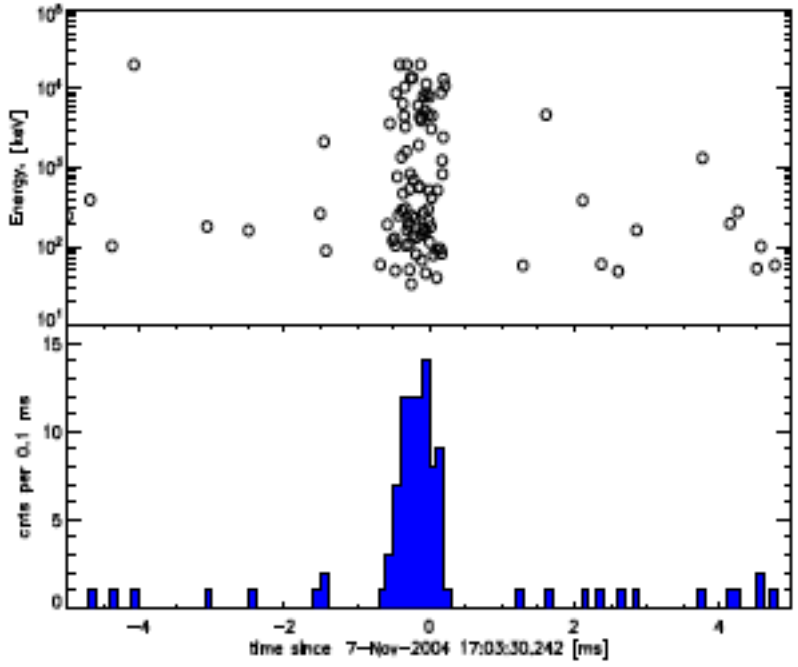




(Gjesteland at al., EGU-2013)

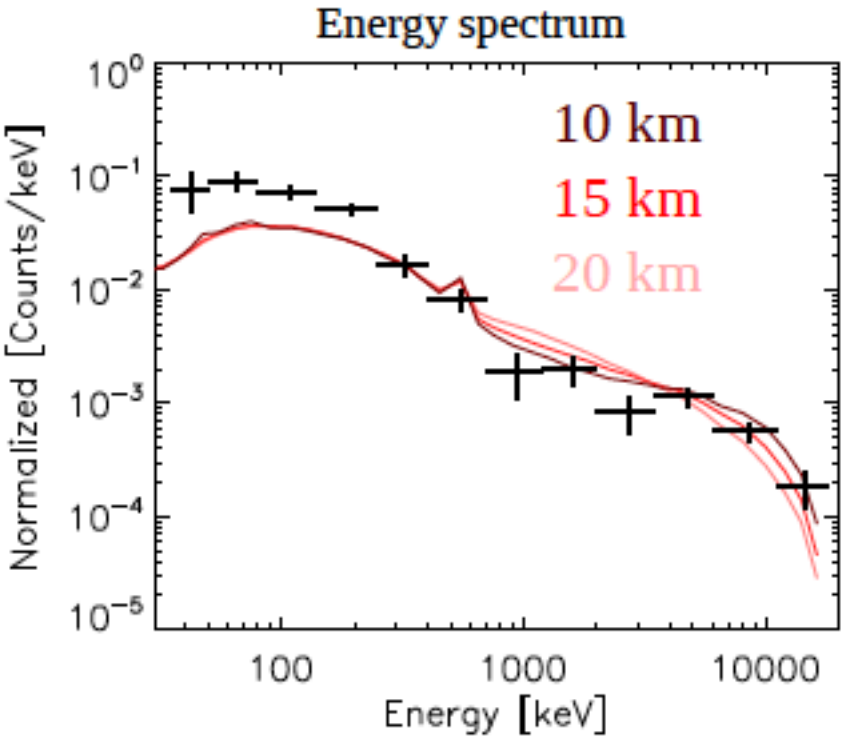
TGF over the Mediterranean sea on November 7th 2004

(Gjesteland at al., EGU-2013)



Energy spectrum

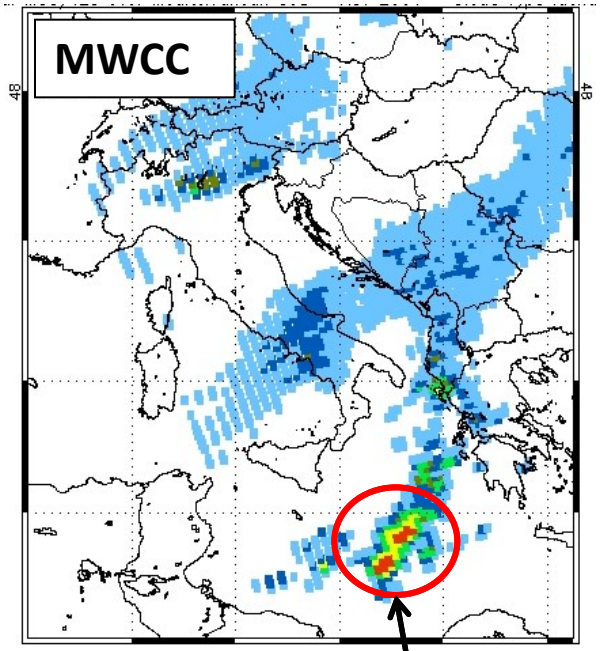
This TGF is unusually bright and it among the 1% brightest RHESSI TGF ever measured



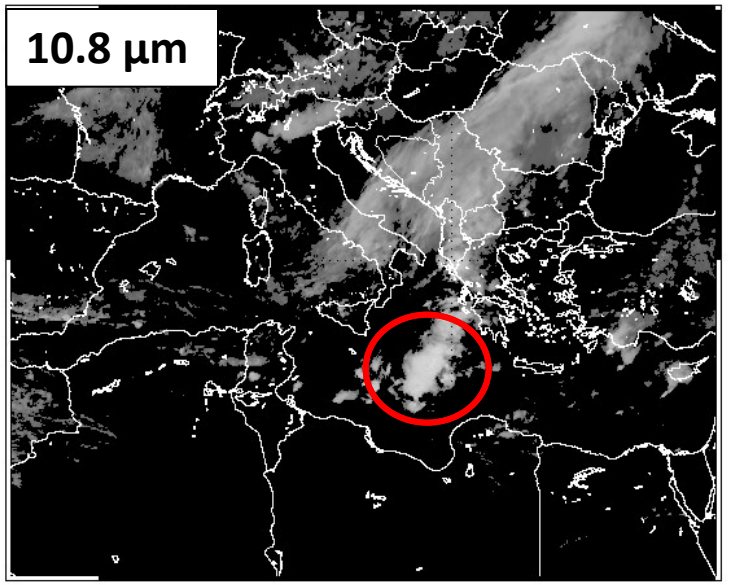
Curves show the simulated TGFs from 10, 15, and 20 Km of altitude folded through the RHESSI detector response matrix. For higher energies the 10 km production altitude gives best fit to the measurements (black crosses)

TGF over the Mediterranean sea on November 7th 2004

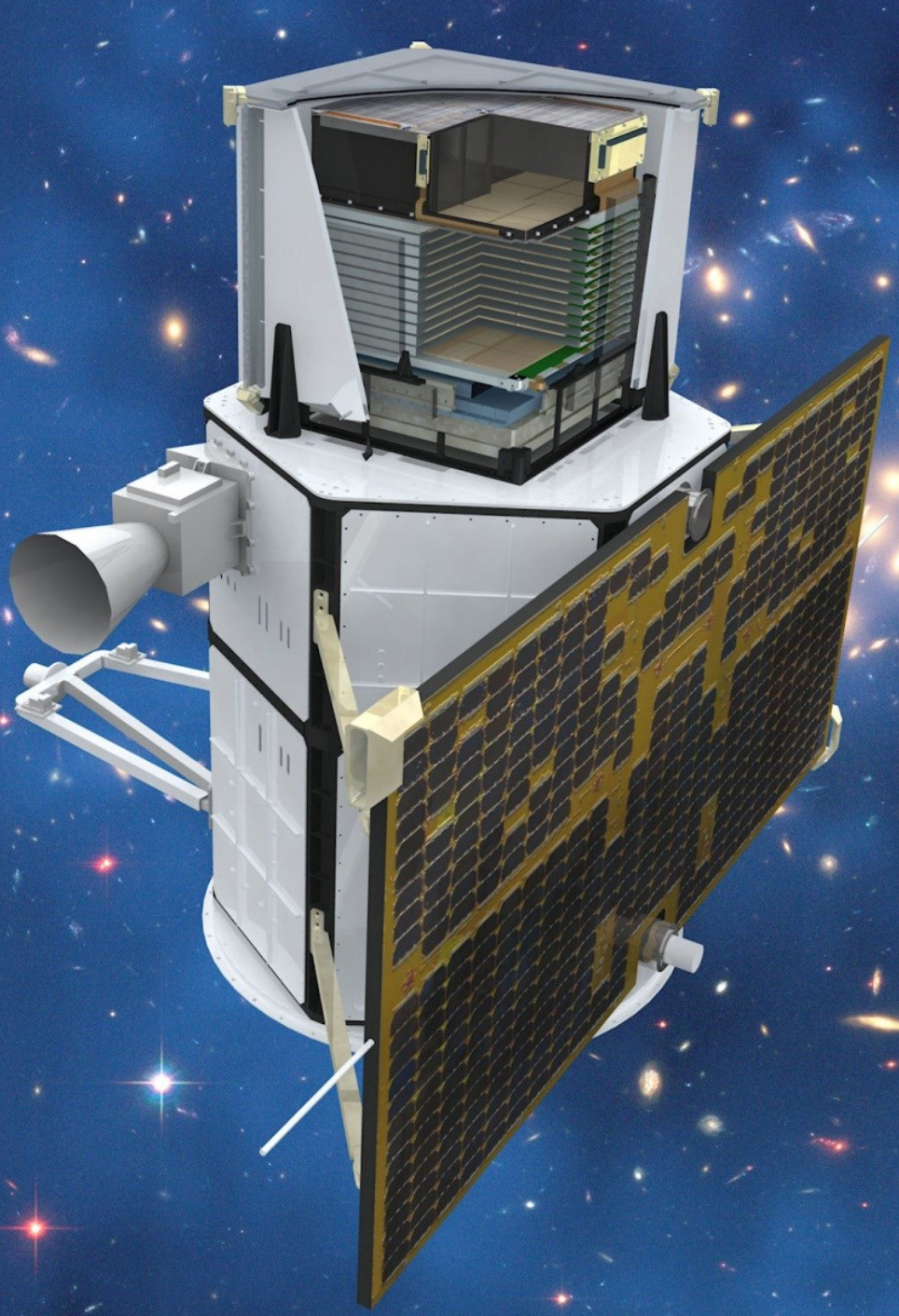
(The satellite analysis has been achieved by Sante Laviola – ISAC-CNR, Bologna)



Convective cores (**red spots**) with altitude greater than 8-10 km calculated on the basis of the MicroWave Cloud Classification method.



The MSG image at 10.8 µm (BT11) with a cloud threshold (BT11<260 K) reveals a cold cloud (red circle) which can be reasonably associated to convective rain cloud.

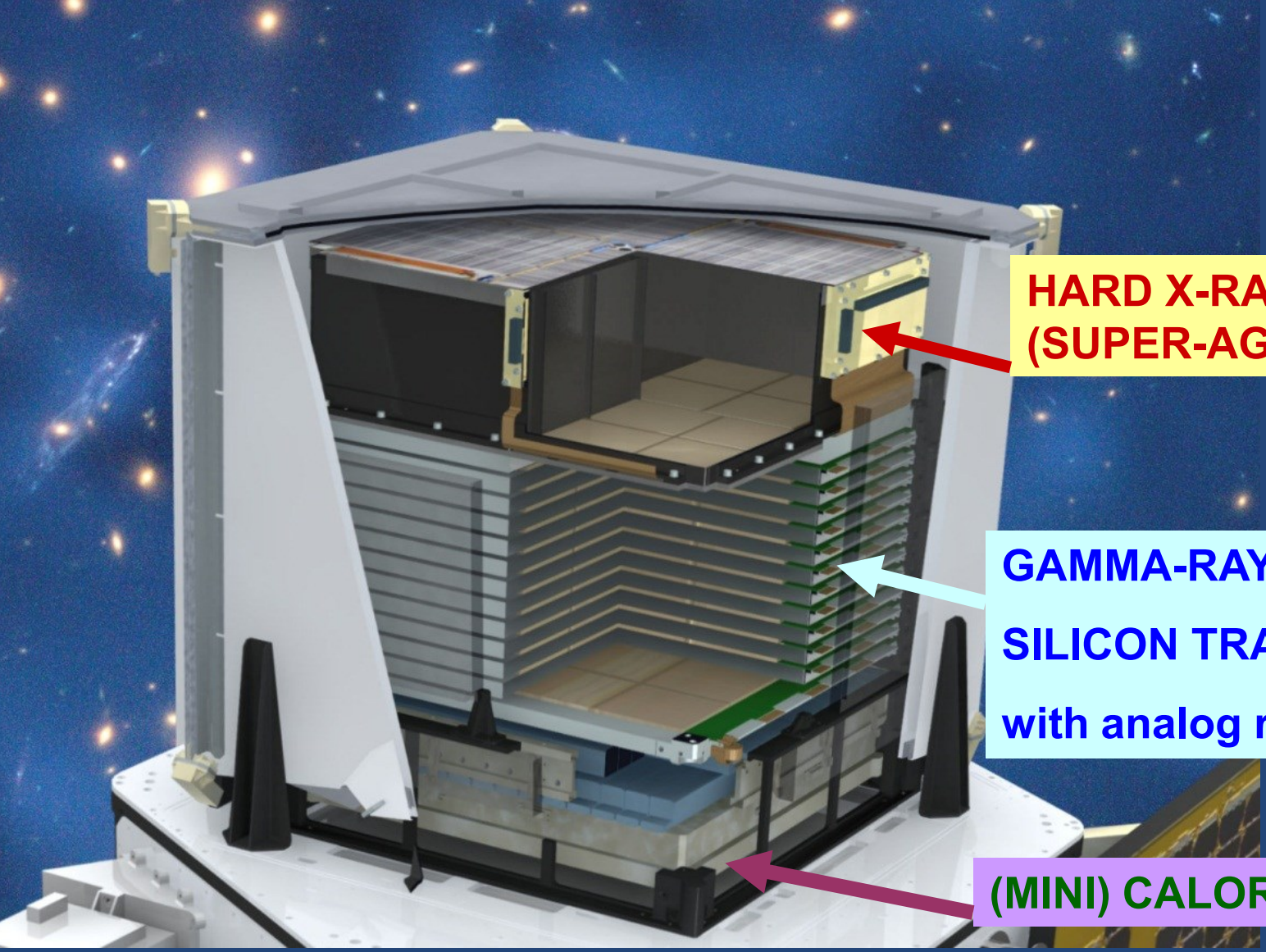


agenzia spaziale italiana

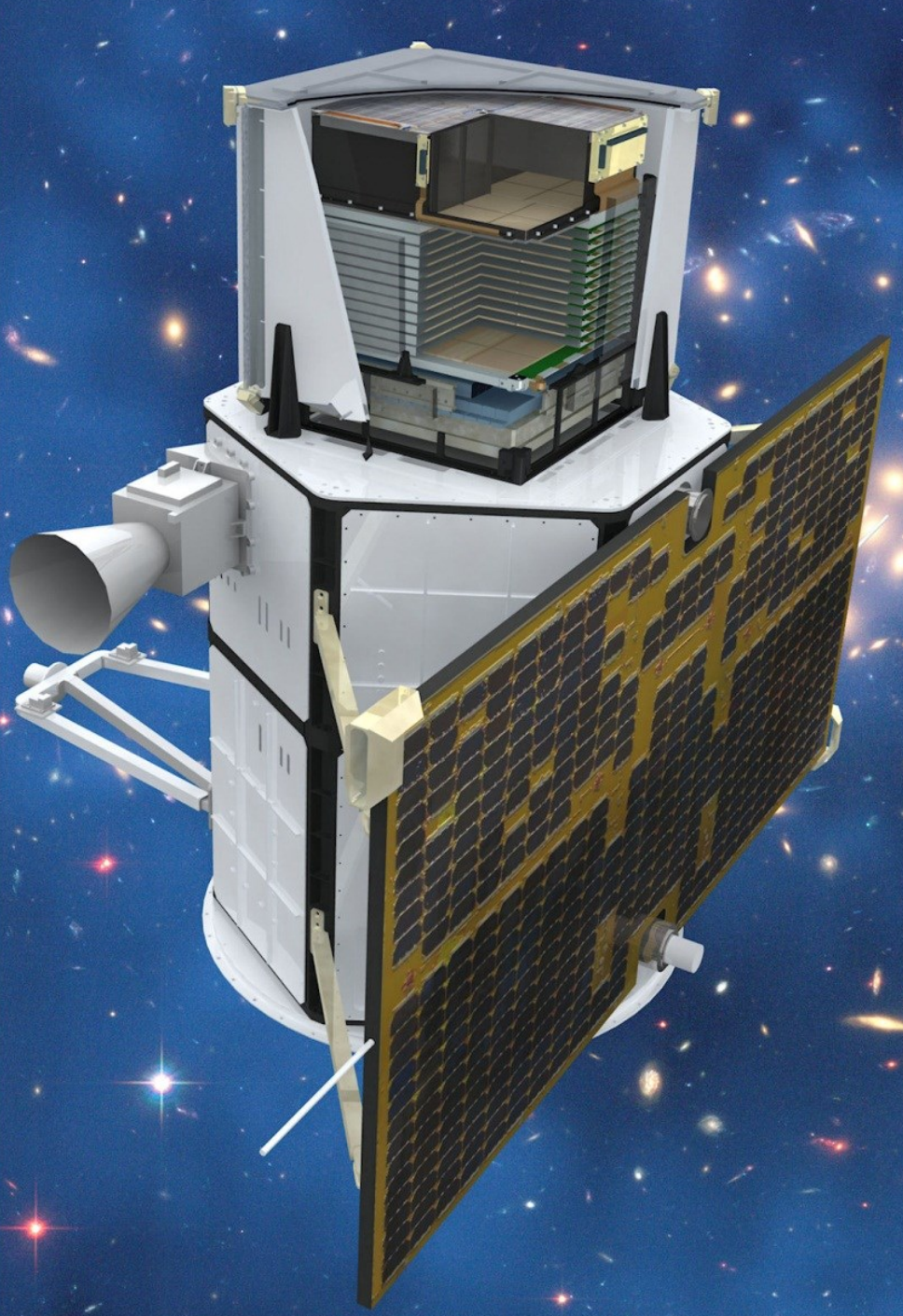
INAF INFN asdc ASI Science Data Center

The AGILE Mission:

