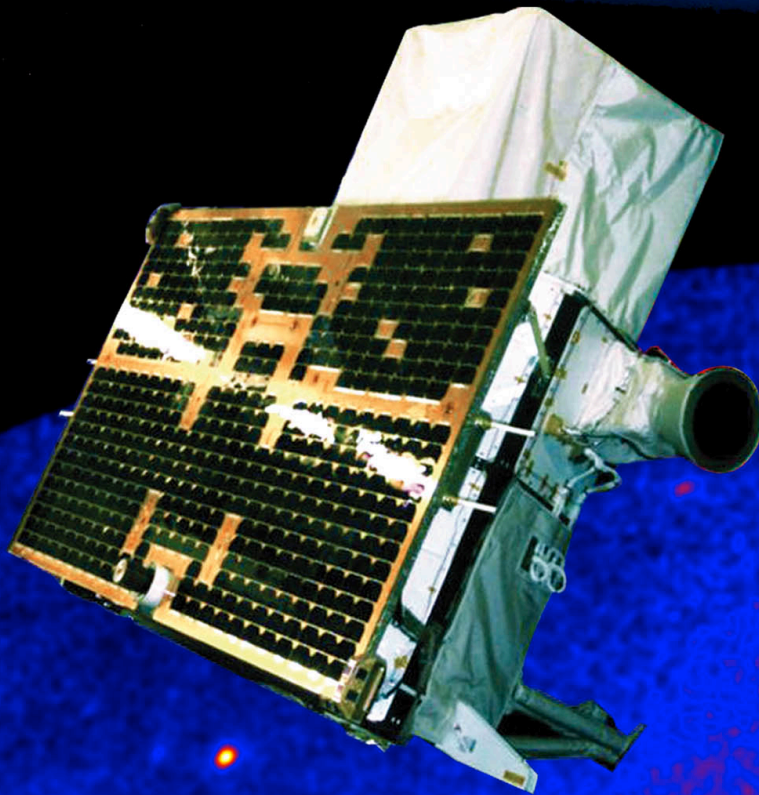


Terrestrial Gamma-ray Flashes

M. Marisaldi – INAF-IASF Bologna

On behalf of the AGILE TGF Team



ASTRO-EARTH

astrophysics and
high-energy terrestrial
phenomena

ASI, Rome
May 8-9, 2014

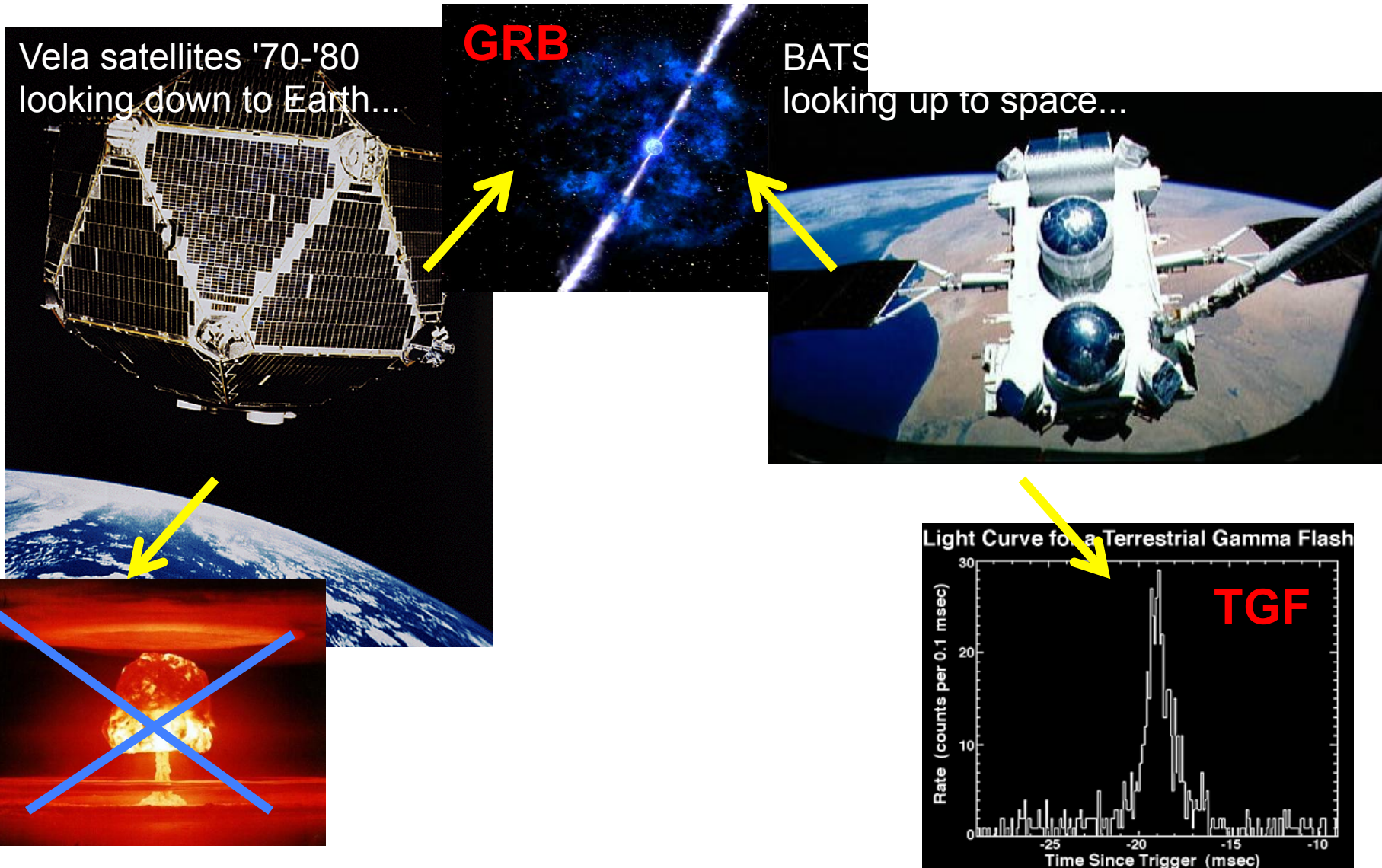
Take-home message:

Thunderstorms are the most powerful and energetic natural particle accelerators on Earth