It combines for the first time a gamma-ray imager (50 MeV- 30 GeV) with a hard X-ray imager (18-60 keV) with large FOVs (1-2.5 sr) and optimal angular resolution



the AGILE instrument

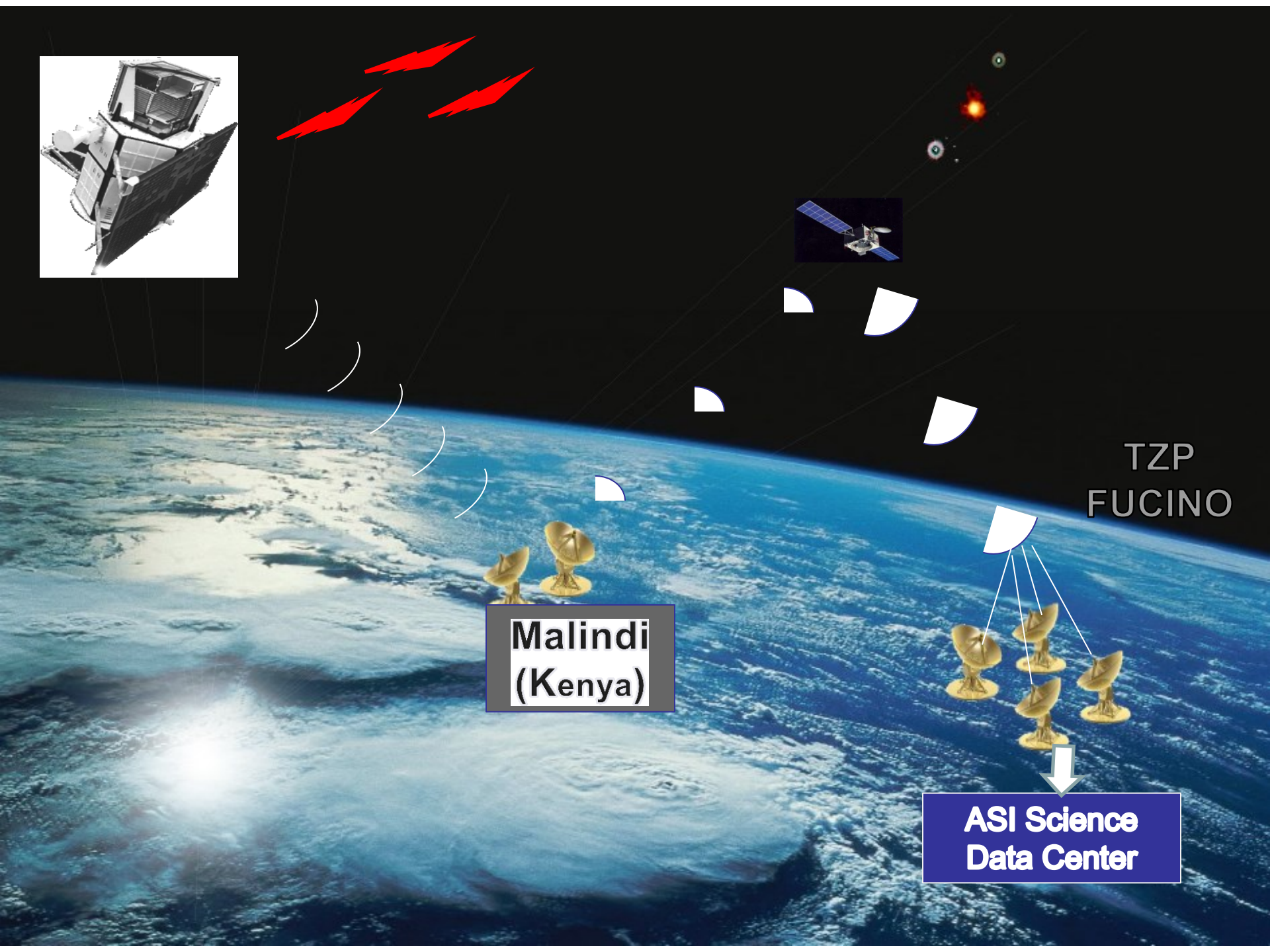


The AGILE Mission:

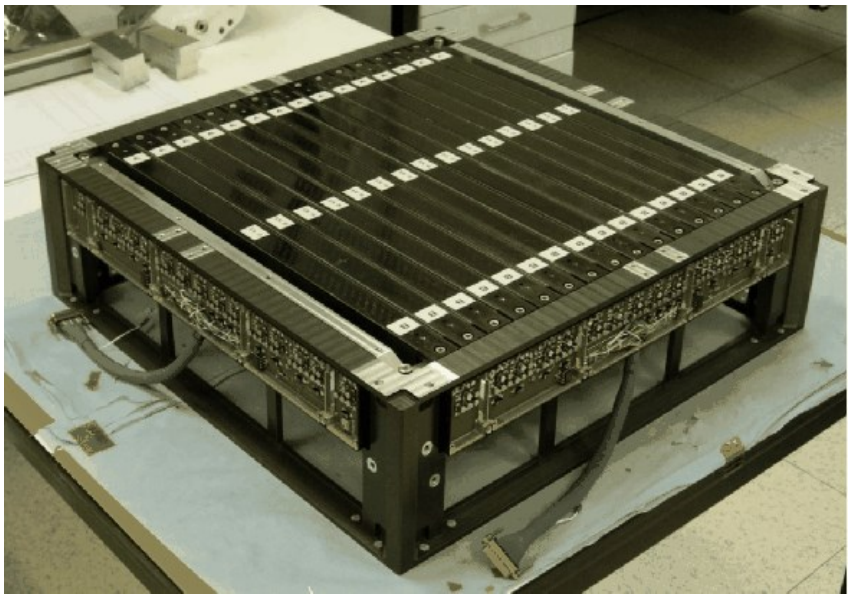
- optimal sensitivity & exposure at "low" γ-ray energies (well calibrated near 100 MeV)

- excellent PSF (100 MeV- 1 GeV)

- VERY EFFICIENT ALERT SYSTEM FOR TRANSIENTS

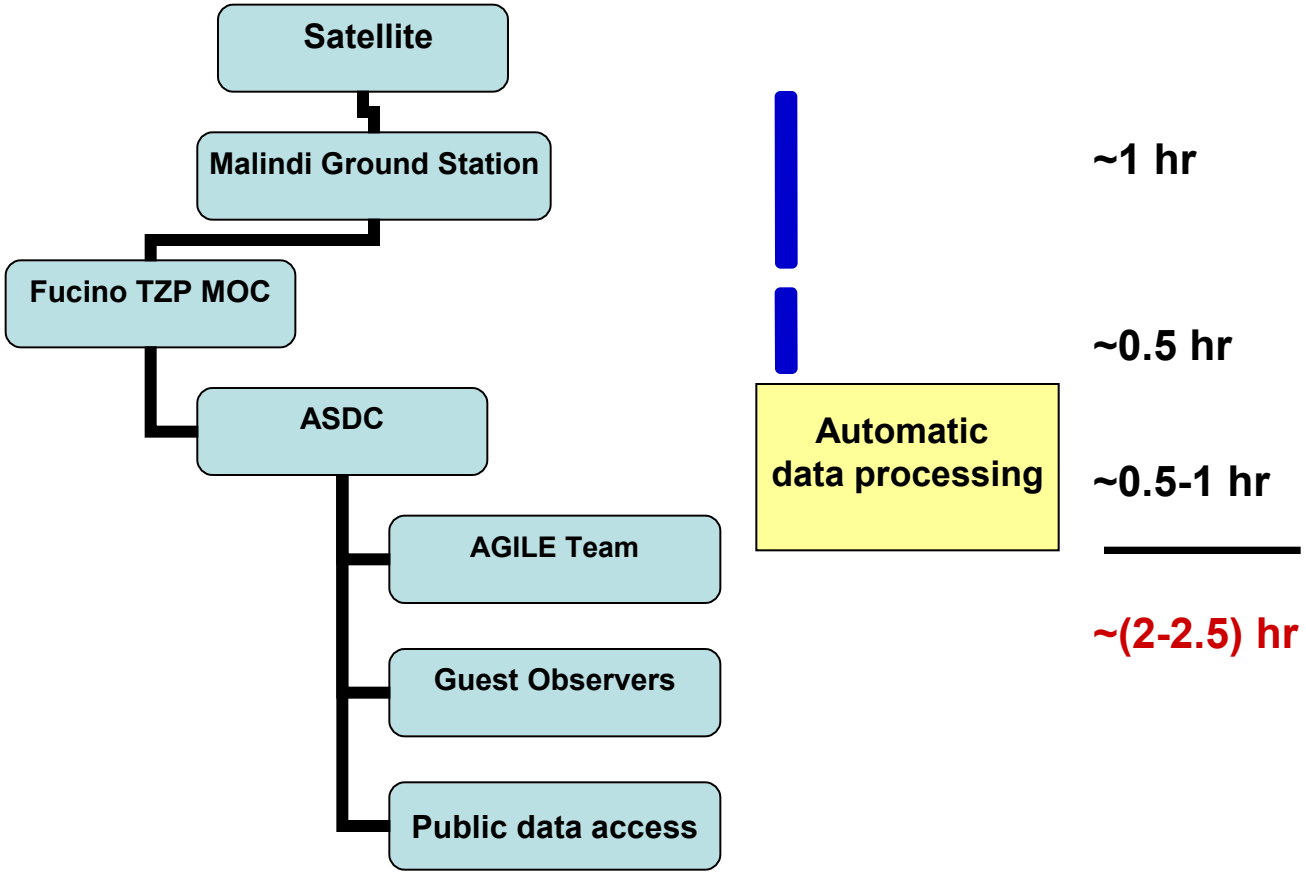

TZP
FUCINO
Malindi
(Kenya)
ASI Science
Data Center

AGILE Mini Calorimeter (MCAL)

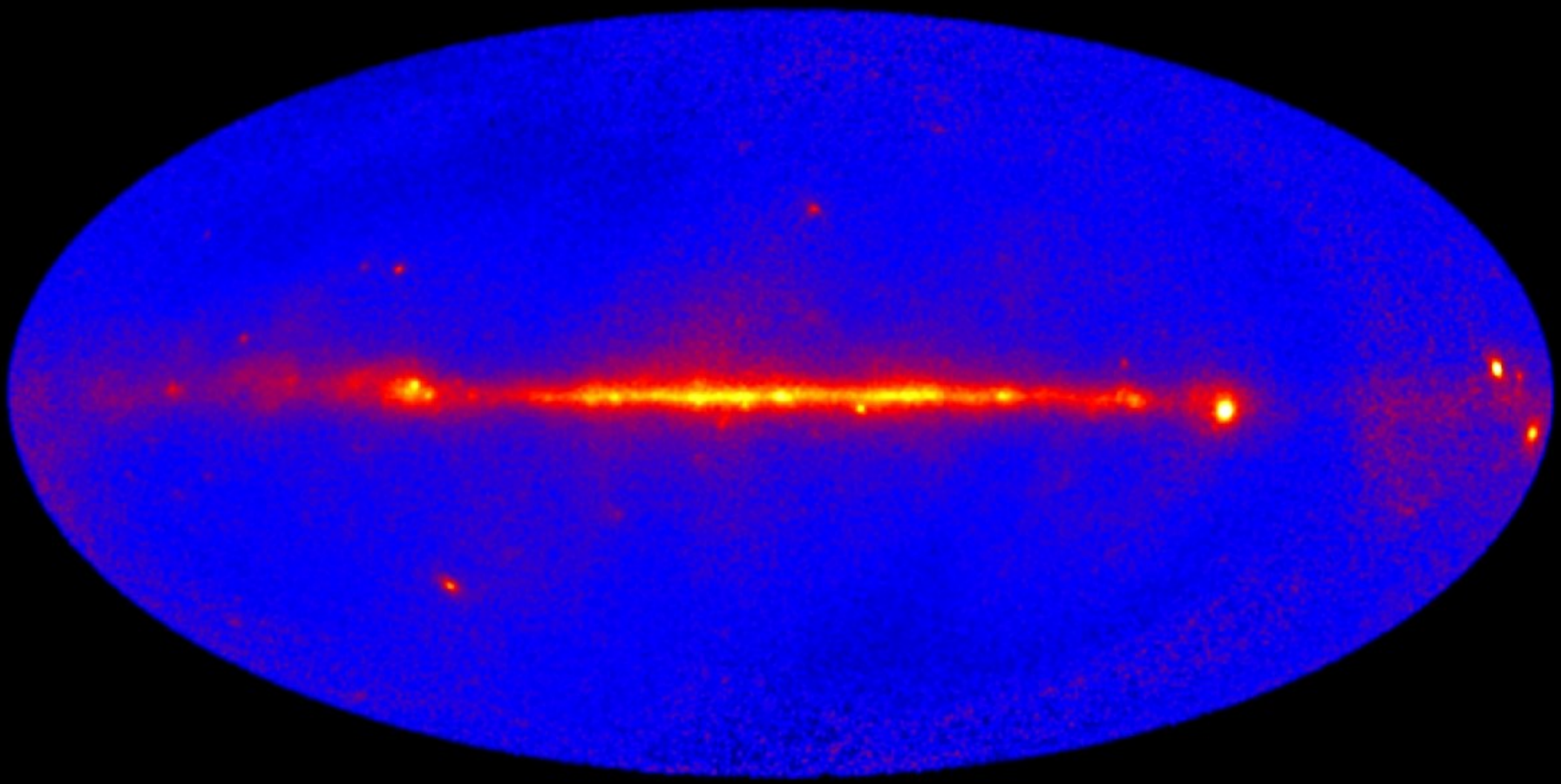


- 30 CsI(Tl) bars (photodiode readout)
- Geometrical area: 1400 cm^2
- Effective area: ~ 300 cm^2
- Energy range: 330 keV ÷ 100 MeV
- Energy resolution: 14% FWHM @ 1.3 MeV
- Timing accuracy: 2 μs (photon-by-photon mode)
- Trigger logic time scales: 8 s, 16 ms, 1 ms, 293 μs

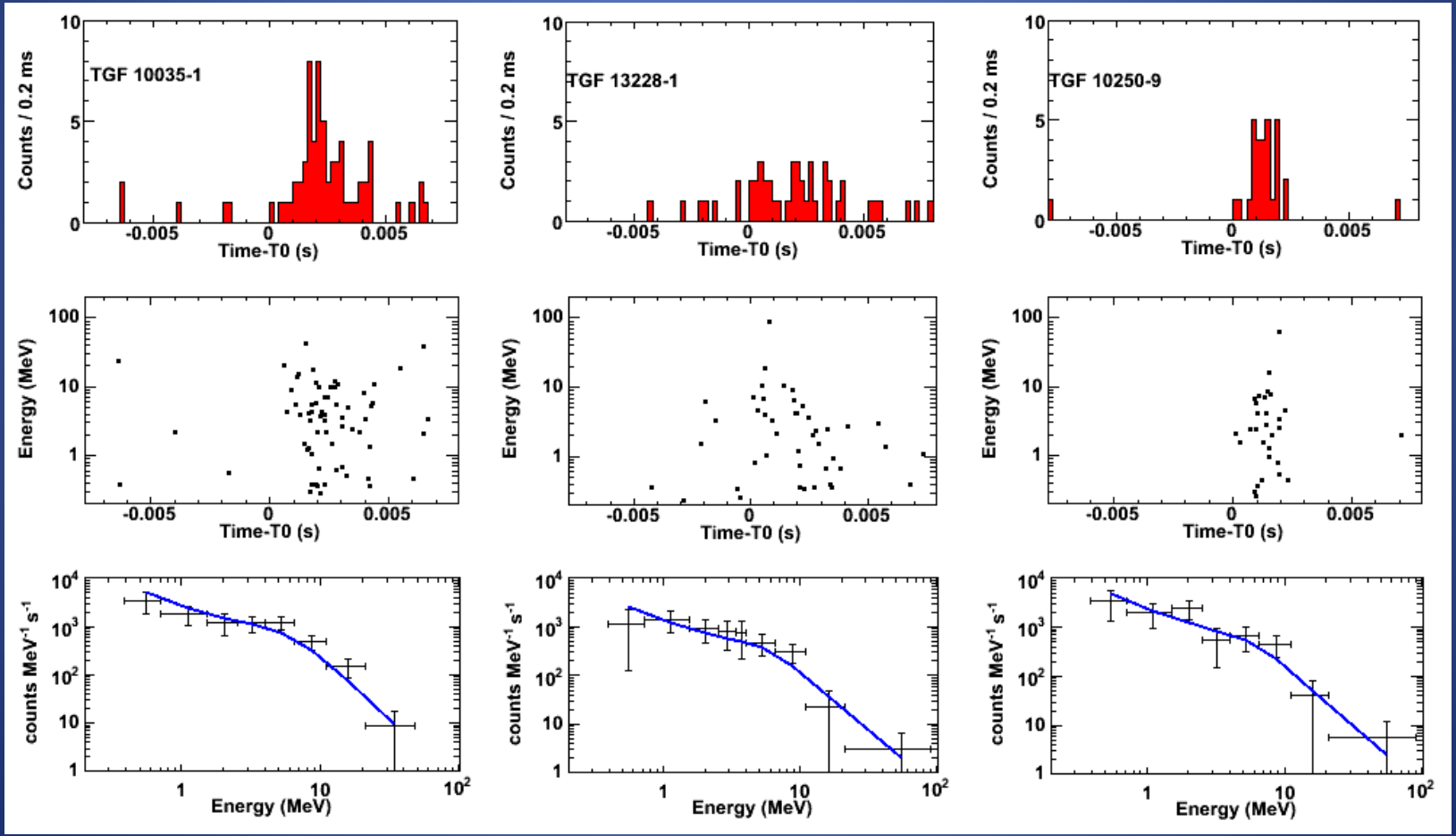
The very fast AGILE Ground Segment



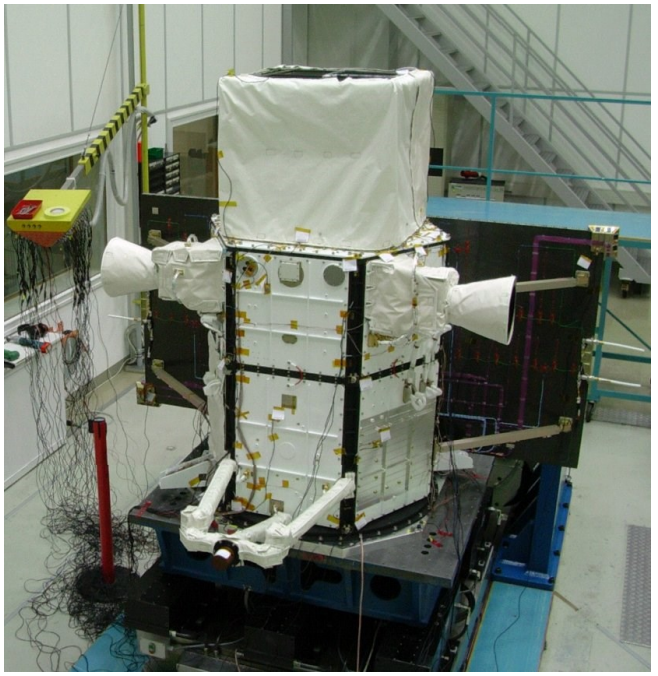
The AGILE gamma-ray sky (E > 100 MeV)
2 year exposure: July 2007 – June 2009



AGILE detection of TGFs

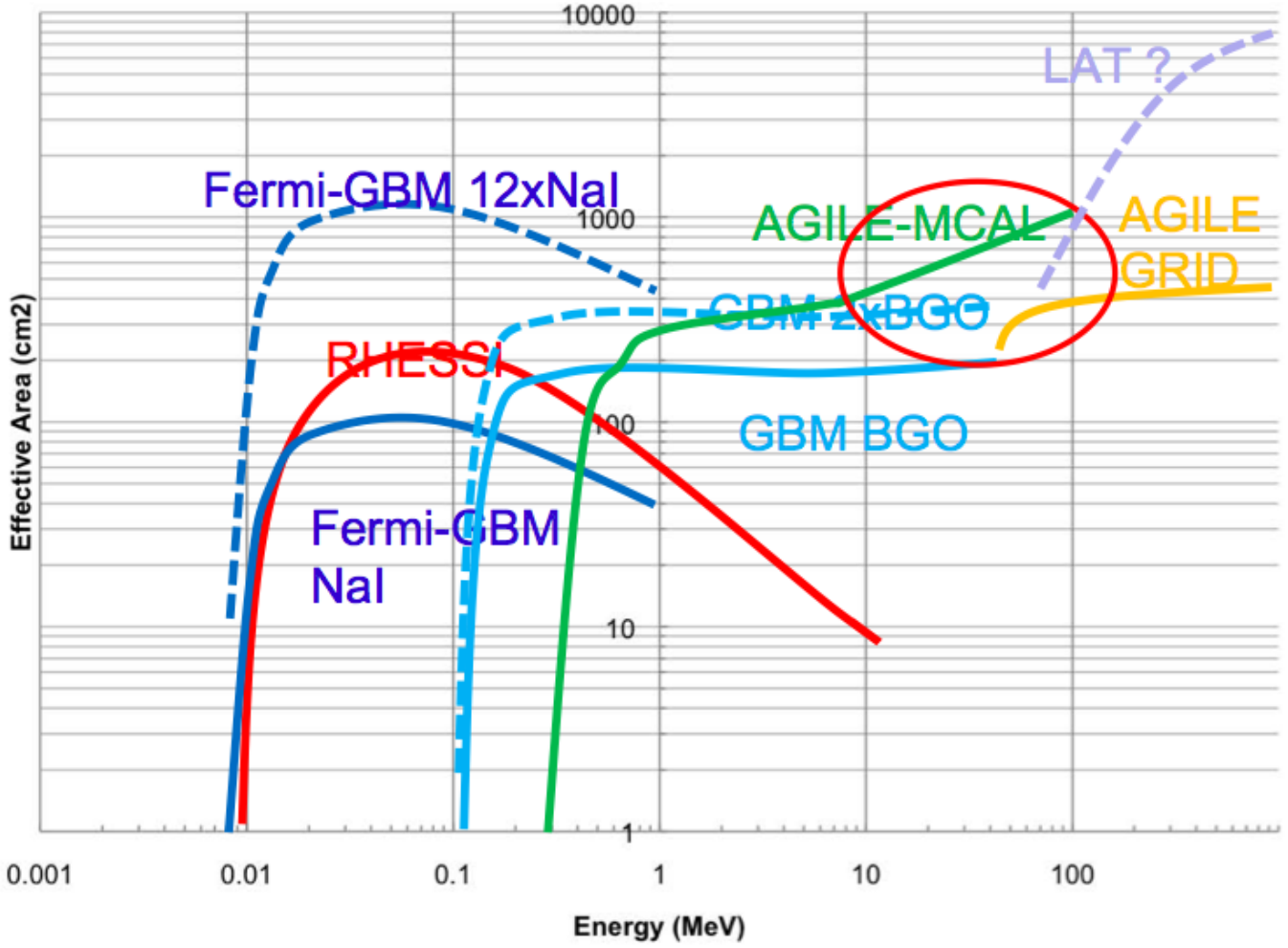


what makes AGILE unique for TGFs:



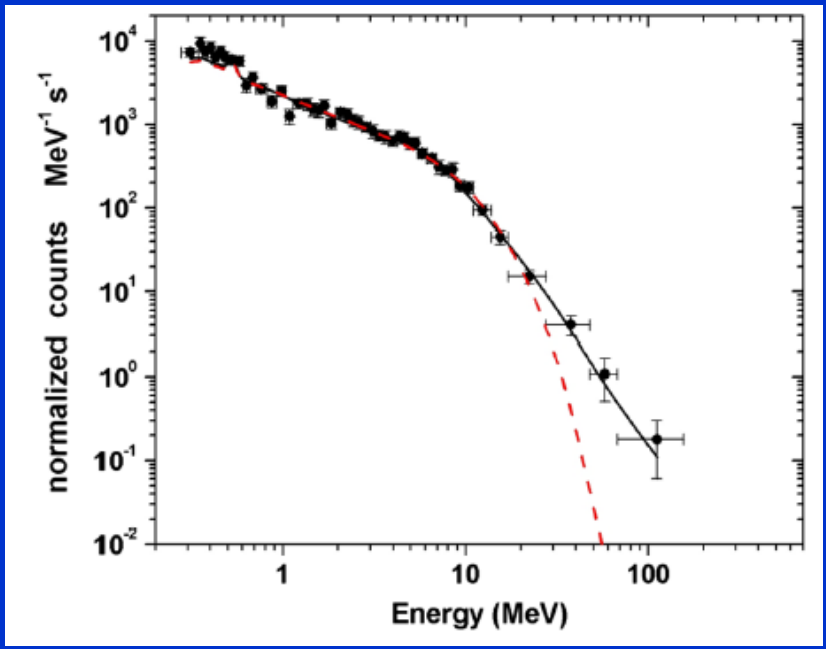
- only instrument in equatorial orbit
  - very low particle background
  - no interference from solar flare particles
- only instrument with sub-msec trigger capability
- only instrument with calorimeter high-energy capability at E > 30 MeV up to 100 MeV

Operating TGF detectors

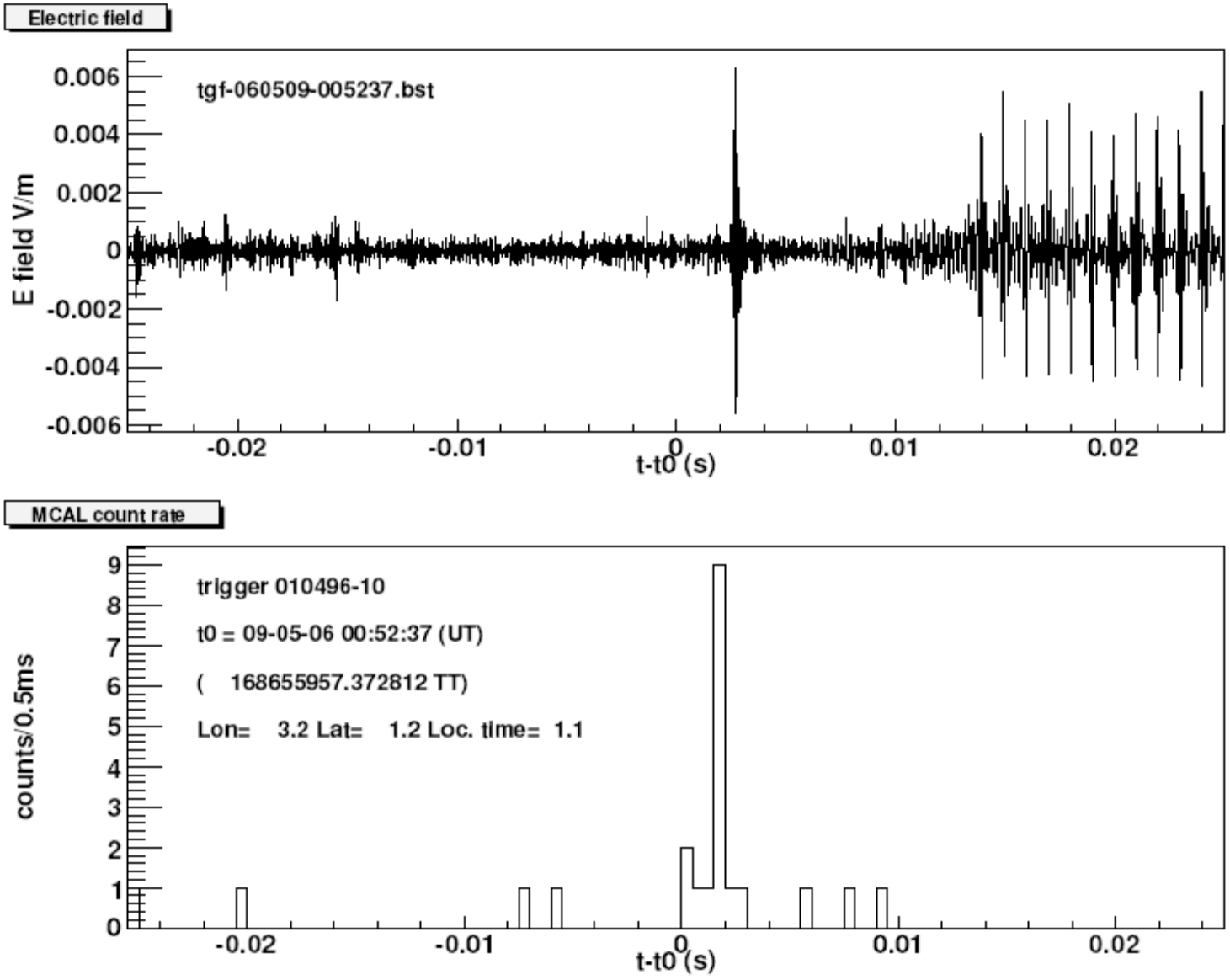


AGILE detection of Terrestrial Gamma-Ray Flashes (TGFs)

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

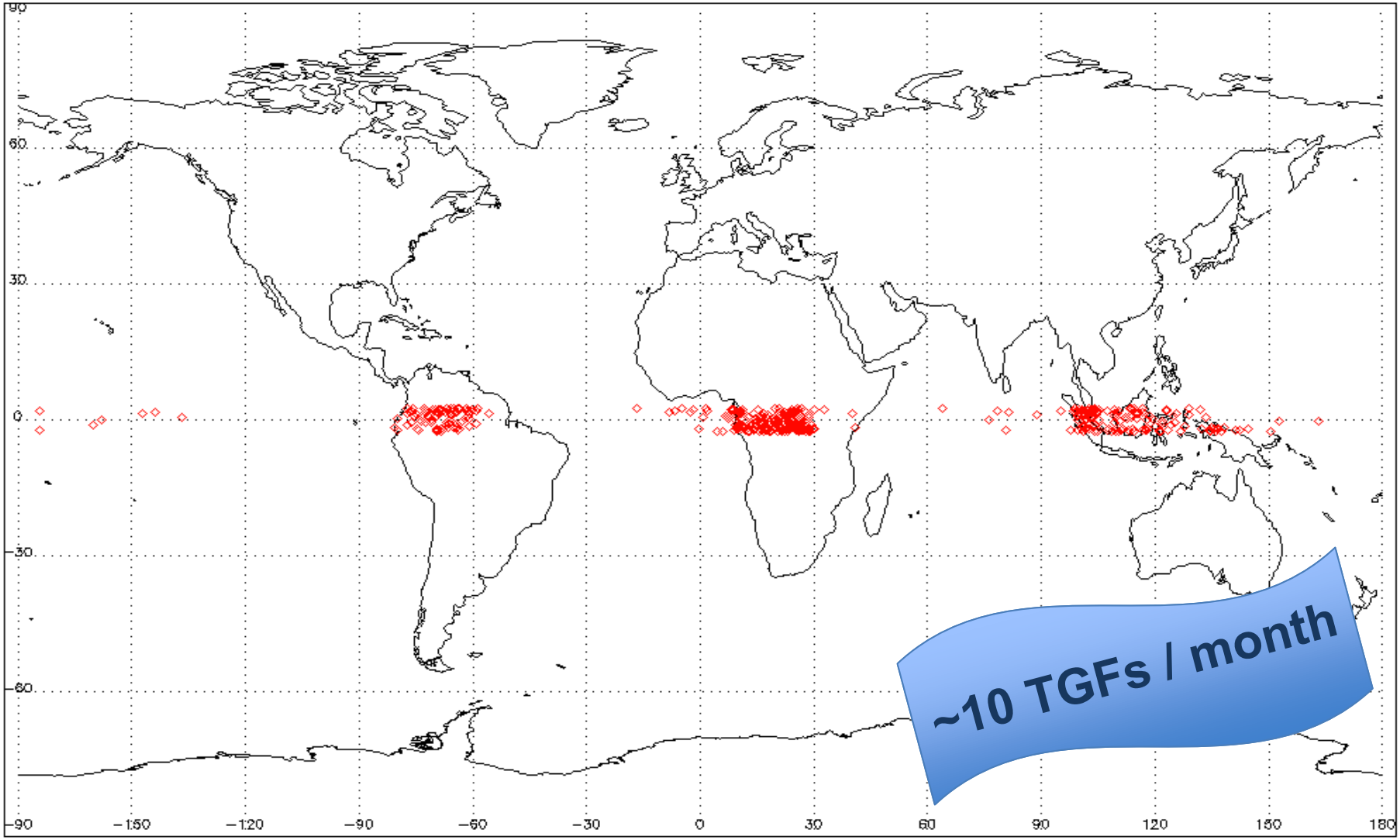


- surprising detections up to 100 MeV;
- ~ thousands of events/year localized by AGILE in the equatorial region;
- TGF impacts for environment and aircraft under study.



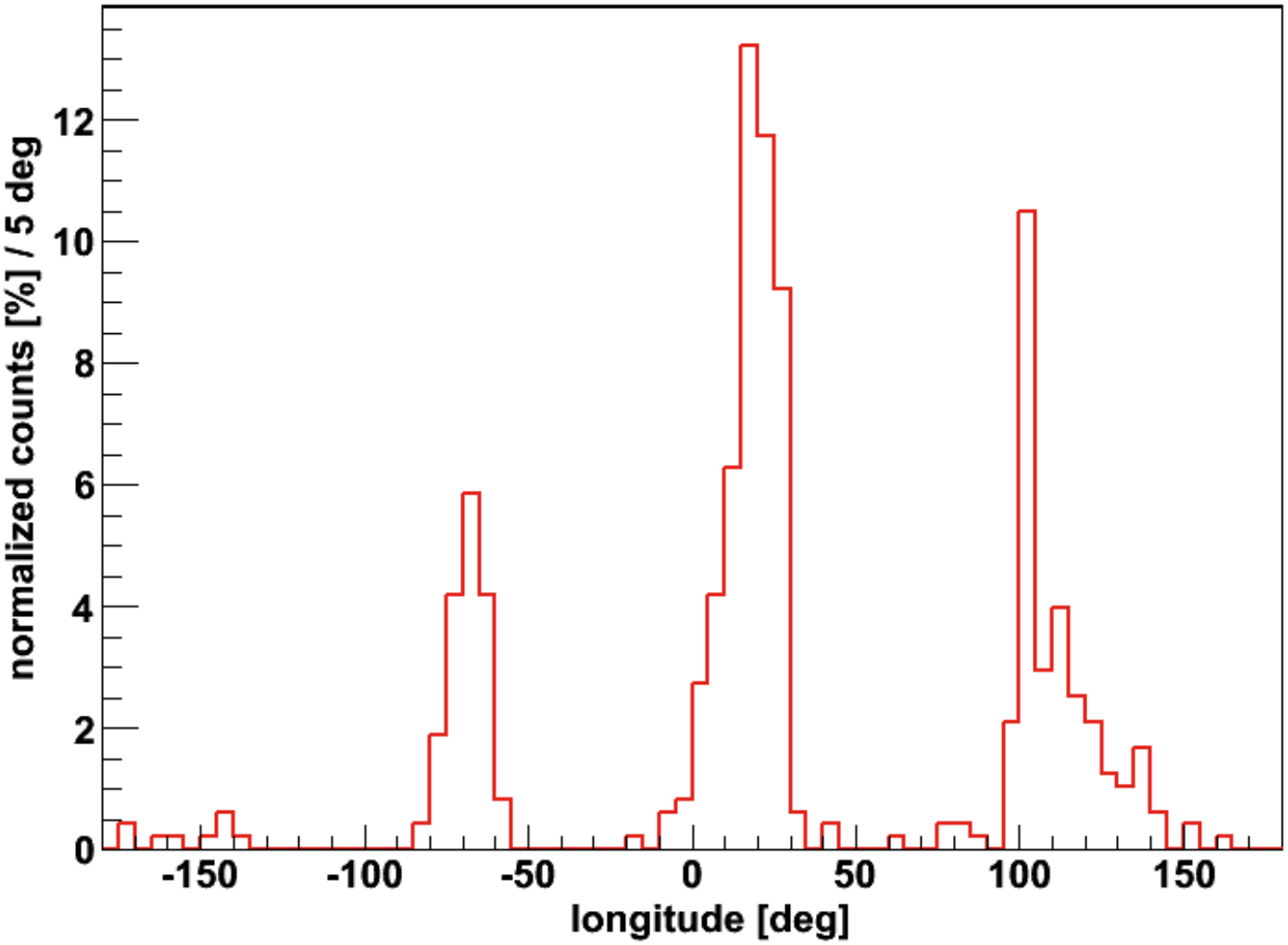
An example of a TGF detected by an electromagnetic sferic on the ground (upper panel) and by AGILE (lower panel).