And many groups in the world are becoming aware of this

The discovery of TGFs: serendipity at play

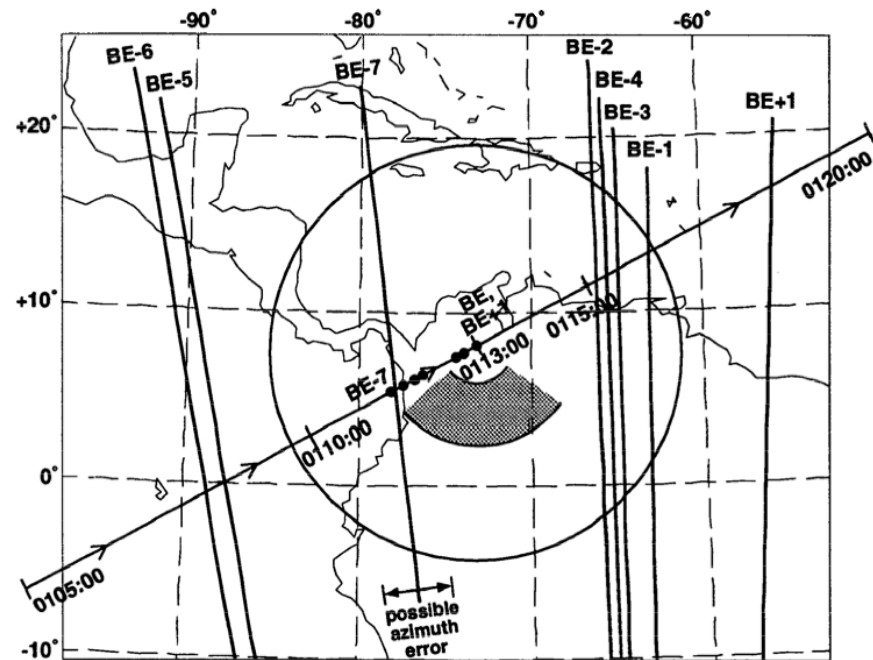
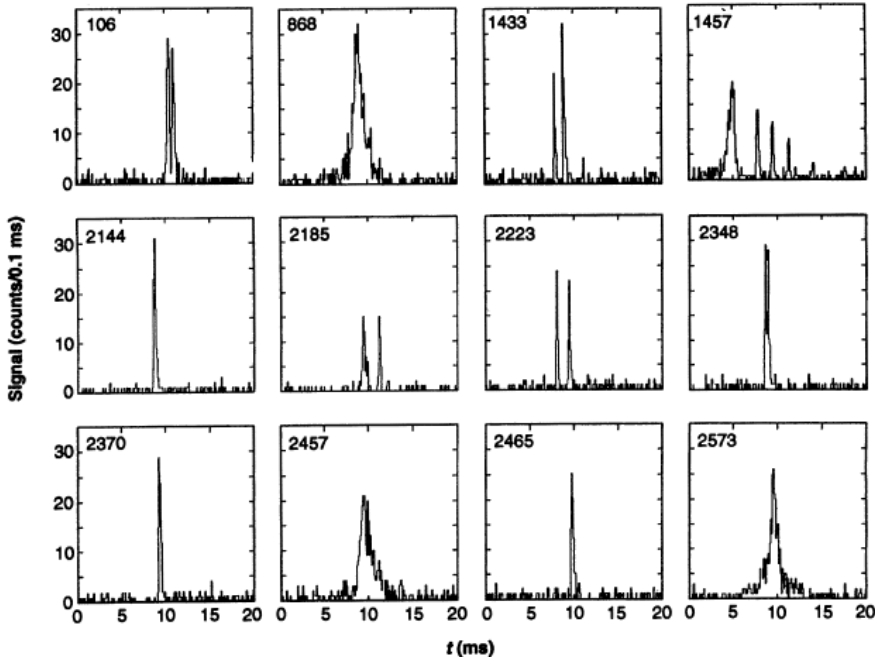


TGFs 20th birthday!

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

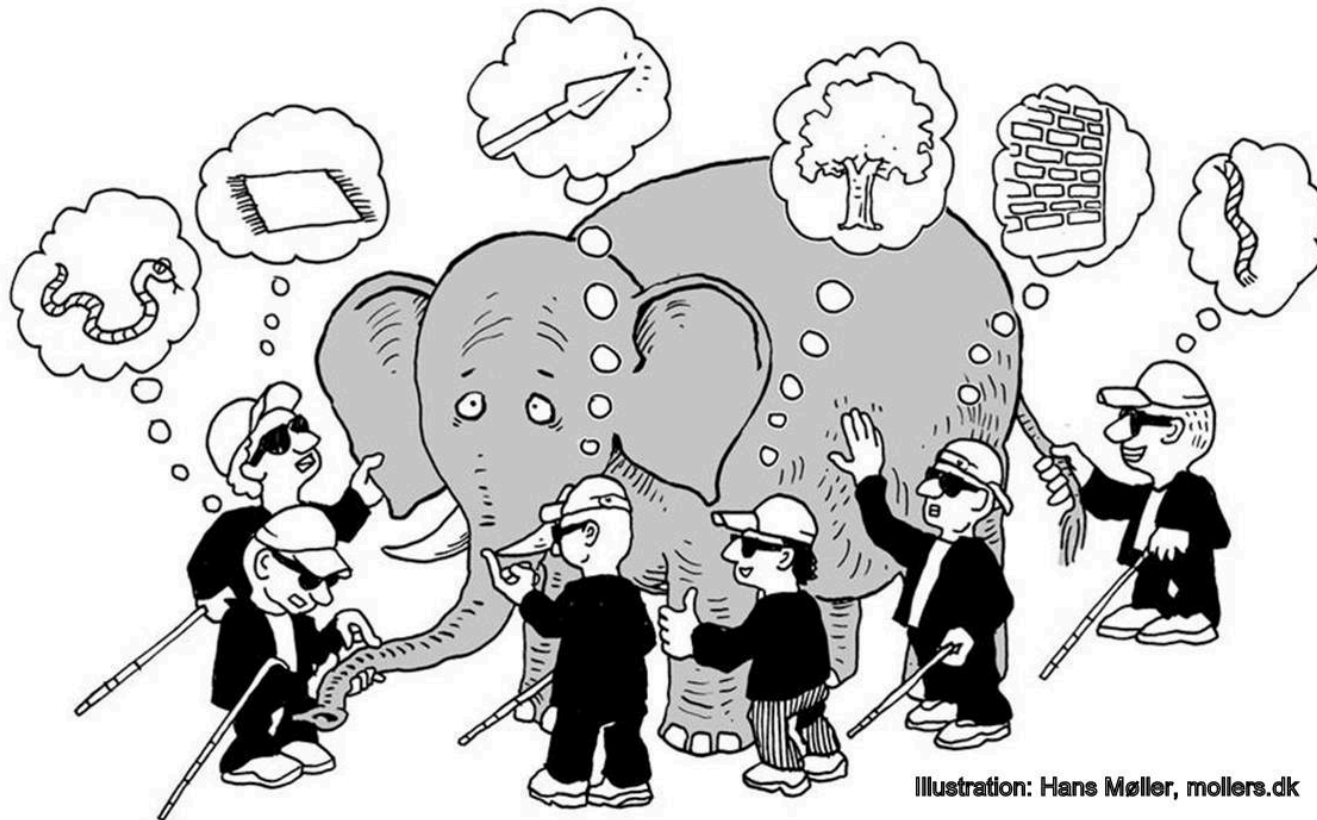
“Discovery of Intense Gamma-Ray Flashes of Atmospheric Origin”, Science (1994)

Accepted 19 April 1994!



- Energy $> 1\text{MeV}$, harder than GRBs
- Very bright, $\sim 1\text{ms}$ duration
- Associated to lightning

What do we really know about TGFs?