AGILE as a TGF detector



March 2009 ÷ December 2013

431 TGFs



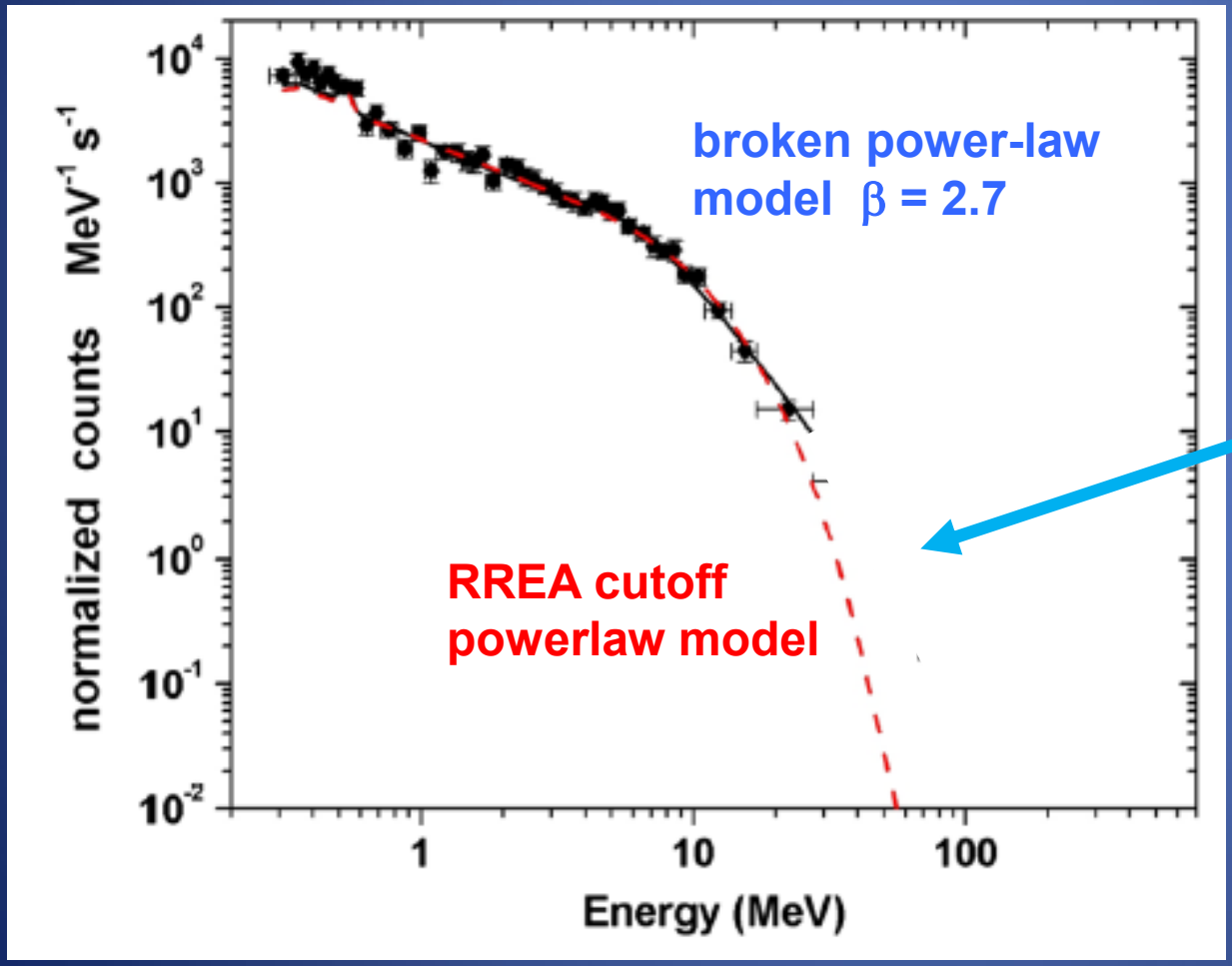
South America
20% TGFs

Africa
45% TGFs

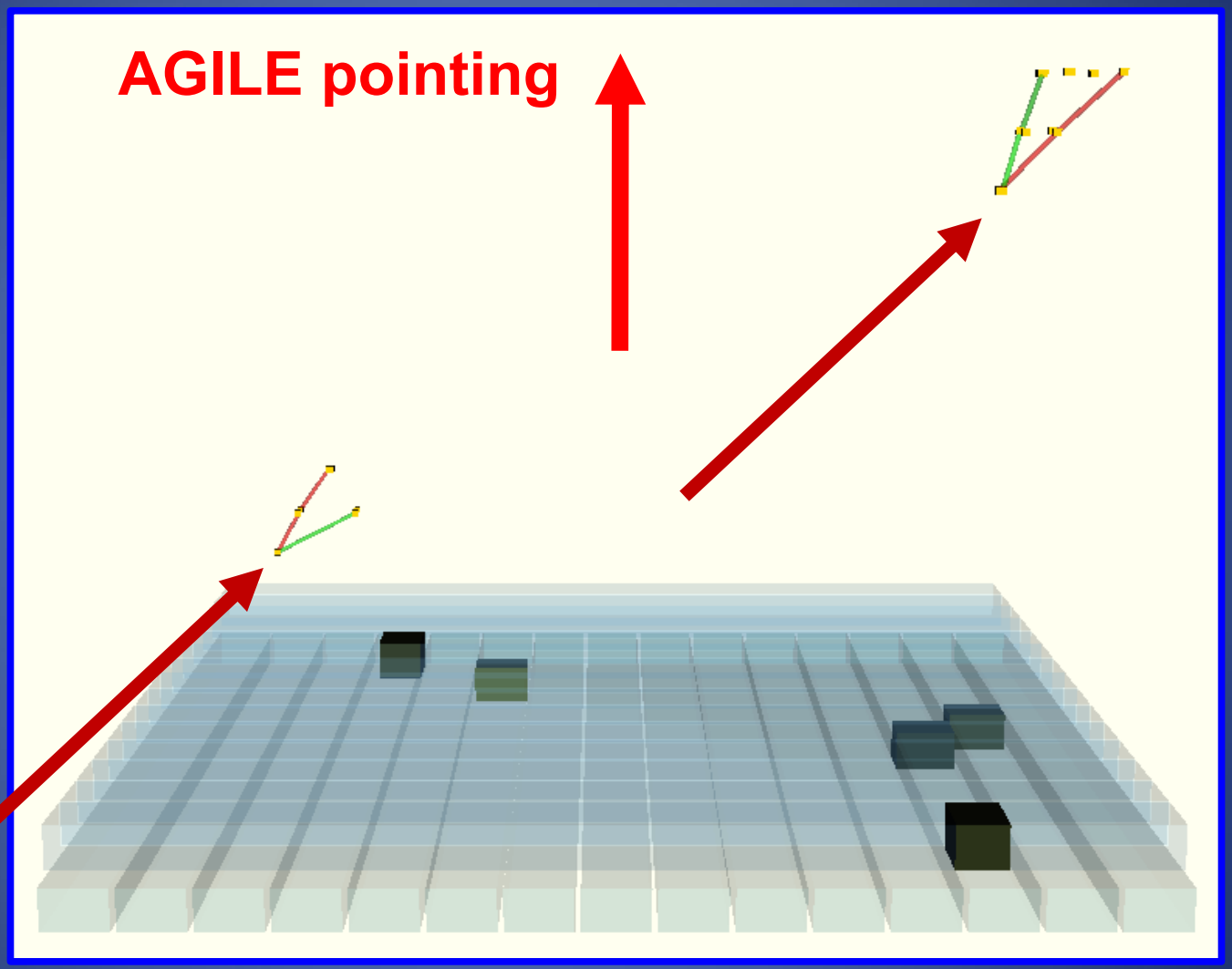
Maritime Continent
32% TGFs

TFG cumulative spectrum

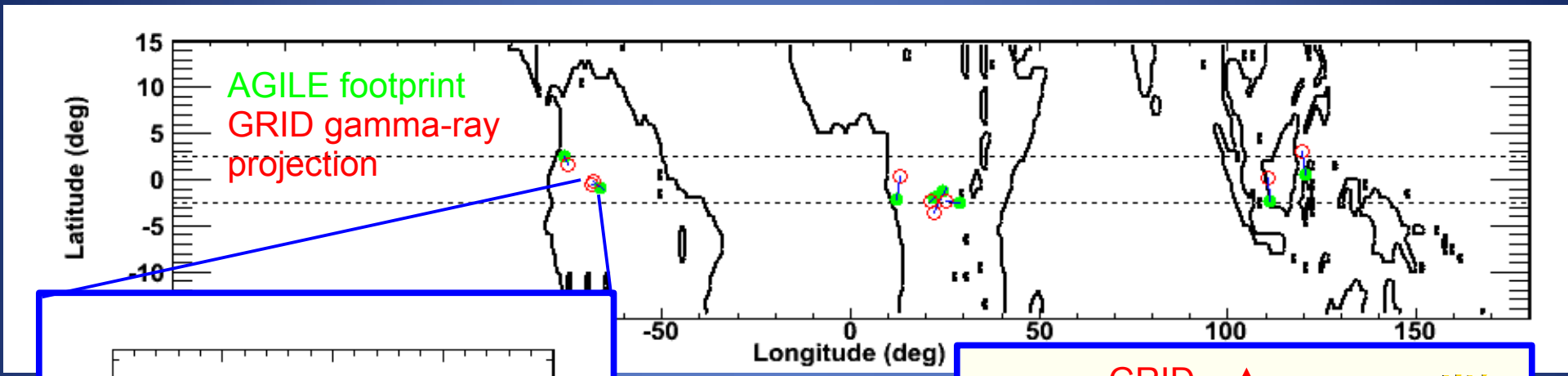
Tavani et al., Phys. Rev. Letters 106, 018501 (2011)

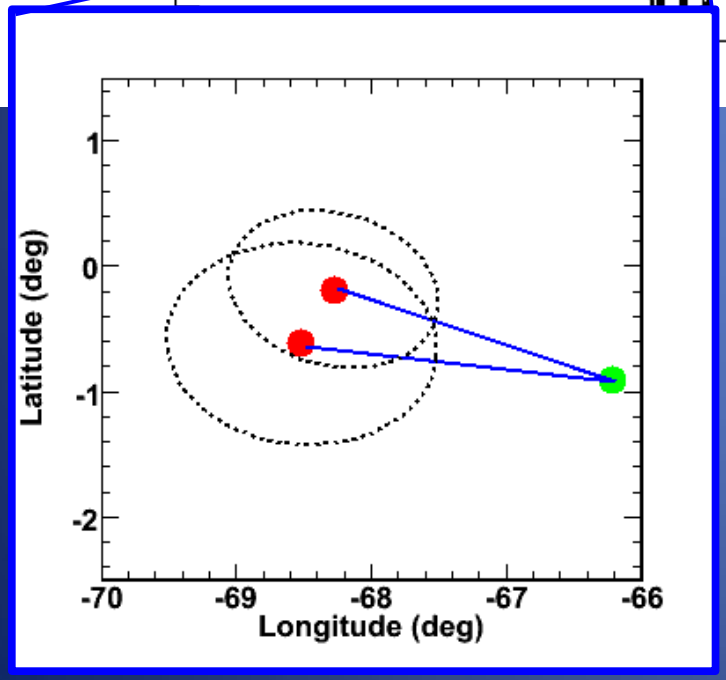


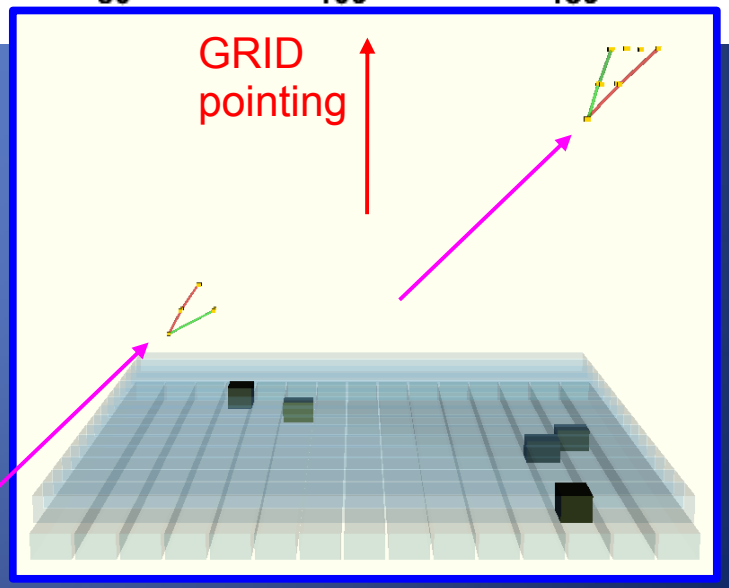
significant detection of γ–rays with E>40 MeV unexplained by standard RREA models: a challenge for emission models


AGILE pointing
"reverse event"
direction
(TGF source)

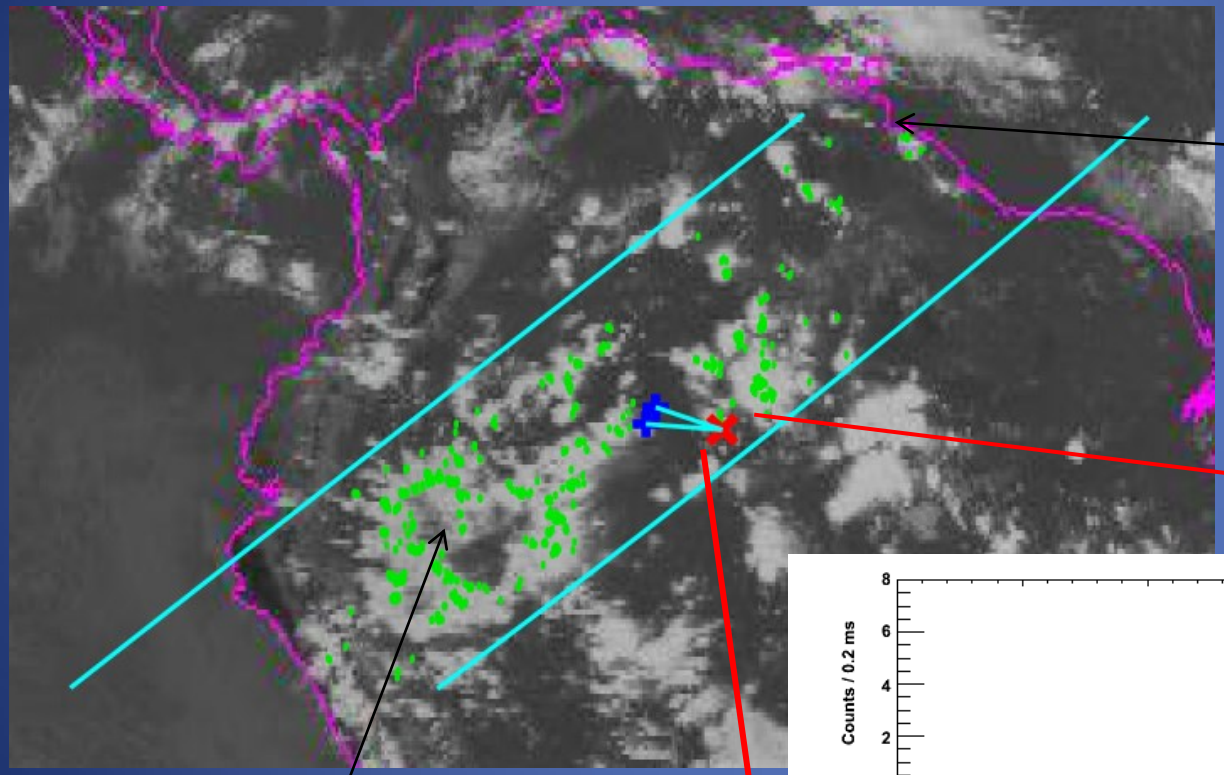
Geographical distribution







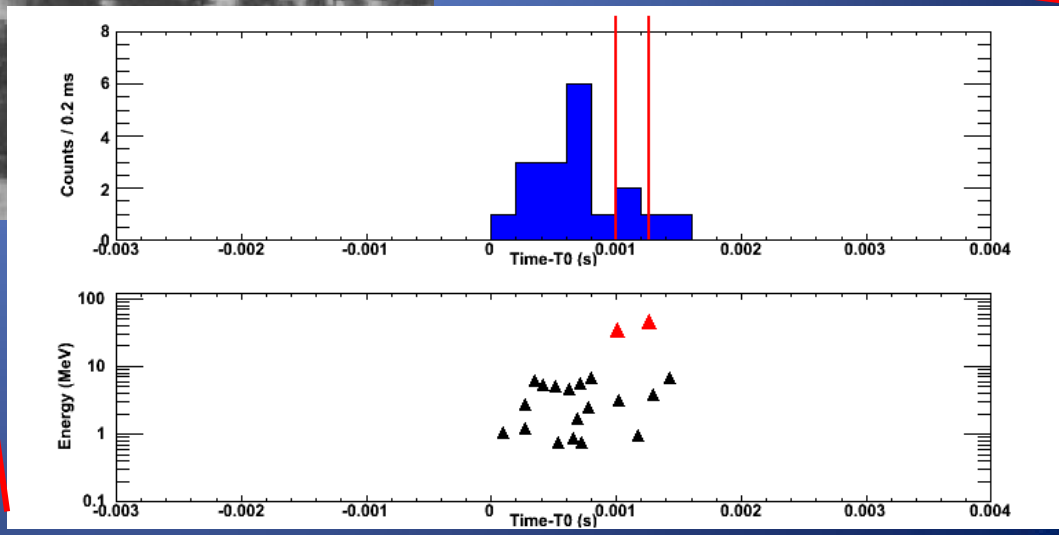
TGF 12809-19 in details (2010 Oct. 16 20:44:55 UT)



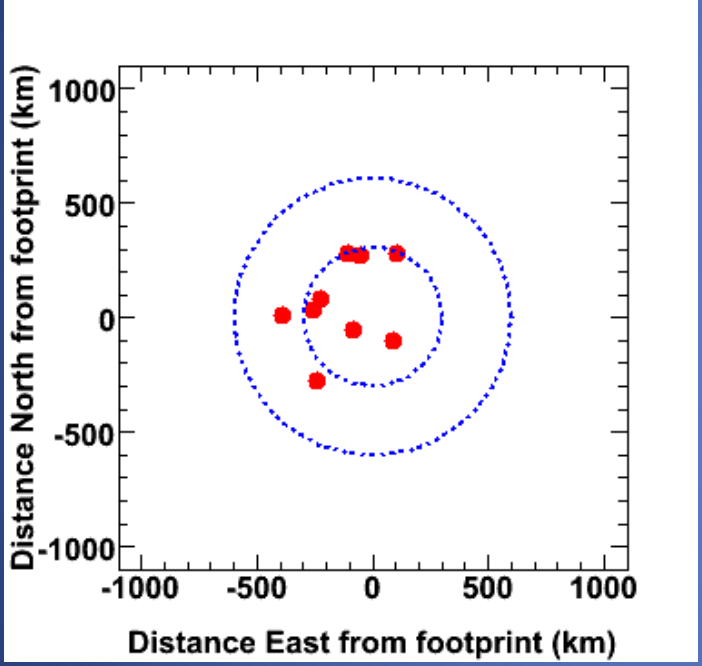
Credits: B. Carlson, Univ. Bergen

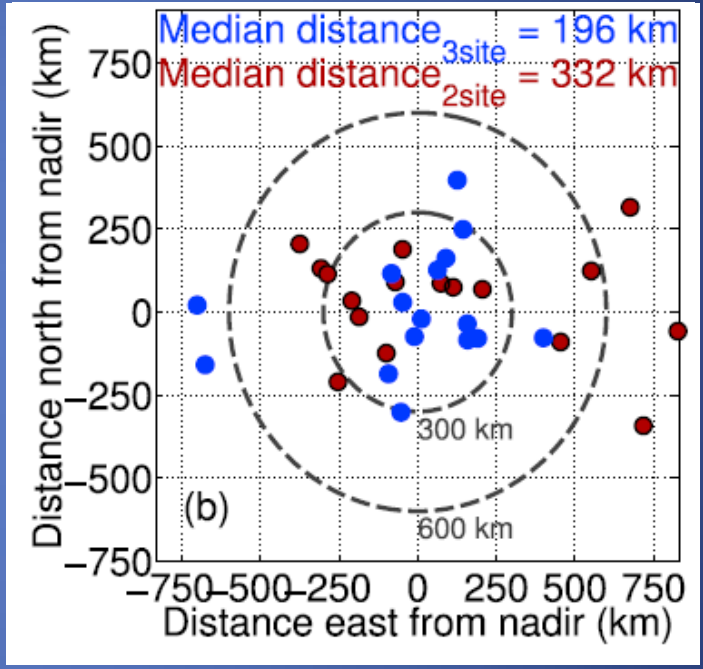
GOES IR image ~5 minutes before TGF

TRMM-LIS pass ~1 hour earlier



First direct imaging from space of TGFs by the AGILE Tracker !





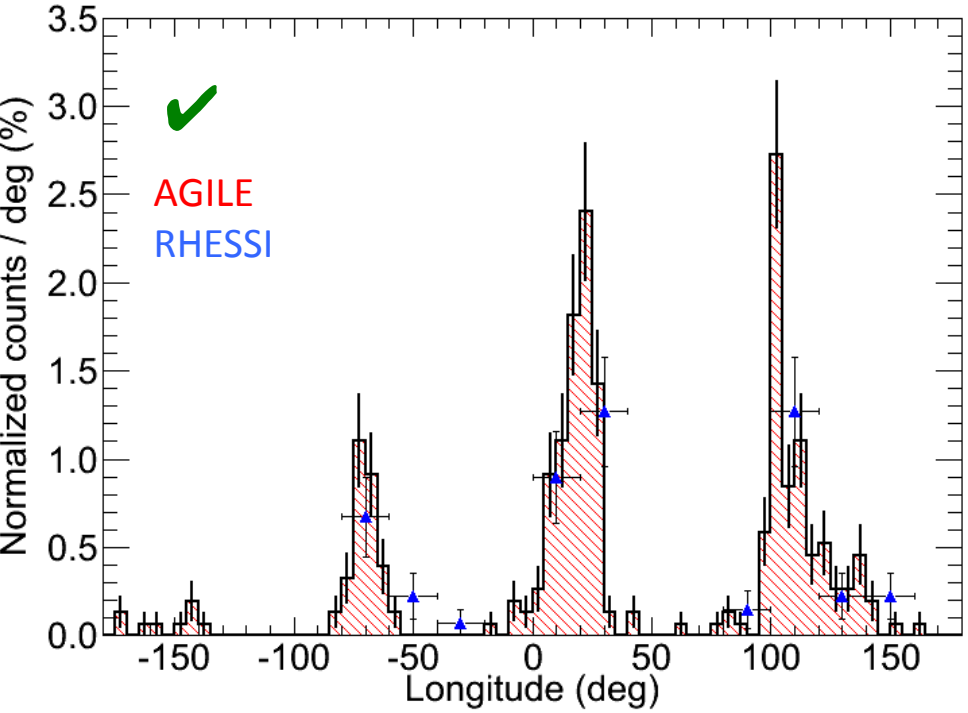
Cohen et al., GRL 2010

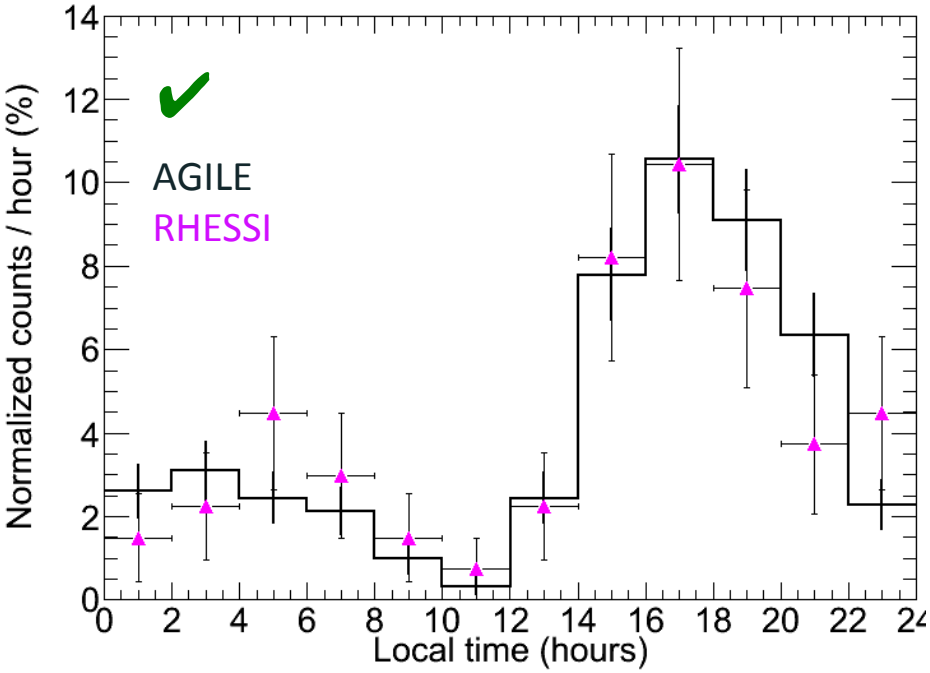
Event clustering at < 400 km from AGILE footprint

Consistency with pervious detections based on RHESSI TGFs and sferics (Cummer et al., GRL 2005, Cohen et al., GRL 2010)

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

AGILE vs. RHESSI: longitude and local time





- Comparison with sample of 67 TGFs detected in the +/- 2.5° latitude band (1st RHESSI catalog)
- Good agreement found

Interactive public TGF catalog

Available on the web through ASI science data center (ASDC) website
www.asdc.asi.it/mcaltgfcat

Properties of Terrestrial Gamma-Ray Flashes detected by AGILE MCAL below 30 MeV

TGF (E <30 MeV) observed from March 2009 to July 2012

Help

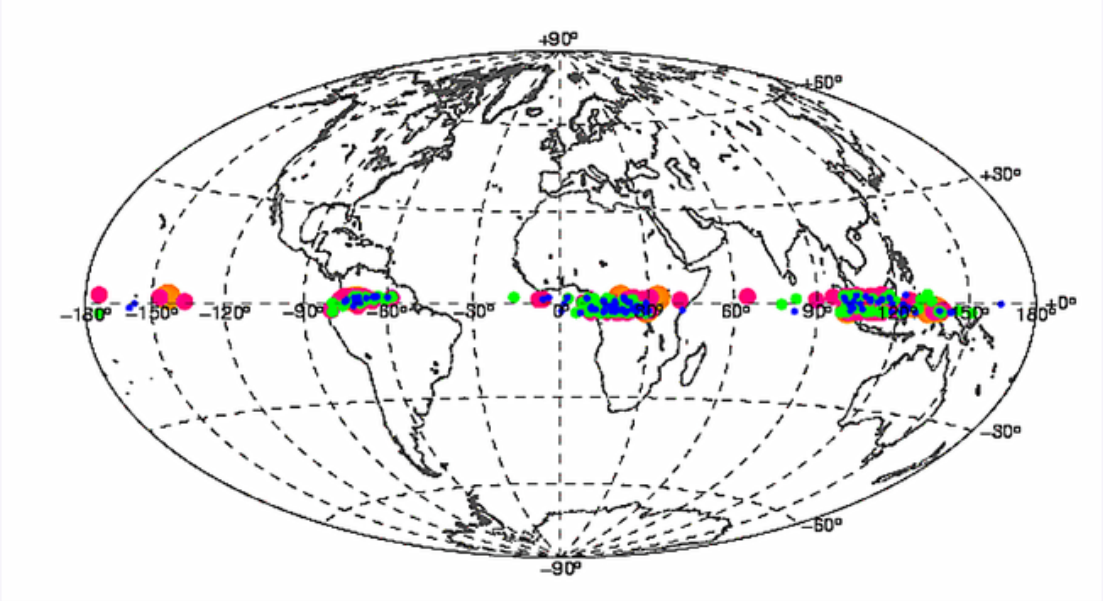
Show/hide columns

Advanced filtering

Print current view of table

Print complete table

Reset all filters



MCAL TGF Catalog (M. Marisaldi et al., 2013) ASDC interactive webpage: www.asdc.asi.it/mcaltg

Properties of Terrestrial Gamma-Ray Flashes detected by AGILE MCAL below 30 MeV

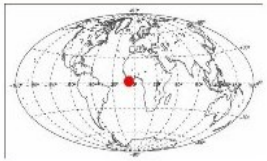
TGF (5 <30 MeV) observed from March 2009 to July 2012

M. Marisaldi et al. 2013, Journal of

« Previous Pag

Entry number		TGF ID	GeoLon	GeoL
1	TGF LC	090302.71821	17.42	-1.6
2	TGF LC	090308.40378	110.96	-2.3
3	TGF LC	090308.61530	106.13	-1.
4	TGF LC	090309.25894	136.68	-1.9
5	TGF LC	090309.37239	-6.65	1.8
6	TGF LC	090309.37239	-6.65	1.8
7	TGF LC	090315.25166	-8.08	1.7
8	TGF LC	090315.54239	28.88	-2.4

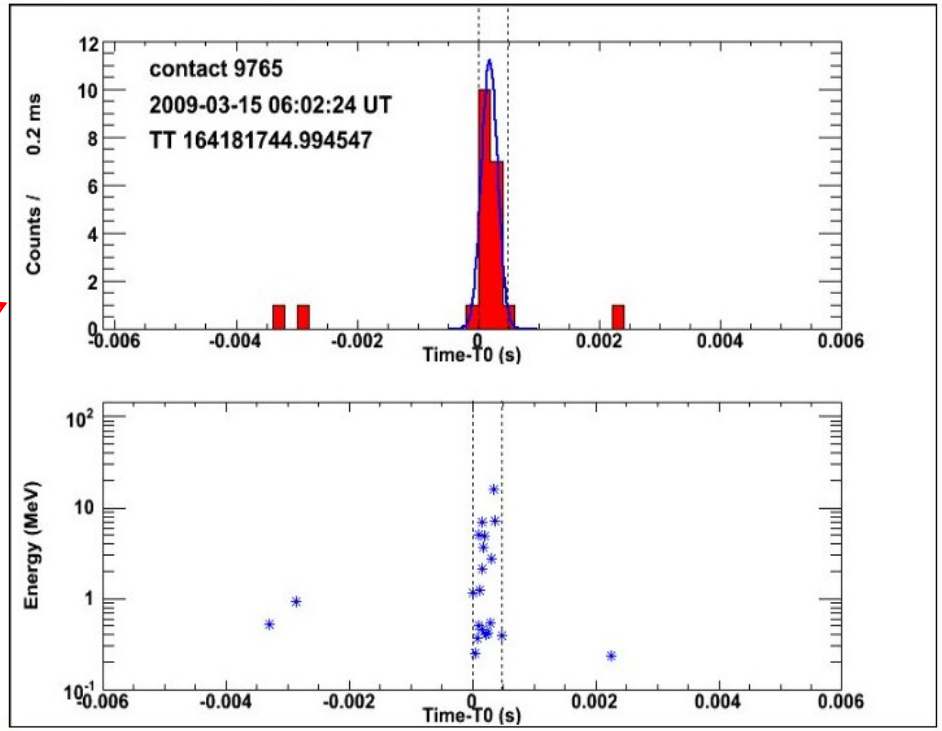
Entry 090315
GeoLong. = -8.08
GeoLat. = 1.73



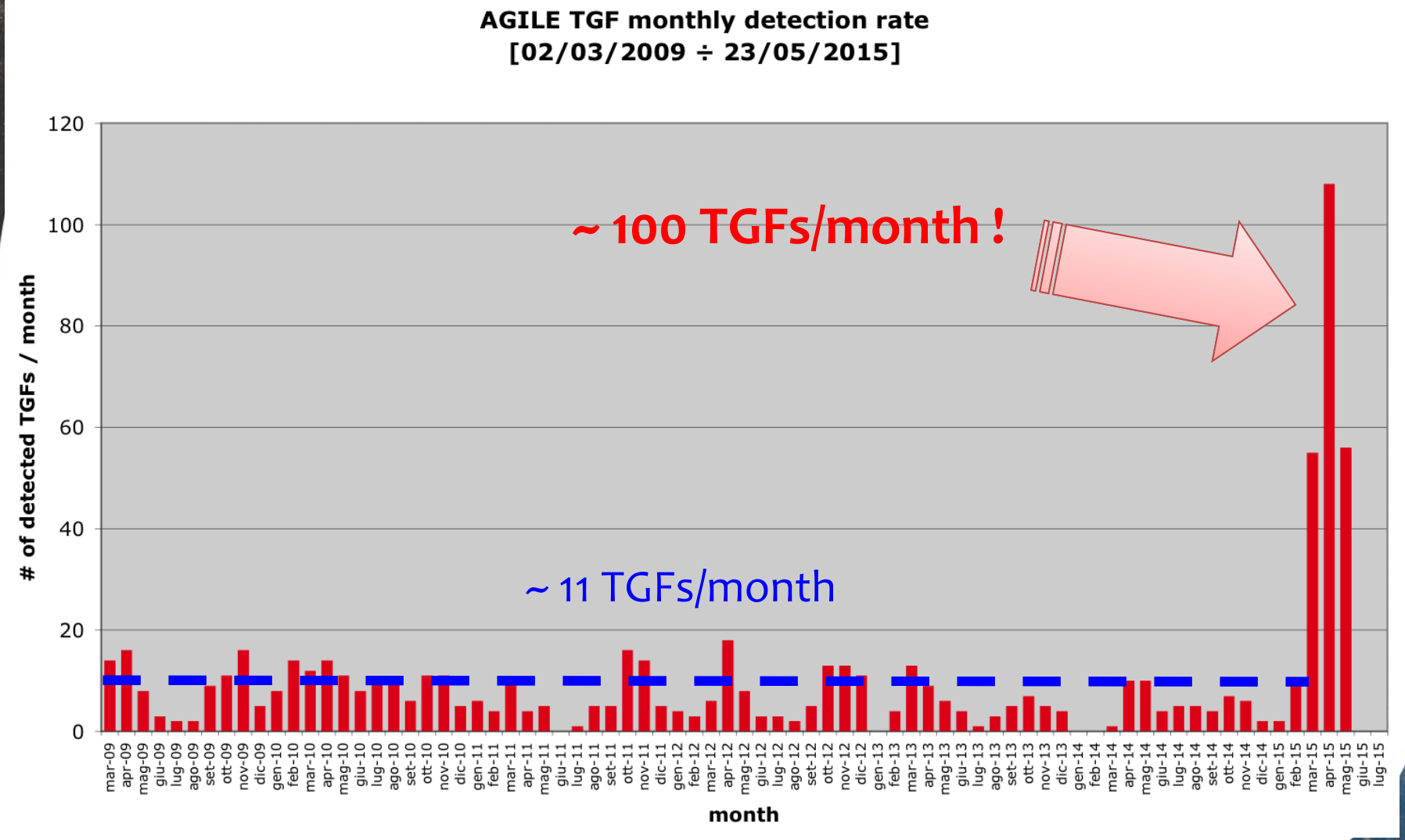
AGILE MCAL Data Products | Source Details

Standard Products

Light Curve broader binning (200 microsec)



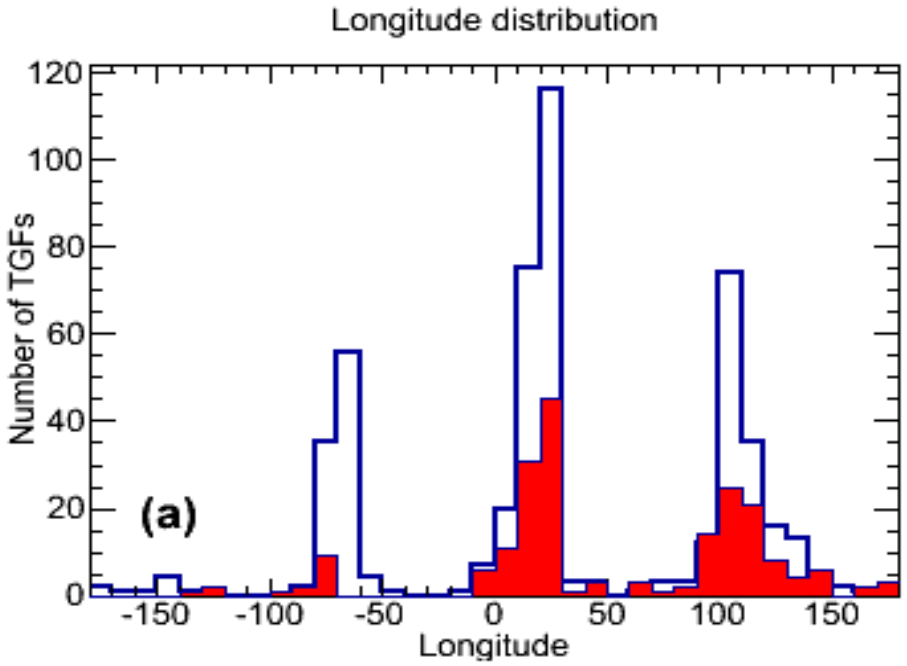
AGILE new TGF detection rate

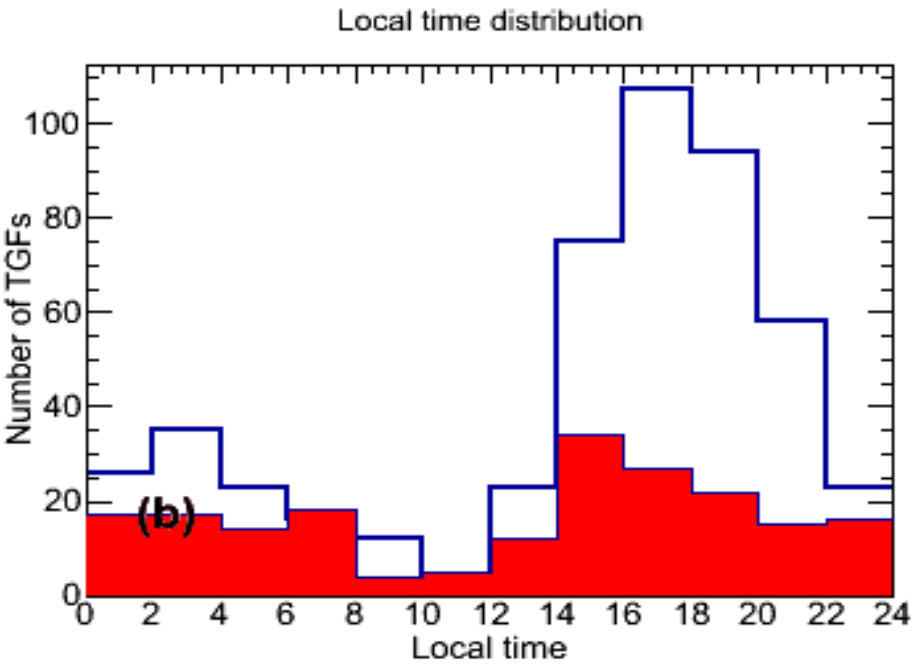


The new sample:

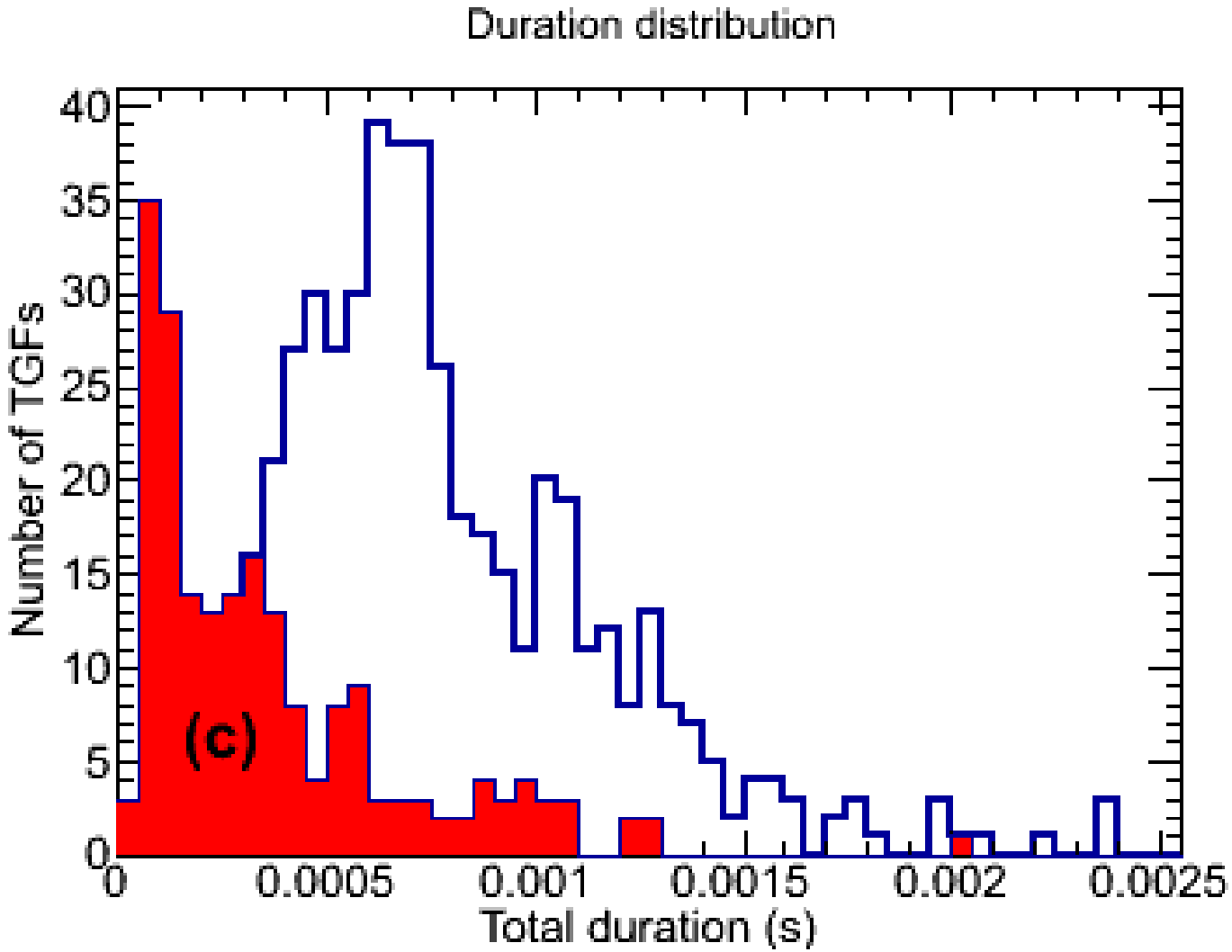
AGILE old config: 495 TGFs / 6 years
~ 0.23 TGFs/day

AGILE NEW config: 152 TGFs / 41 days
~ 3.7 TGFs/day

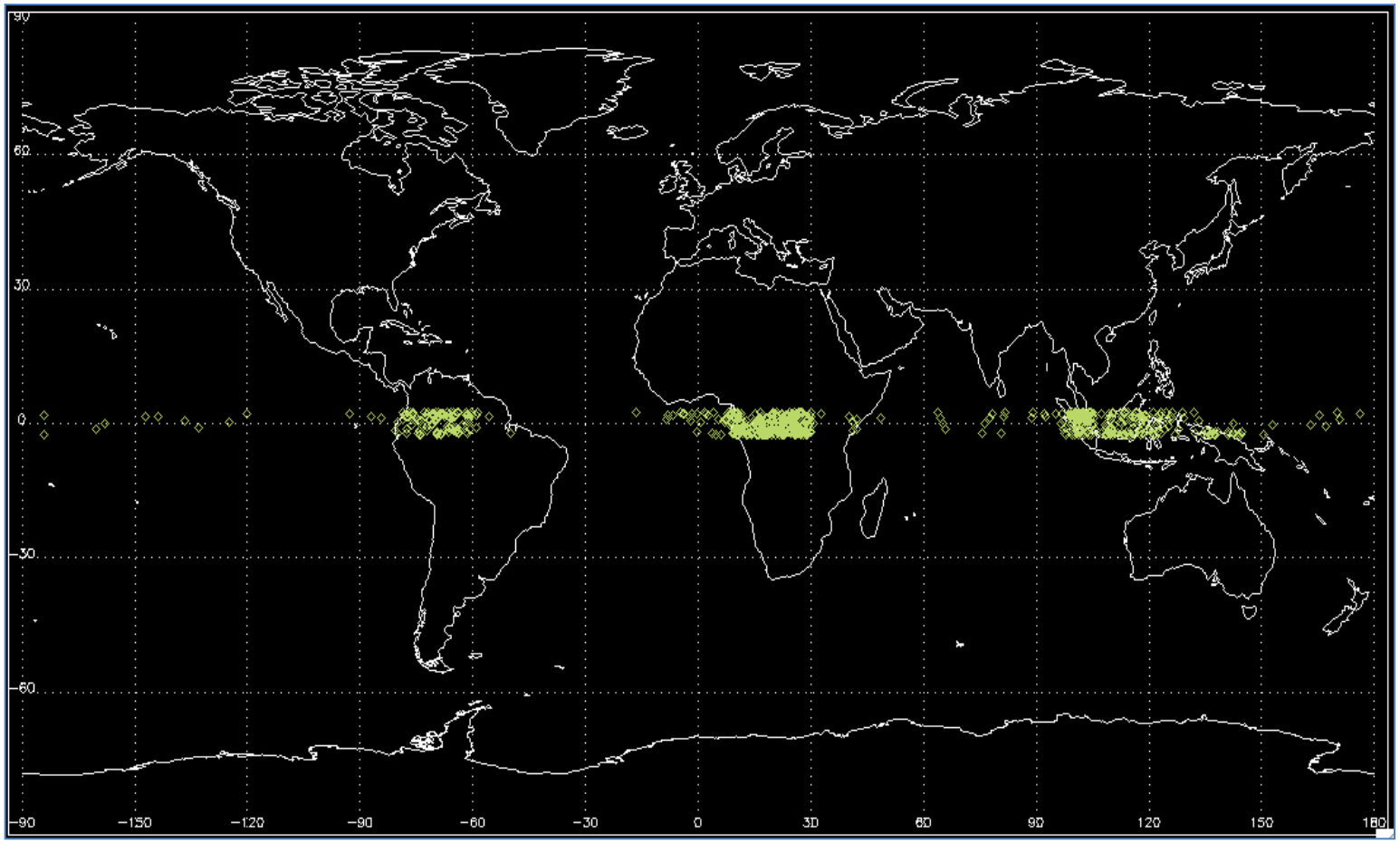




The new sample:



AGILE new TGF detection rate



AGILE 700 TGFs

rate ~ 100 TGFs/month

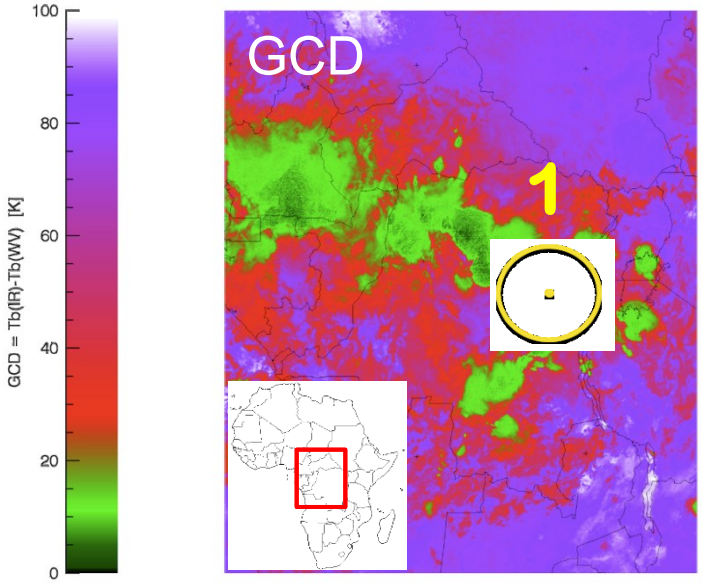
AGILE new TGF detection rate

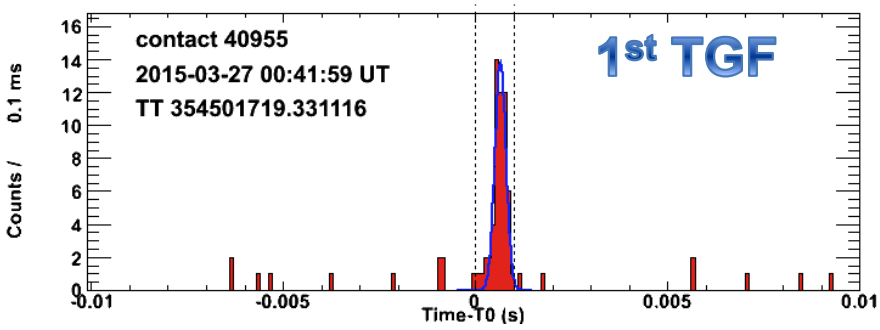
# TGF	dd-mm-yyyy	hh:mm:ss	lon (deg)	lat (deg)	Δt (hh:mm:ss)	Δlon (deg)
…	…	…	…	…		
562	8-04-2015	13:56:21	21,01	-1,70	**0:00:08**	**0,45**
563	8-04-2015	13:56:29	21,46	-1,72		
…	…	…	…	…		
583	13-04-2015	12:06:36	99,78	-1,65	**0:00:17**	**1,00**
584	13-04-2015	12:06:53	100,78	-1,62		
…	…	…	…	…		
606	19-04-2015	15:46:41	10,53	-0,95	**0:00:21**	**1,23**
607	19-04-2015	15:47:02	11,76	-0,90	**0:02:02**	**7,25**
608	19-04-2015	15:49:04	19,01	-0,58	**0:00:42**	**2,52**
609	19-04-2015	15:49:46	21,53	-0,46		
…	…	…	…	…		
…	…	…	…	…		
517	27-03-2015	0:41:59	27,47	-2,41	**1:40:05**	**-3,18**
518	27-03-2015	2:22:04	24,29	-2,02		
…	…	…	…	…		
585	13-04-2015	17:09:11	98,51	1,39	**0:00:43**	**2,60**
586	13-04-2015	17:09:54	101,11	1,48	**1:39:47**	**-4,32**
587	13-04-2015	18:49:41	96,79	2,10		