Credits: Michael Briggs, EGU 2014

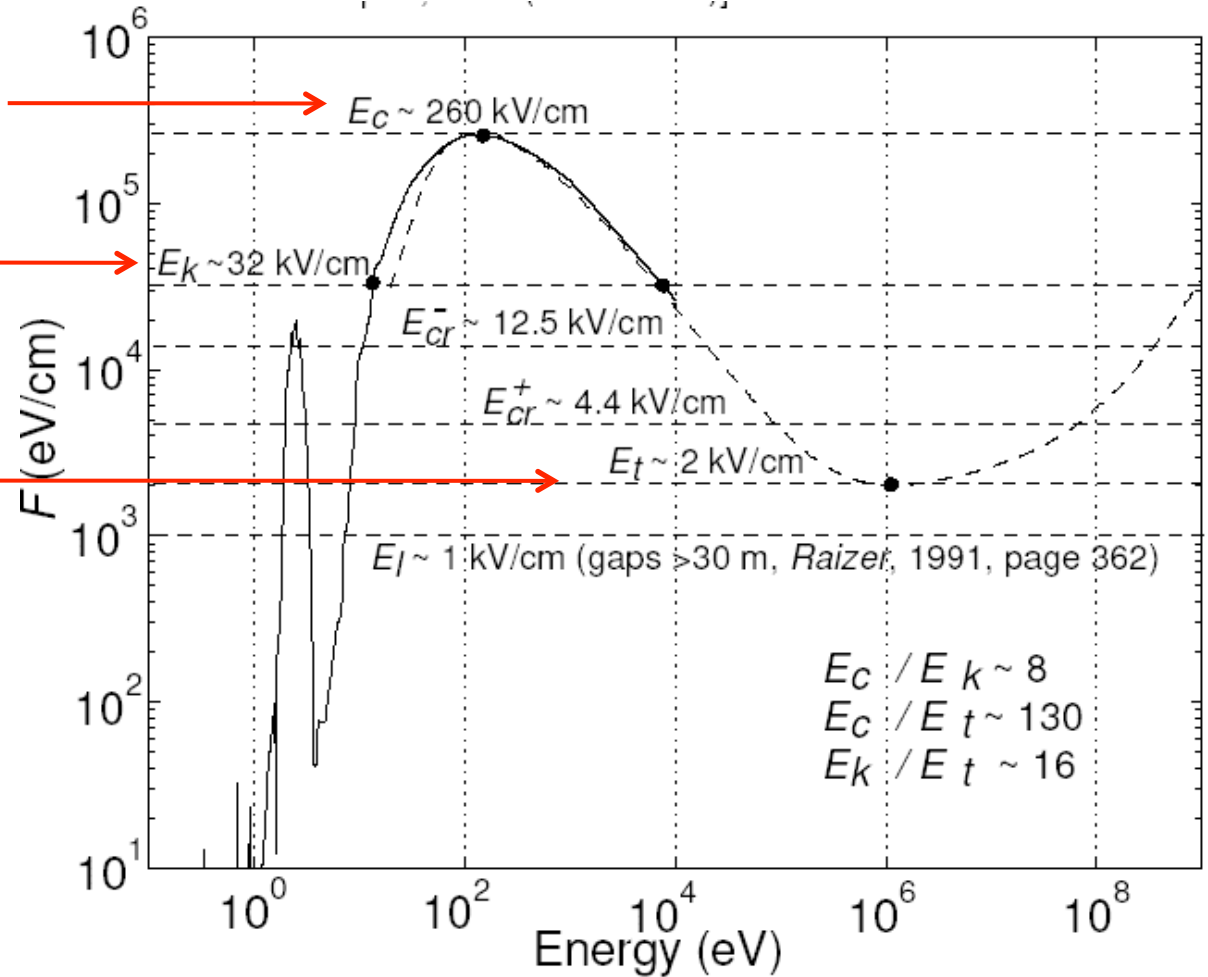
Physical scenario: runaway electrons

Cold runaway:
any electron goes relativistic

Conventional breakdown:
ionization > attachment

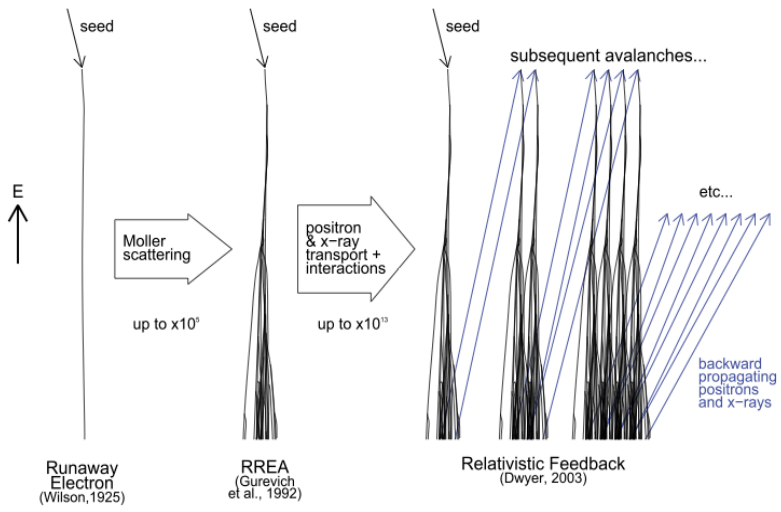
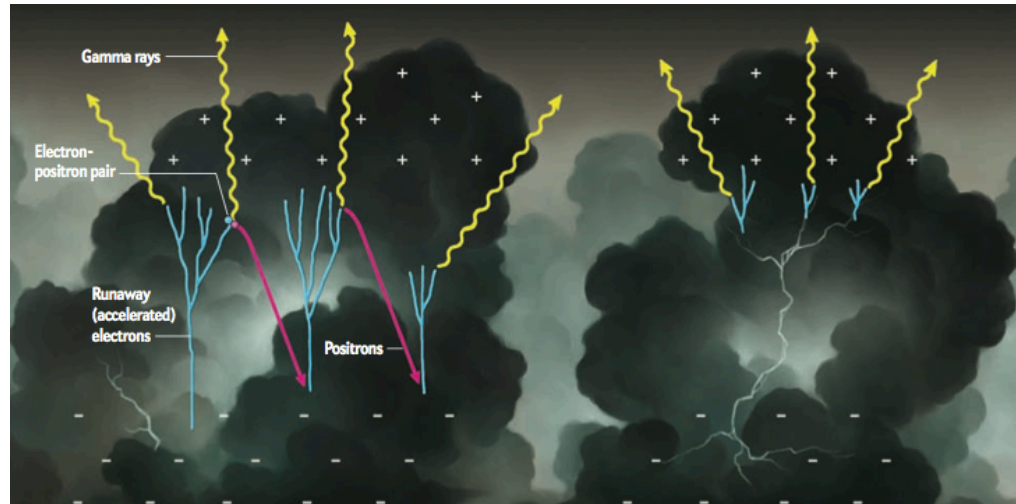
Relativistic runaway regime:
seed electrons get accelerated to relativistic energies and undergo avalanche multiplication

Gurevich, Phys. Lett. A(1992)

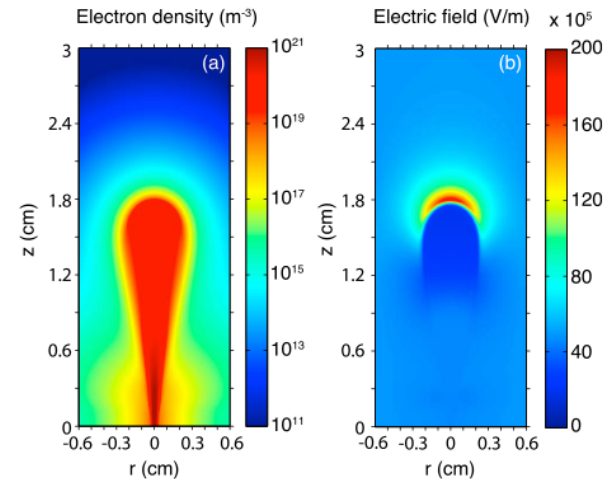


Two competing models

Dwyer and Smith,
Scientific American
(2012)



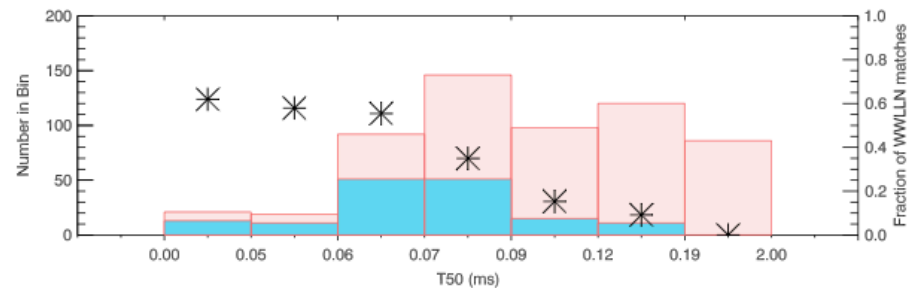
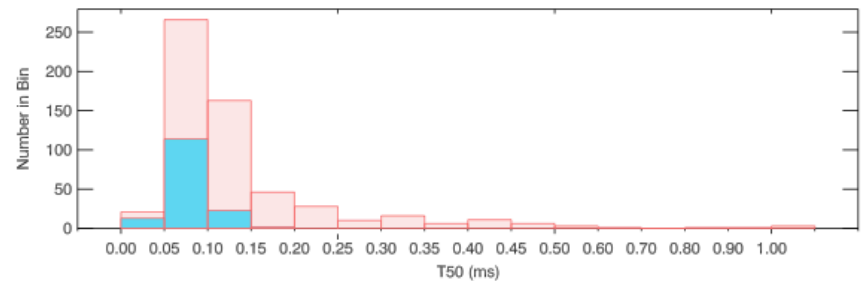
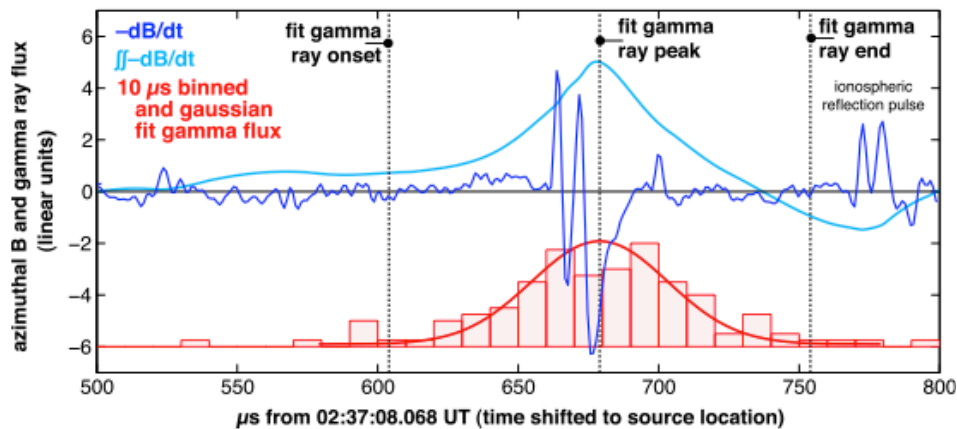
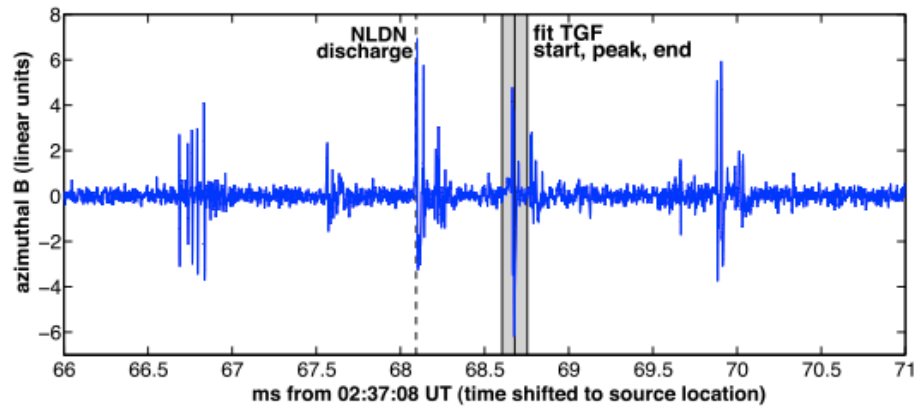
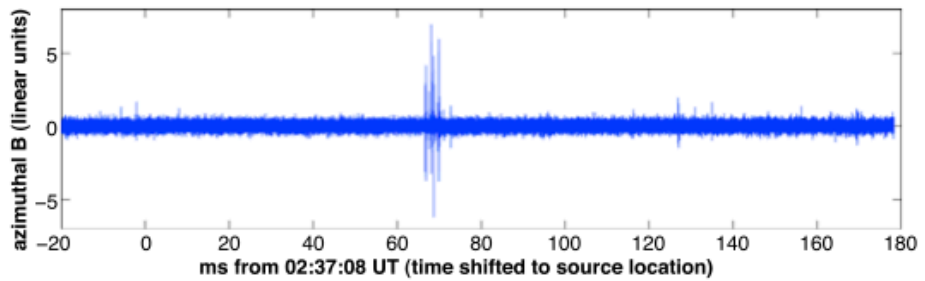
$E_0 = 50 \text{ kV/cm}$, $t = 8.5 \text{ ns}$



Dwyer, Smith & Cummer (2012)

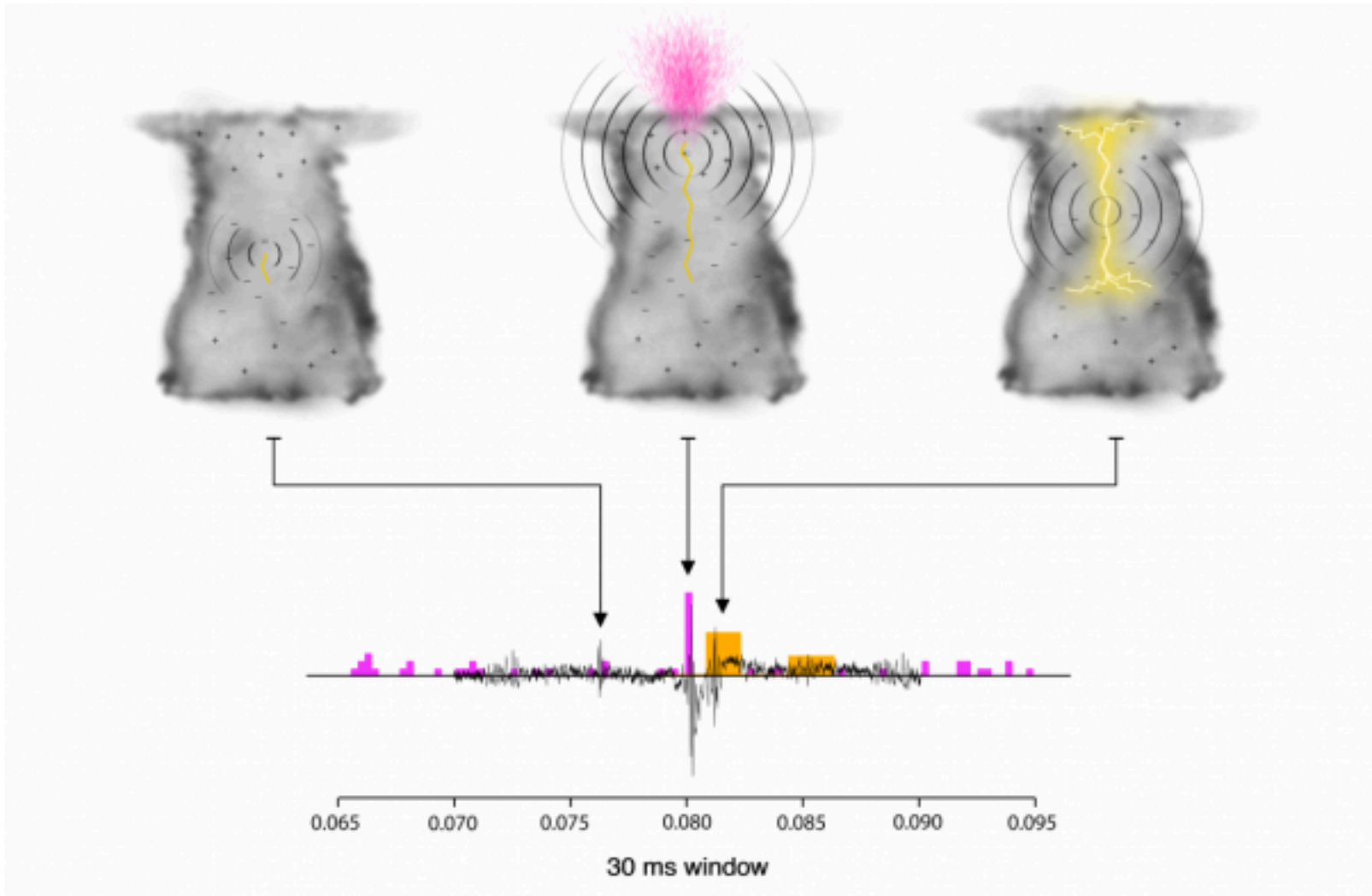
Celestin+ (2011)