Some examples: "multiple" TGFs

Example 1

UTC
00:42:40





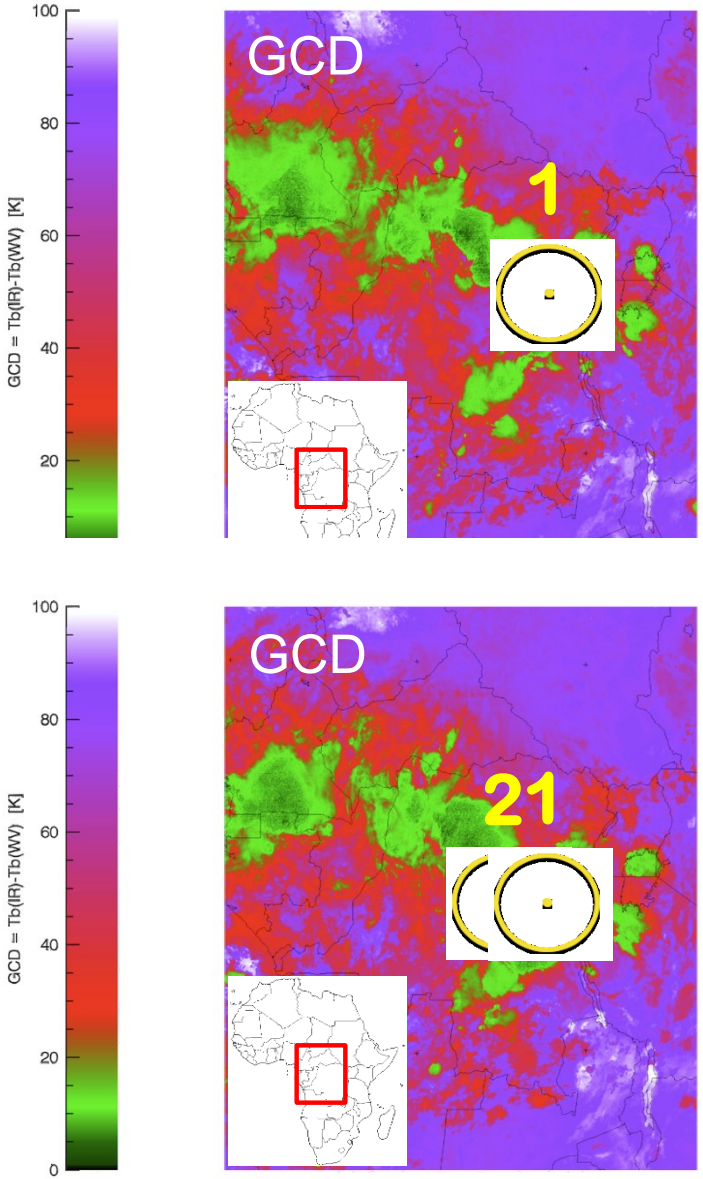
Some examples: "multiple" TGFs

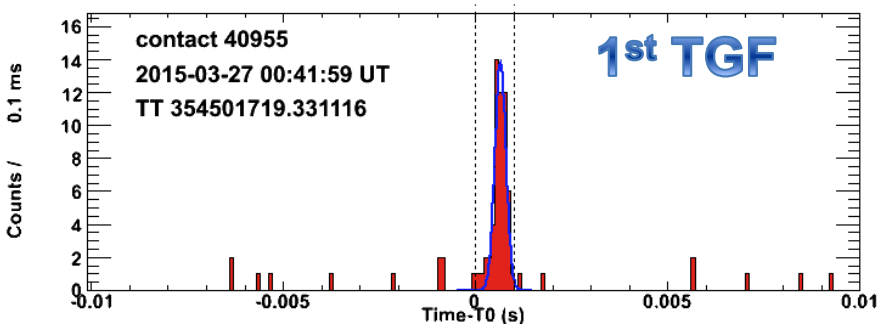
Example 1

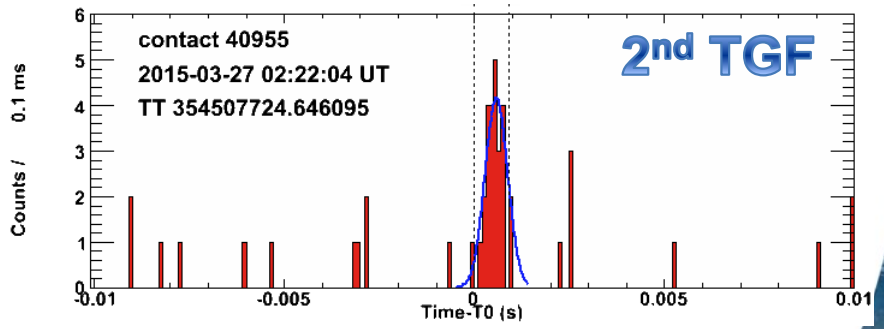
UTC
00:42:40

1 orbit

UTC
02:27:40







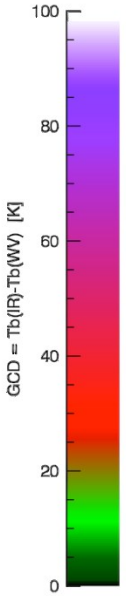
Some examples: "multiple" TGFs

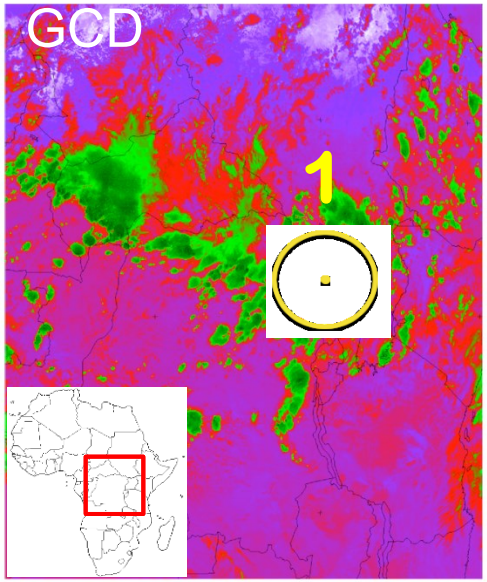
Example 2

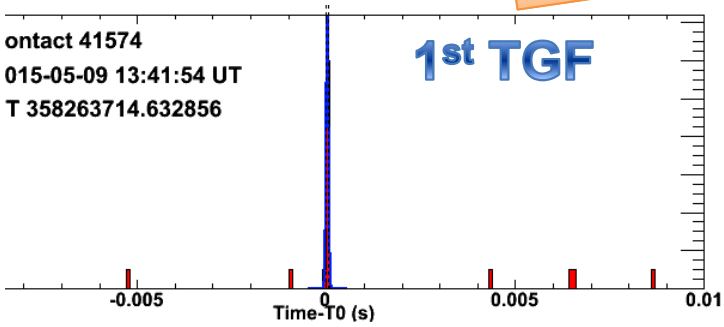
UTC 13:42:40

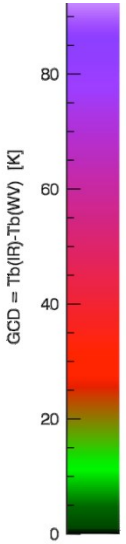
1 orbit

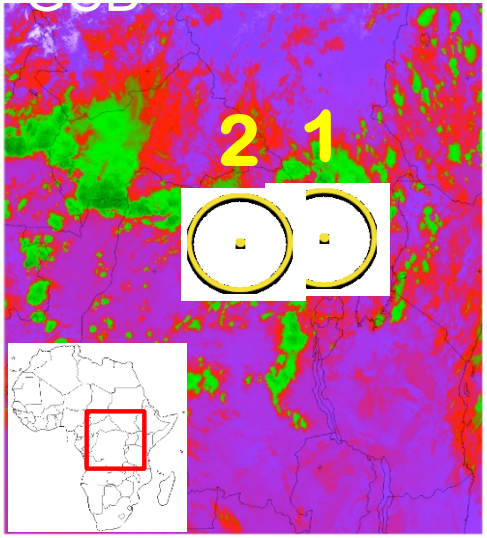
UTC 15:27:40

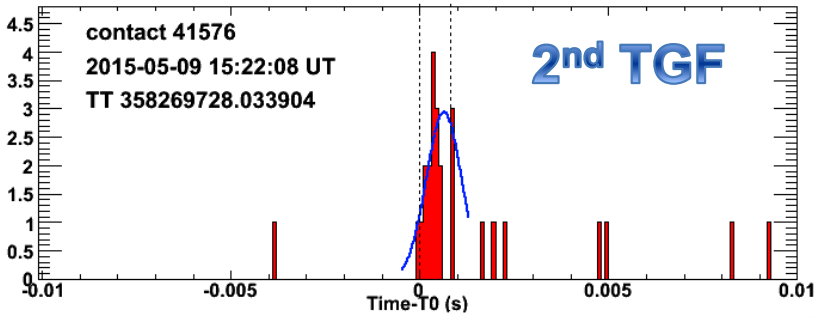








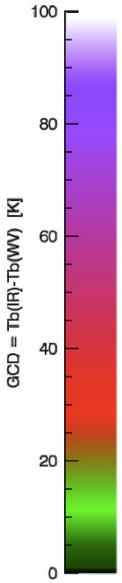


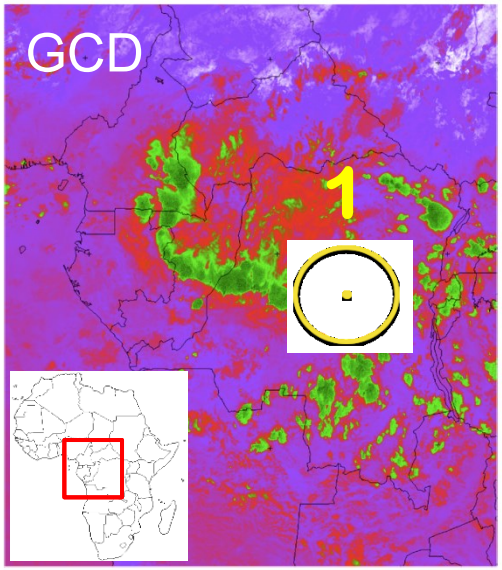


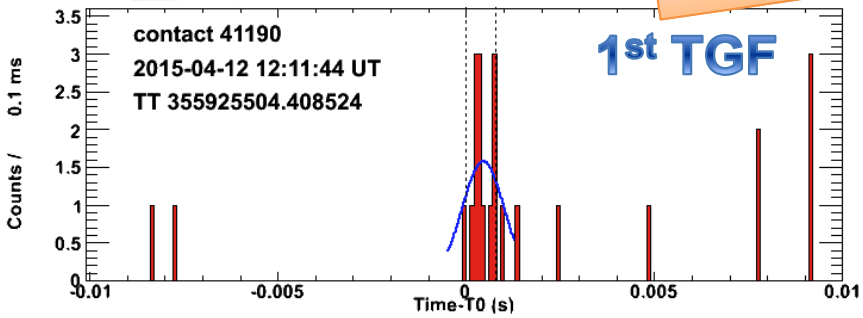
Some examples: "multiple" TGFs

Example 3

UTC
12:12:40



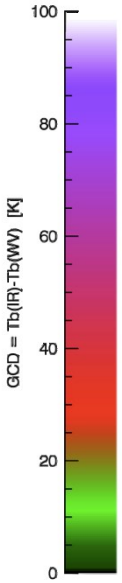


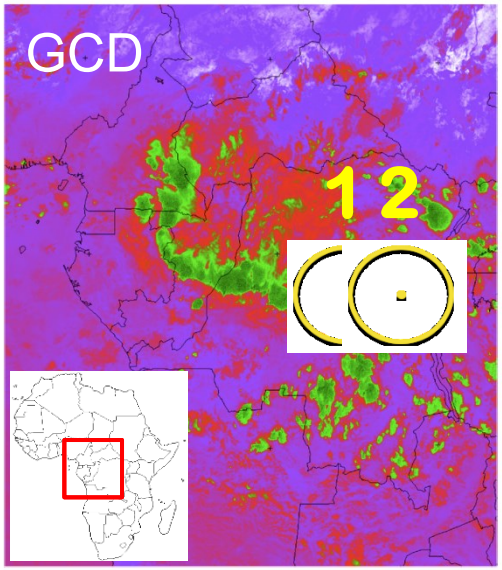


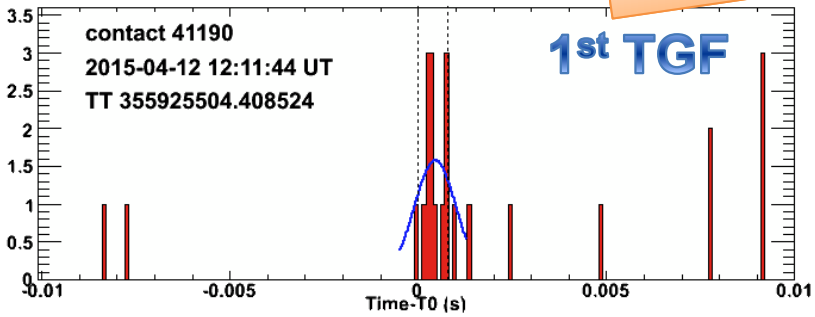
Some examples: "multiple" TGFs

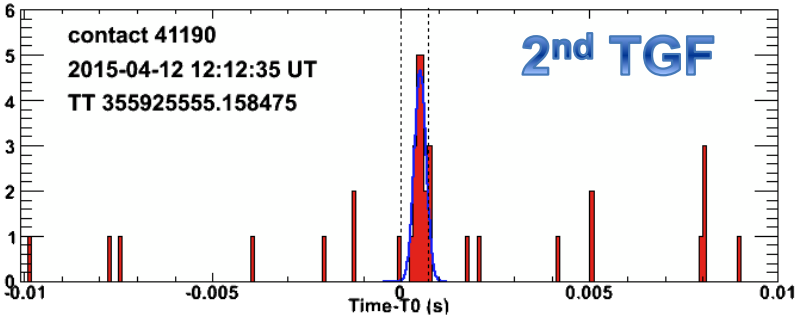
Example 3

UTC
12:12:40









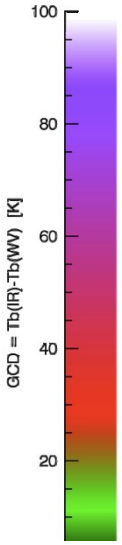
Some examples: "multiple" TGFs

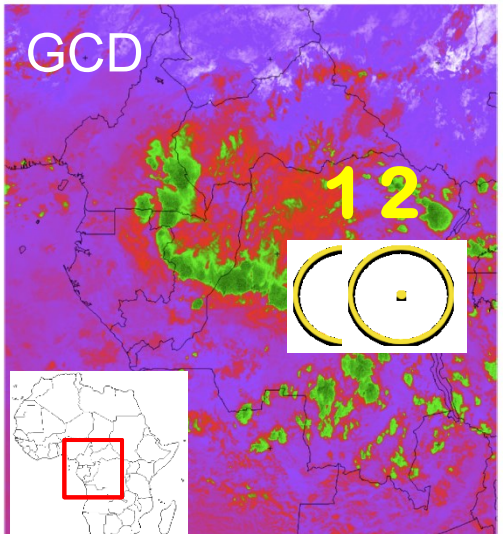
Example 3

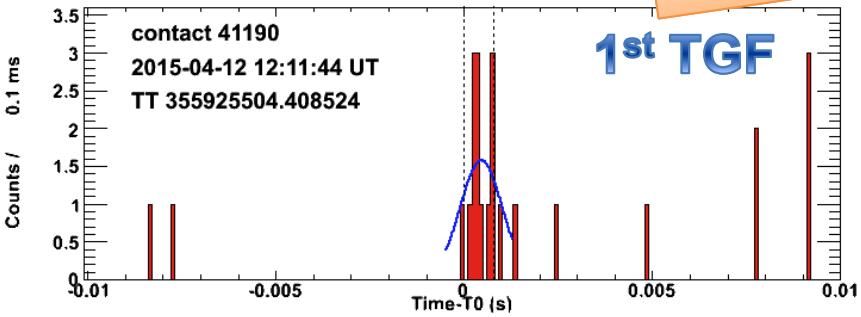
UTC
12:12:40

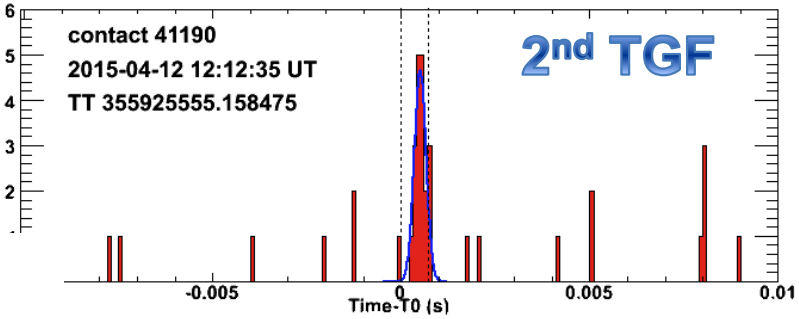
1 orbit

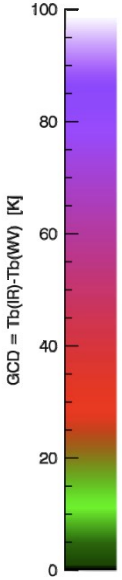
UTC
13:57:41

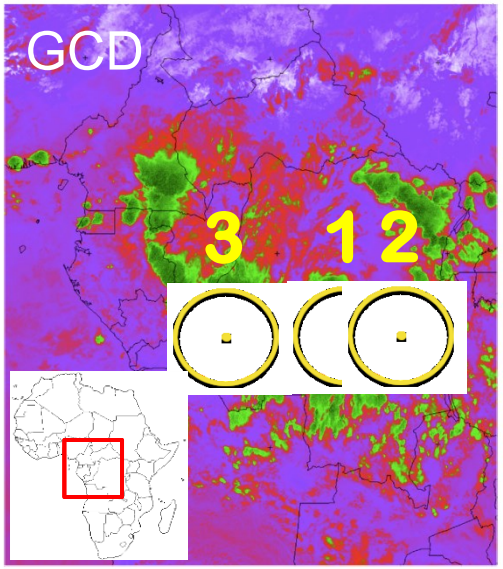


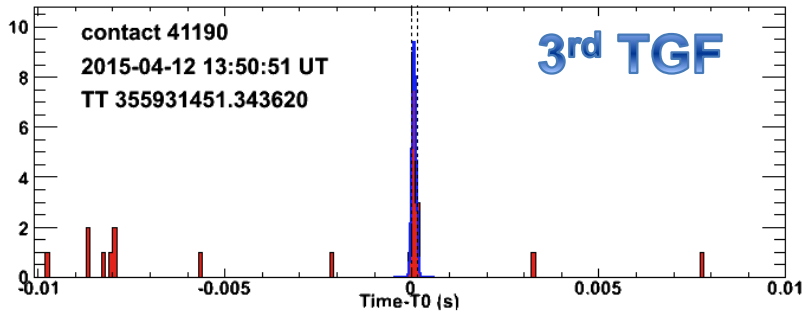












Some examples: "multiple" TGFs

Example 4

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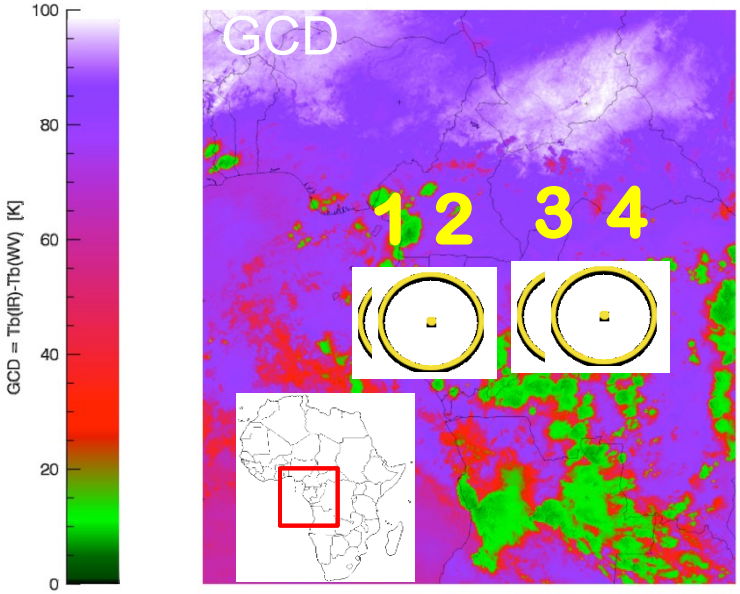
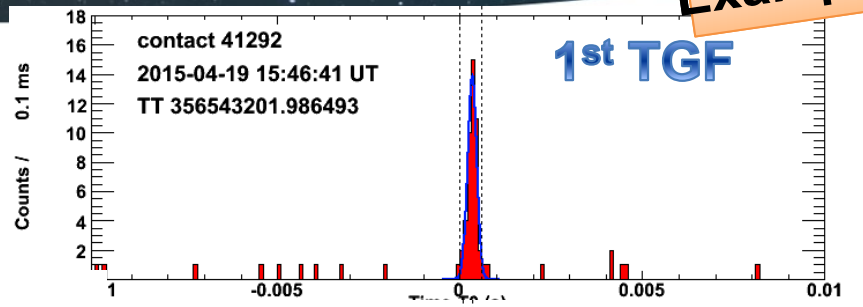
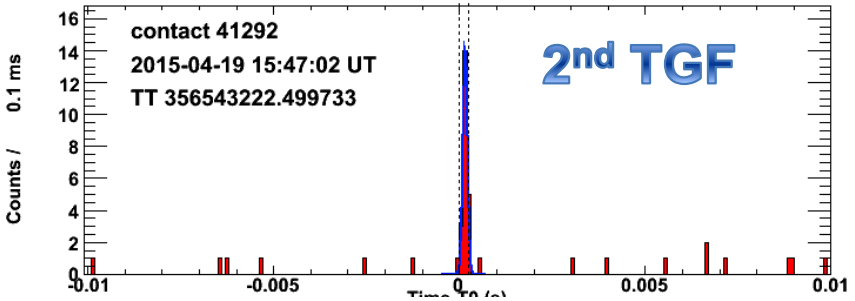
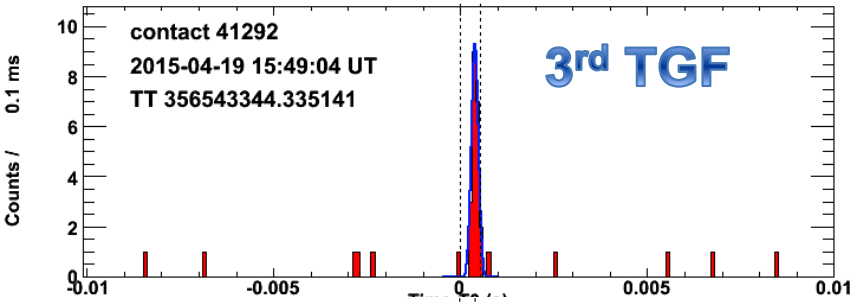
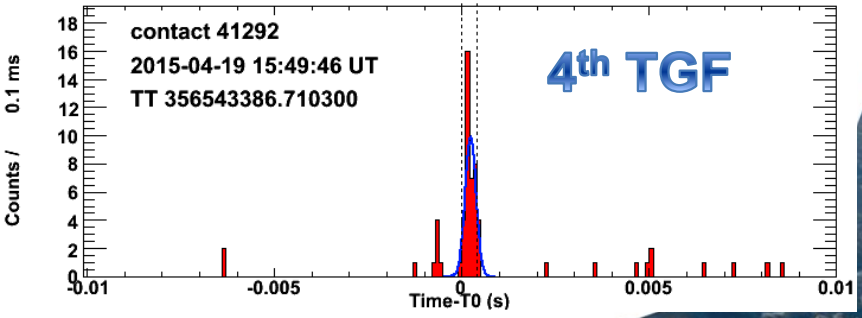




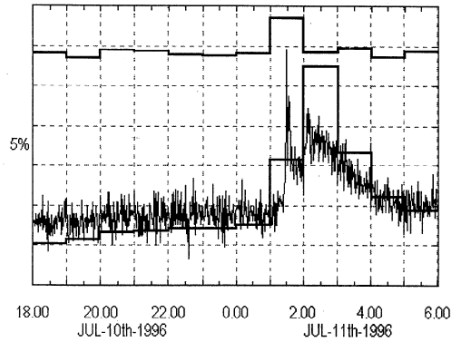




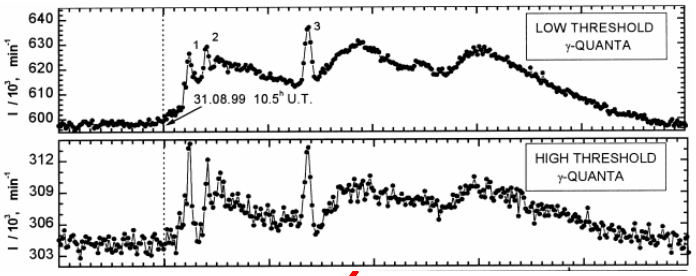


Gamma-ray glows: ground observations

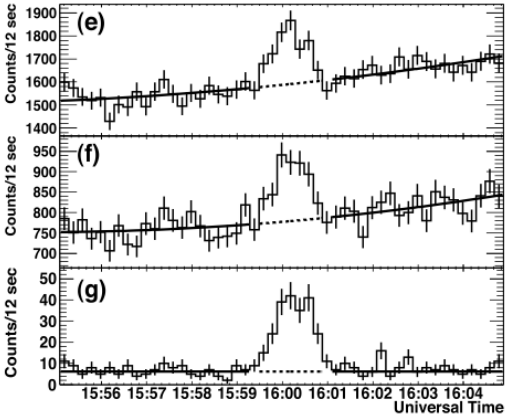
Italy, Gran Sasso, 2005 m a.s.l.
(Brunetti+2000)

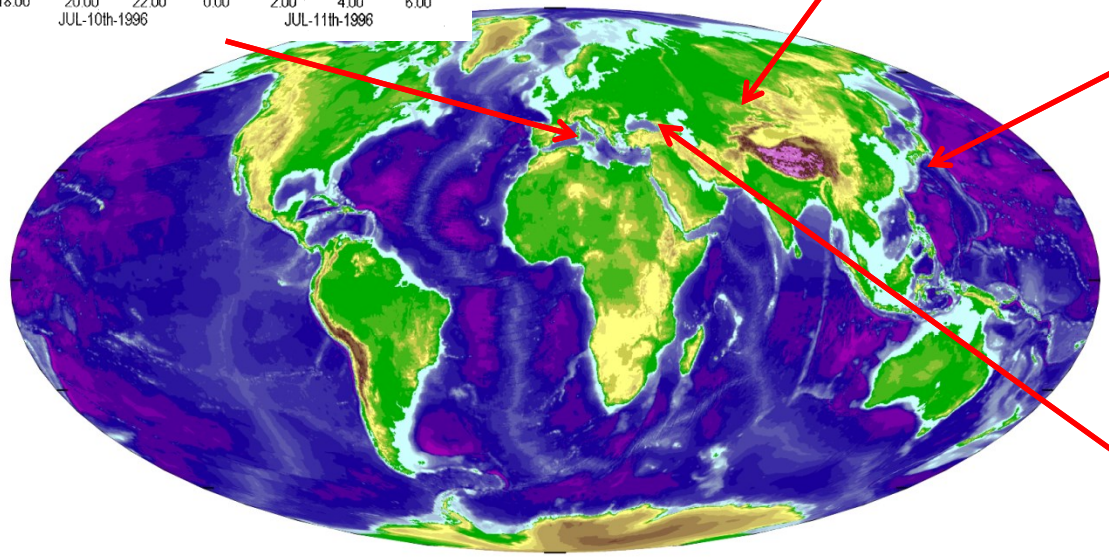


Russia / Kazakhstan, Tien-Shan, 3340 m a.s.l.
(Chubenko+2000)