TGF / lightning connection



Connaughton+ JGR (2013)

TGF / lightning connection



Ostgaard+2013

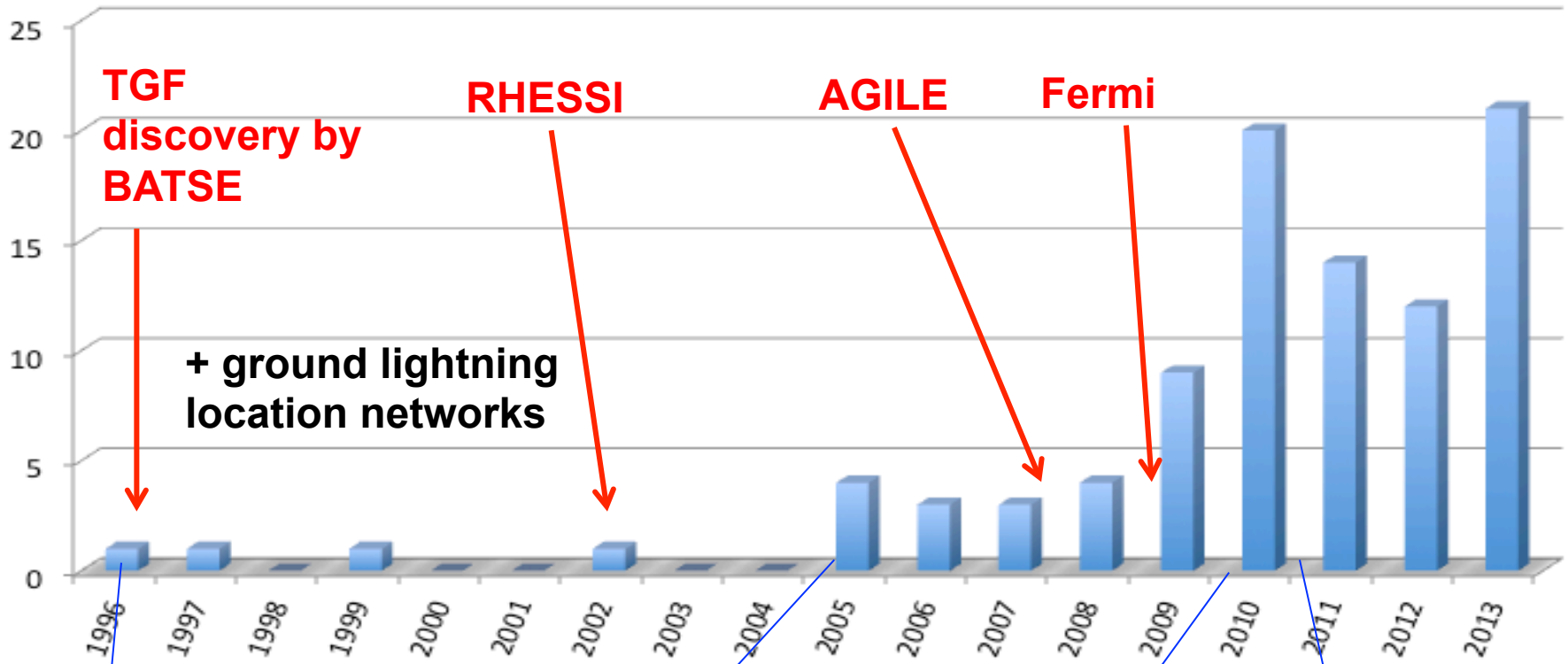
9 May 2014

M. Marisaldi - 12 AGILE WS

Credits: birkeland.uib.no

Observational breakthrough

TGF related publications (from ADS)



Association to lightning

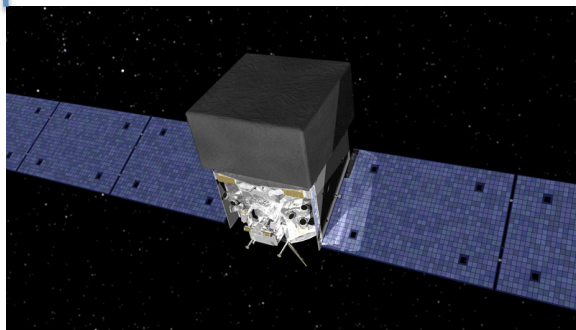
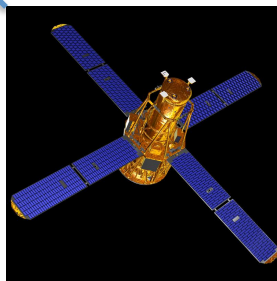
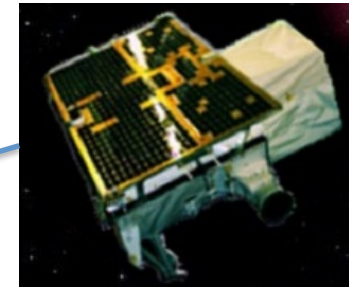
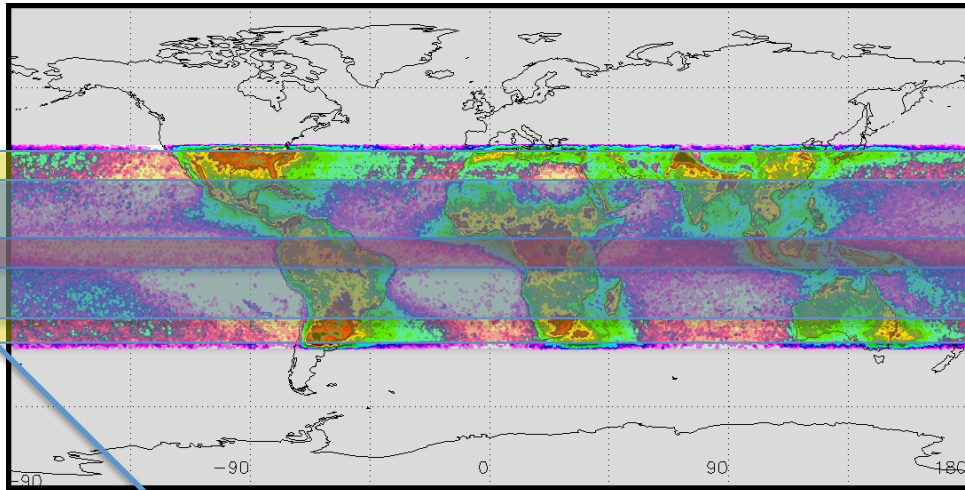
- Cumulative spectrum
- Energy up to 20 MeV
- production altitude < 20km

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

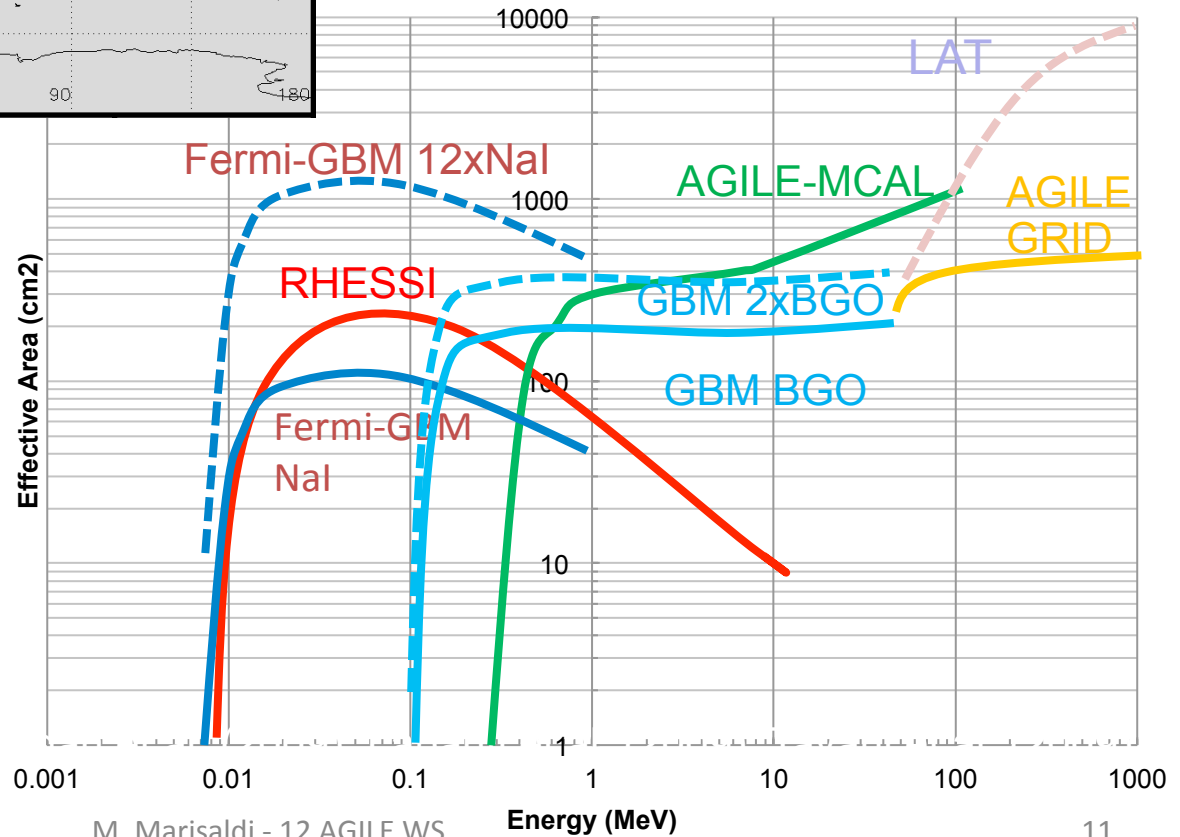


- Discovery of e^+e^- flashes
- Radio emission from TGFs
- Improved selection

Operating TGF detectors



9 May 2014

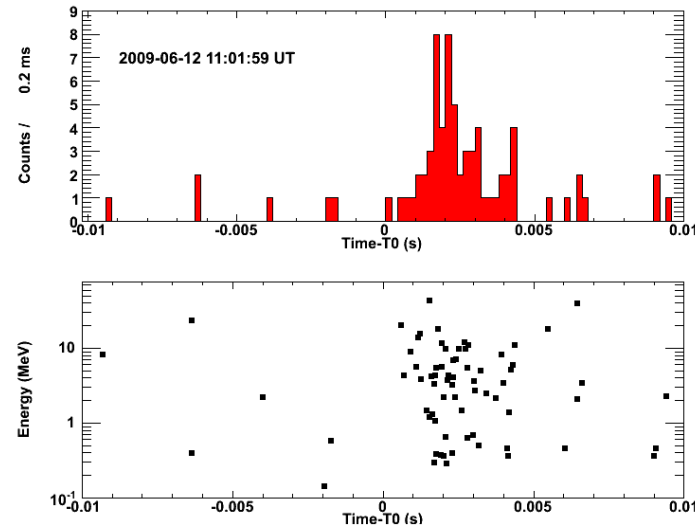


M. Marisaldi - 12 AGILE WS

AGILE contributions to TGF science

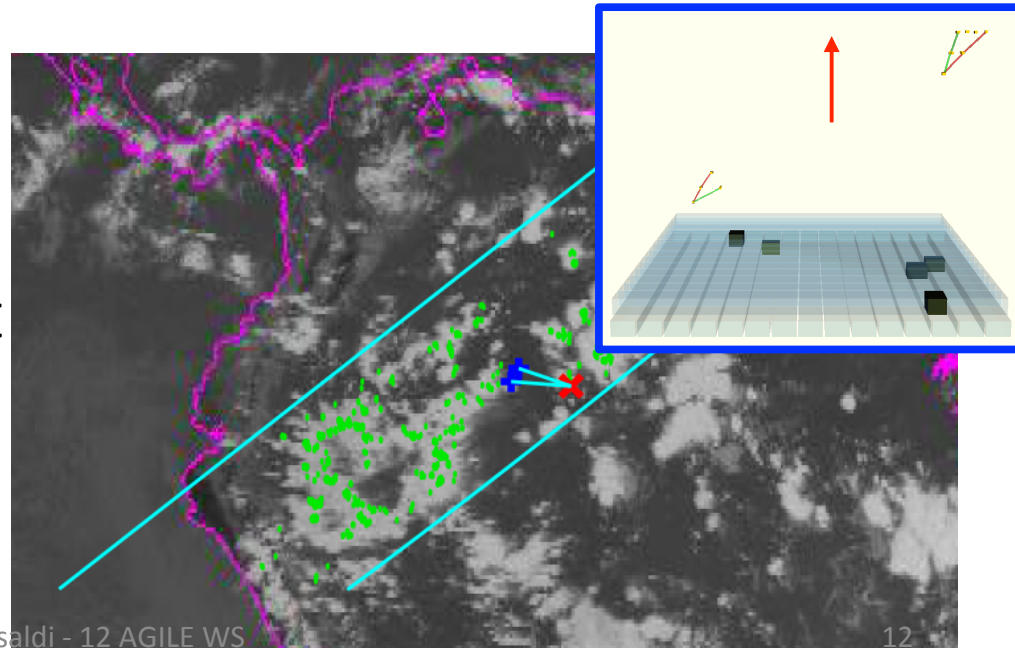
- TGF energy range extends at least to 40 MeV, doubling the previous range set by RHESSI:

Marisaldi et al., *J. Geophys. Res.* 115 (2010)



- TGFs can be localized from space directly in gamma-rays by the AGILE silicon tracker:

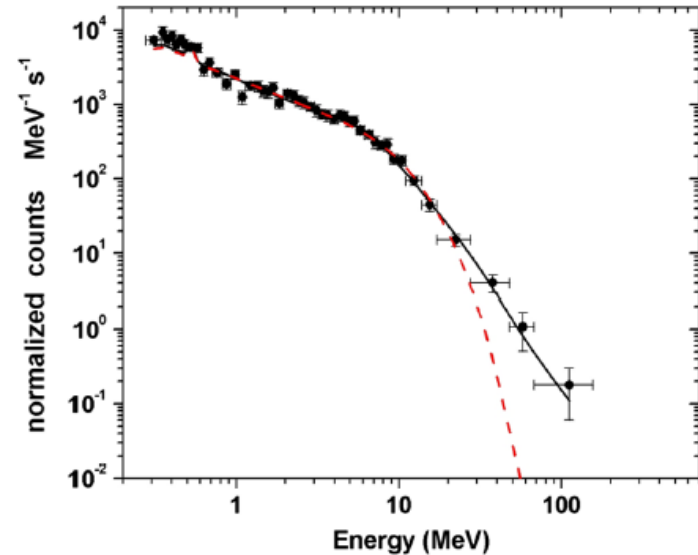
Marisaldi et al., *Phys. Rev. Lett.* 105 (2010)



AGILE contributions to TGF science

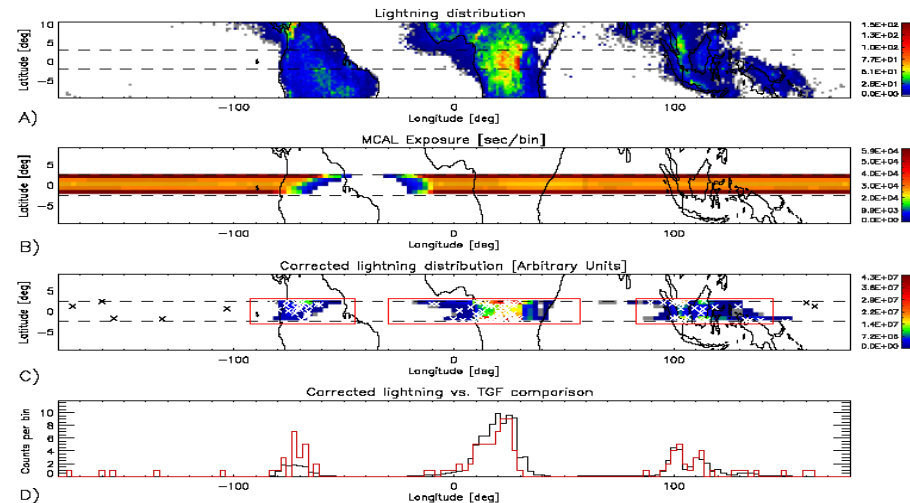
- TGFs high-energy spectrum extends up to ~ 100 MeV and challenges current models:

Tavani et al., *Phys. Rev. Lett.* 106 (2011)



- The TGF / lightning flash ratio is not constant over different geographical regions:

Fuschino et al., *Geophys. Res. Lett.* 38 (2011)



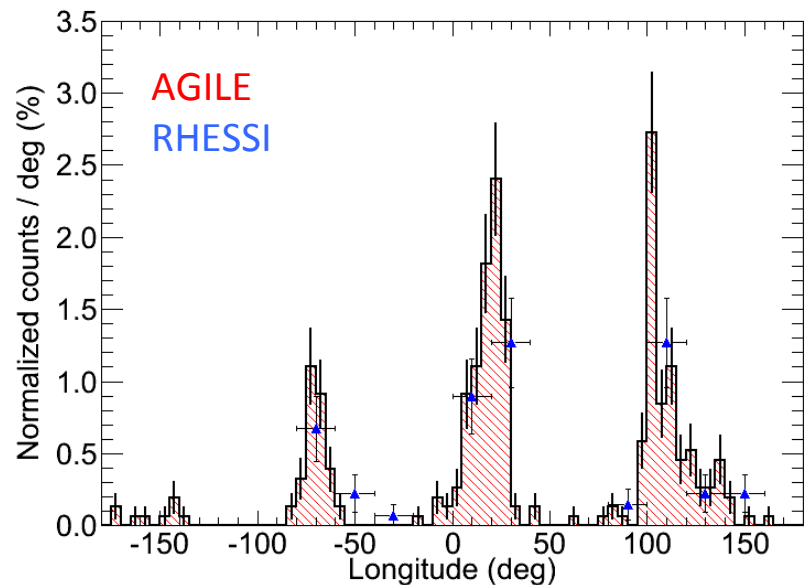
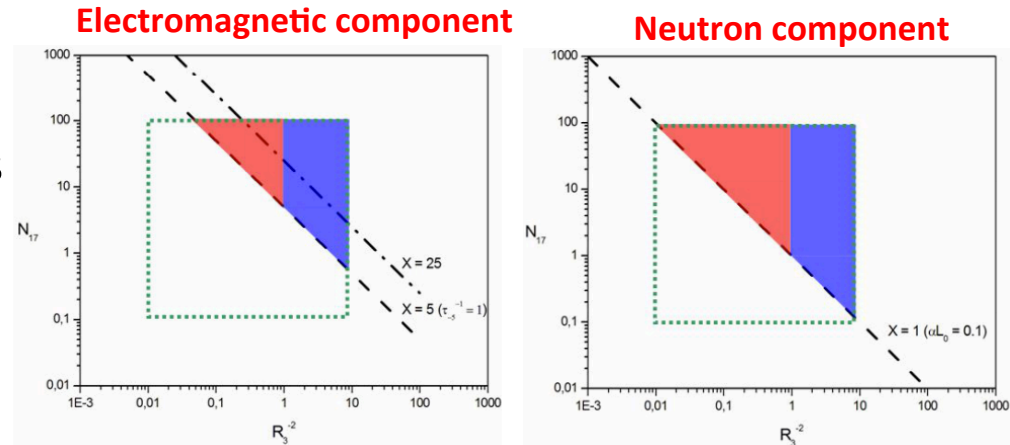
AGILE contributions to TGF science

- ❑ TGFs can potentially affect aircraft avionics:

Tavani et al., NHESS 13 (2013)

- ❑ AGILE TGFs in the frame of current observational framework; delivery of the 1st AGILE TGF catalog:

Marisaldi et al., J. Geophys. Res. 119 (2014)



The First AGILE TGF catalog

RESEARCH ARTICLE

10.1002/2013JA019301

Key Points:

- Terrestrial gamma ray flashes detected by the AGILE satellite are described
- The data set properties provide independent confirmation for key TGF properties

Properties of terrestrial gamma ray flashes detected by AGILE MCAL below 30 MeV

M. Marisaldi^{1,2}, F. Fuschino¹, M. Tavani^{3,4}, S. Dietrich⁵, C. Price⁶, M. Galli⁷, C. Pittori^{8,9}, F. Verrecchia^{8,9}, S. Mereghetti¹⁰, P. W. Cattaneo¹¹, S. Colafrancesco^{9,12}, A. Argan¹³, C. Labanti¹, F. Longo^{14,15}, E. Del Monte³, G. Barbiellini^{14,15}, A. Giuliani¹⁰, A. Bulgarelli¹, R. Campana¹, A. Chen^{10,12}, F. Gianotti¹, P. Giommi⁸, F. Lazzarotto³, A. Morselli¹⁶, M. Rapisarda¹⁷, A. Rappoldi¹¹, M. Trifoglio¹, A. Trois¹⁸, and S. Vercellone¹⁹

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

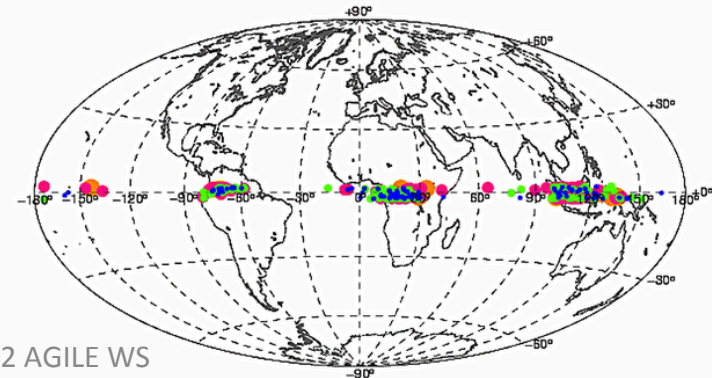
Show/hide columns

Advanced filtering

Print current view of table

Print complete table

Reset all filters



An interactive tool for the TGF community

Available at the ASI Science Data Center (ASDC) website: www.asdc.asi.it/mcaltgfcats