Japan winter thunderstorms Sea level (Tsuchiya+2009, 2011)

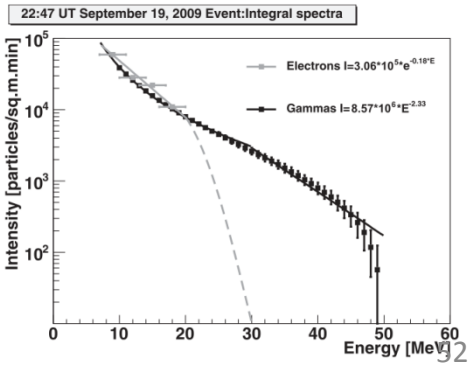




Present day Earth topography [m]

−6000 −4000 −2000 0 2000 4000 6000

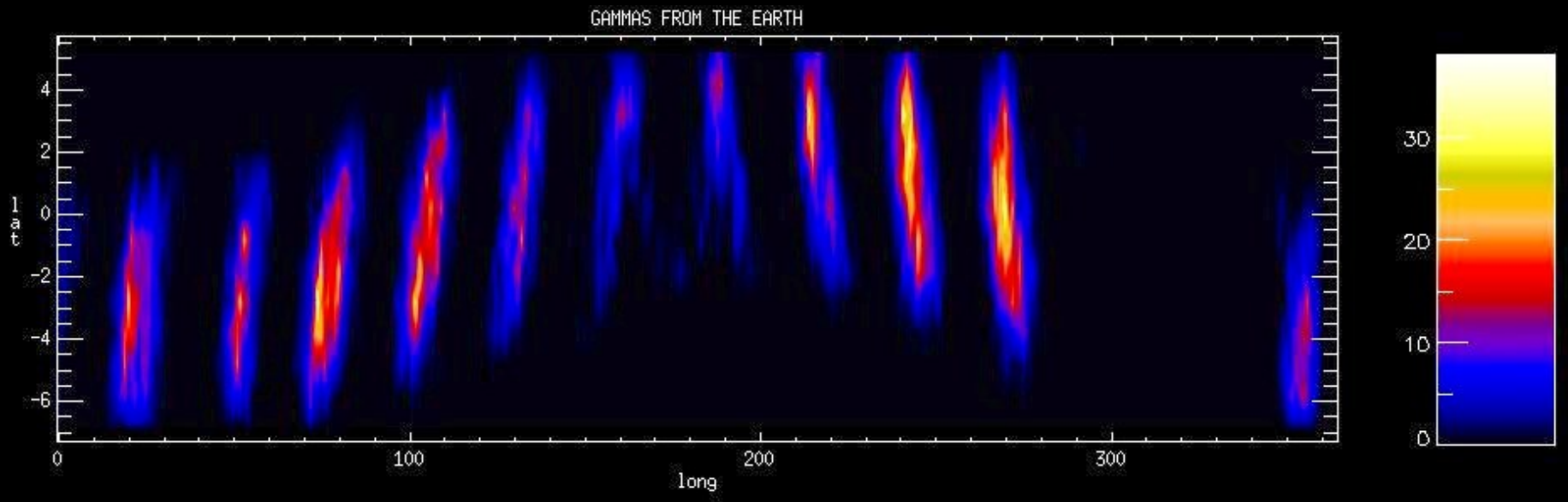
Armenia, Aragats 3250 m a.s.l.
(Chilingarian+ 2010,2011,2013)



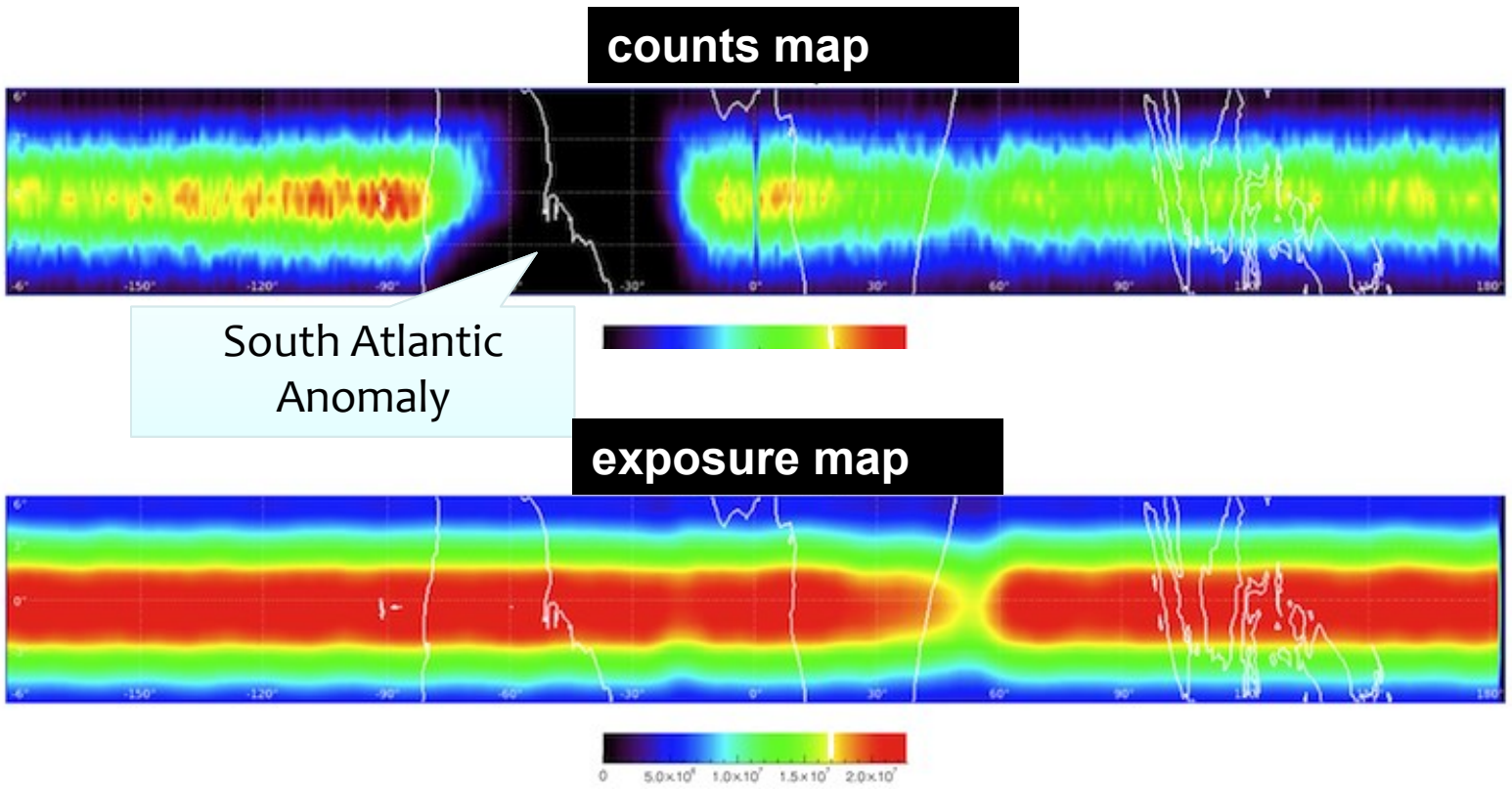
- **Since April 2014, AGILE is able to directly detect gamma-rays from Earth**

AGILE gamma-ray imaging of the Earth

AGILE scan of the Earth per orbit

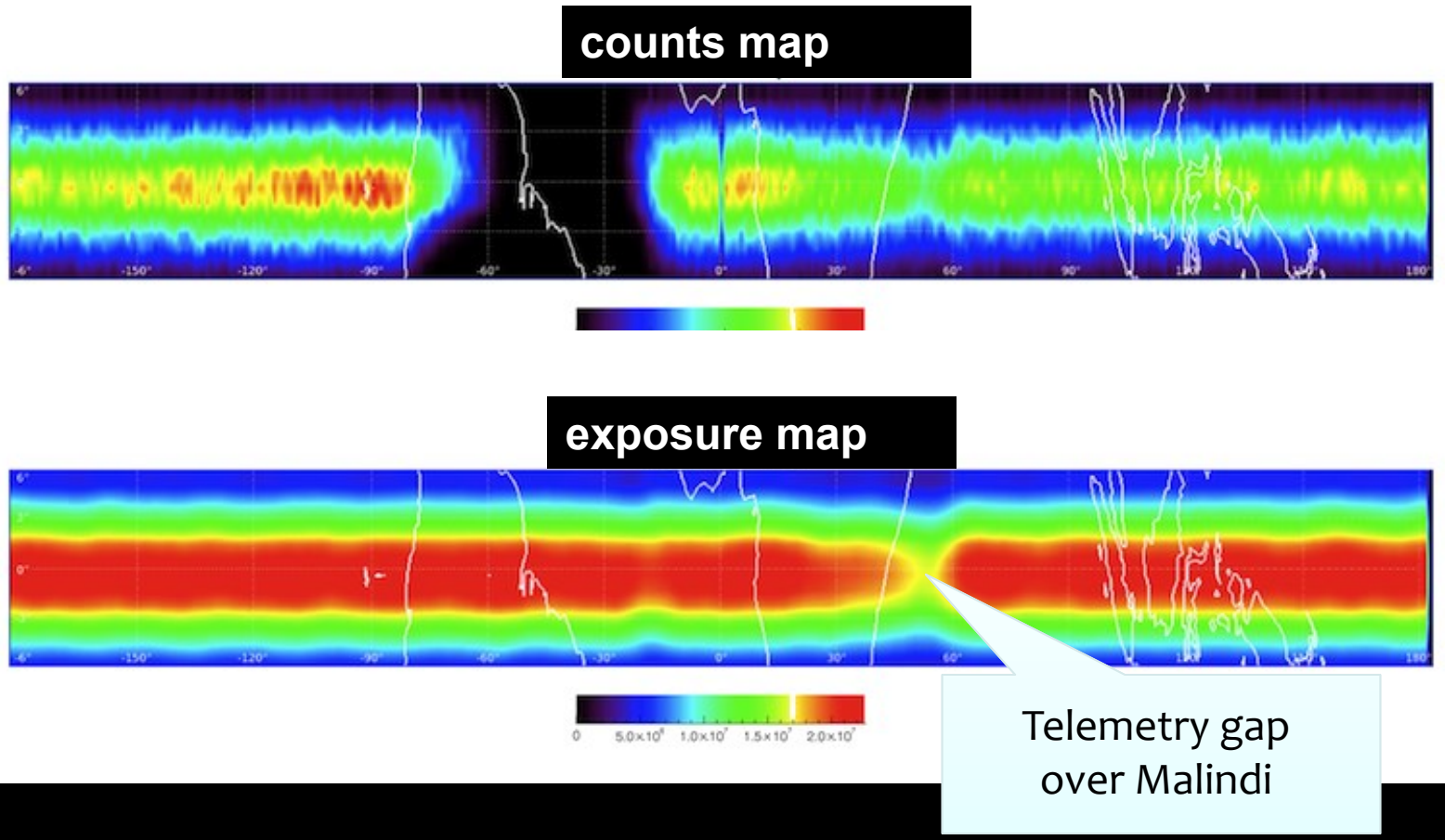


AGILE gamma-ray mapping of the Earth



(thanks to A. Argan, A. Trois, G. Piano, A. Ursi)

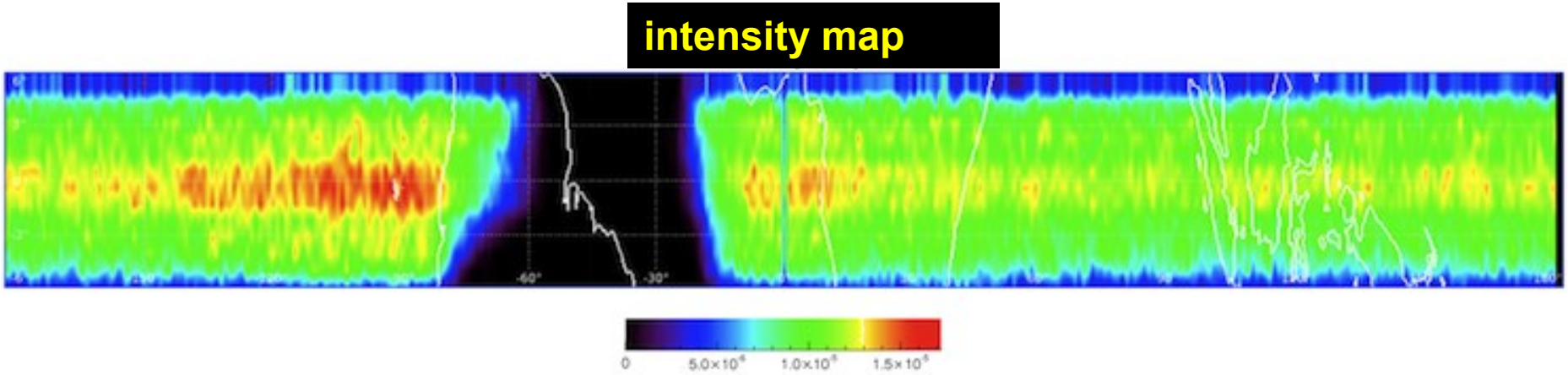
AGILE gamma-ray mapping of the Earth



(thanks to A. Argan, A. Trois, G. Piano, A. Ursi)

AGILE gamma-ray mapping of the Earth

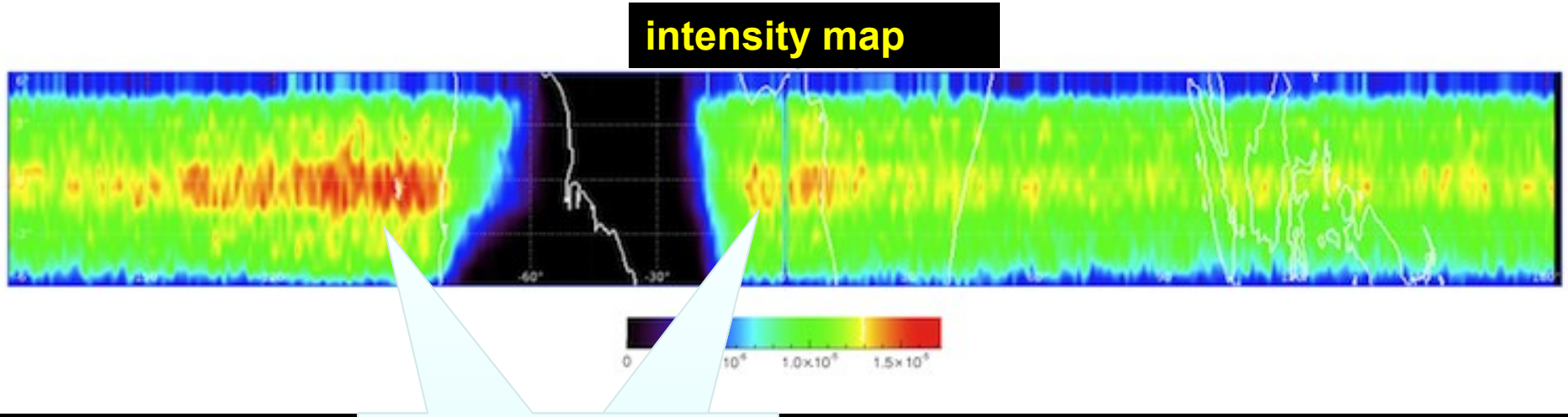
01/07/2014 ÷
19/03/2015



(thanks to A. Argan, A. Trois, G. Piano, A. Ursi)

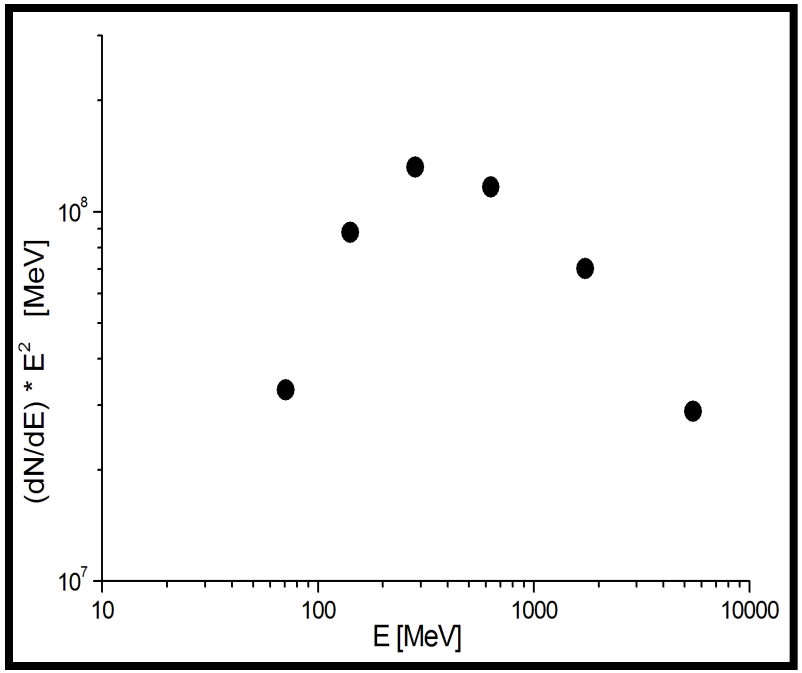
AGILE gamma-ray mapping of the Earth

01/07/2014 ÷
19/03/2015



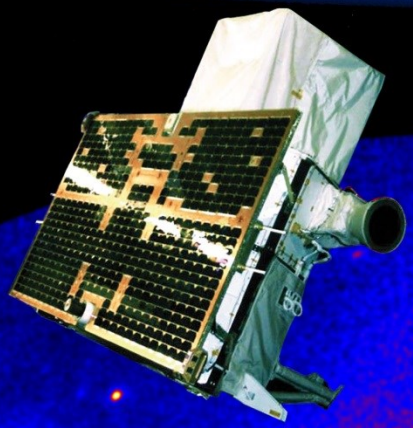
enhancement
due to the SAA ?

(thanks to A. Argan, A. Trois, G. Piano, A. Ursi)



PRELIMINARY:
Spectrum consistent with π^o decay

12th **AGILE** Science Workshop



ASTRO-EARTH

astrophysics and high-energy terrestrial phenomena

ASI, Rome
May 8-9, 2014

agenzia spaziale italiana

INAF

INFN

Consiglio Nazionale delle Ricerche

- **AGILE continues to detect TGFs, now with a quite high detection rate**
- **Unique database for the equatorial region**
- **Many open questions related to TGFs, their physics and their impacts**

- **to high-energy astrophysicists: let’s keep looking at the Earth !**

- **to atmospheric physics friends: let’s join forces…**