Entry number	TGF ID	GeoLon	GeoLat	Date (UTC)	Trigger Time T0 (MET in s)	T0_micro (μ s)	T50 (ms)	Raw Counts	HR	ML Counts+/-Err	Notes
1	090302.71821	17.42	-1.64	2009-03-02T17:14:14	163098854	254076	0.103	12	1.4	10.8+/-3.3	---
2	090308.40378	110.96	-2.33	2009-03-08T09:41:27	163590087	958609	0.48	17	1.4	19.9+/-4.8	---
3	090308.61530	106.13	-1.46	2009-03-08T14:46:02	163608362	205006	0.154	10	2.3	10.7+/-3.3	---
4	090309.25894	136.68	-1.93	2009-03-09T06:12:53	163663973	166566	0.2	11	1.4	10.8+/-3.3	---
5	090309.37239	-6.65	1.89	2009-03-09T08:56:15	163673775	205677	0.2	11	1.4	10.8+/-3.3	---
6	090309.37239	-6.65	1.89	2009-03-09T08:56:15	163673775	207136	0.2	11	1.4	10.8+/-3.3	---
7	090315.25166	-8.08	1.73	2009-03-15T06:02:24	164181744	994547	0.1	11	1.4	10.8+/-3.3	---
8	090315.51239	28.88	-2.43	2009-03-15T13:01:03	164206863	83205	0.2	11	1.4	10.8+/-3.3	---
9	090318.11112	123.28	-2.15	2009-03-18T02:40:01	164428801	655135	0.1	11	1.4	10.8+/-3.3	---
10	090320.97835	-65.7	1.17	2009-03-20T23:28:50	164676530	559745	0.5	11	1.4	10.8+/-3.3	---
11	090321.13434	7.48	0.89	2009-03-21T03:13:27	164690007	624520	0.2	11	1.4	10.8+/-3.3	---
12	090323.70296	100.89	2.16	2009-03-23T16:52:16	164911936	749444	0.1	11	1.4	10.8+/-3.3	---
13	090326.75312	121.85	-0.17	2009-03-26T18:04:30	165175470	924223	0.4	11	1.4	10.8+/-3.3	---
14	090330.00988	112.88	-2.23	2009-03-30T00:14:14	165456854	92700	0.1	11	1.4	10.8+/-3.3	---
15	090403.32898	102.52	2.4	2009-04-03T07:53:44	165830024	913614	0.1	11	1.4	10.8+/-3.3	---
16	090403.47065	102.34	1.93	2009-04-03T11:17:45	165842265	218162	0.2	11	1.4	10.8+/-3.3	---
17	090403.54289	109.32	0.75	2009-04-03T13:01:46	165848506	649177	0.2	11	1.4	10.8+/-3.3	---
18	090403.86059	-75.86	2.46	2009-04-03T20:39:15	165875955	460826	0.2	11	1.4	10.8+/-3.3	---
19	090404.46177	99.27	1.87	2009-04-04T11:04:57	165927897	969787	0.2	11	1.4	10.8+/-3.3	---
20	090414.64481	9.89	-0.61	2009-04-14T15:28:32	166807712	294310	0.42	10	1	11.3+/-3.5	---

The ASDC TGF Data Explorer

www.asdc.asi.it/explorer_TGF.php

ASDC ASI Science Data Center

Entry 090318 GeoLong. = 123.28 GeoLat. = -2.15

AGILE/MCAL Data Products Source Details

Standard Products
Light Curve broader binning (200 microseconds)

contact 9806
2009-03-18 02:40:01 UT
TT 164428801.655135

What is going on in the world?



Space

AGILE, RHESSI, Fermi

+

ASIM (ESA) - ISS

TARANIS (CNES)

Firefly (USA)

Firestation (USA) – ISS

GLIMS (JP) – ISS

Balloon

COBRAT (CNES+)

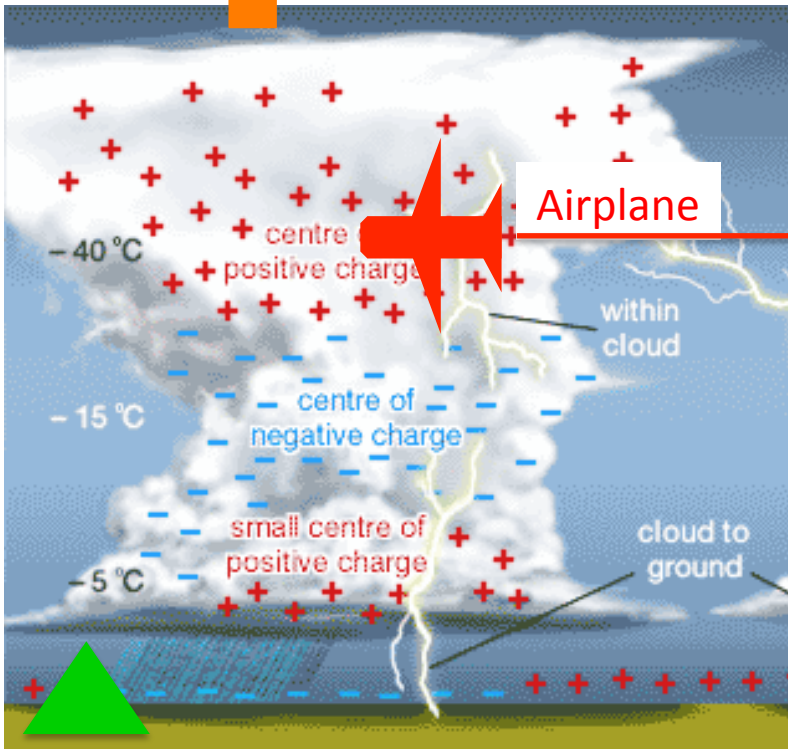
USA

Airplane

ADELE (USA)

ILDAS (NL)

Air France + IRSN

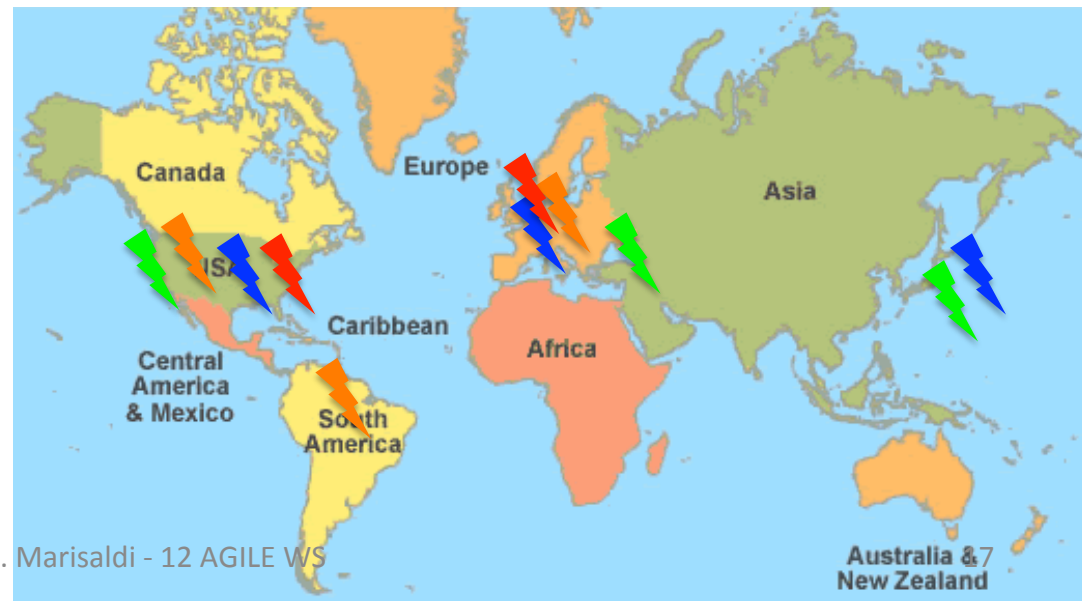


Ground

USA

Japan

Armenia



What next?

AGILE, RHESSI and Fermi still have a lot more to say!

ASIM

ESA \geq 2014



Listen to T. Neubert talk

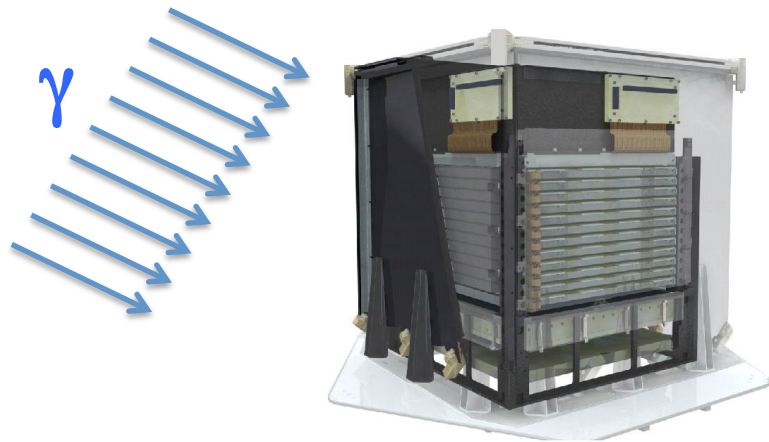
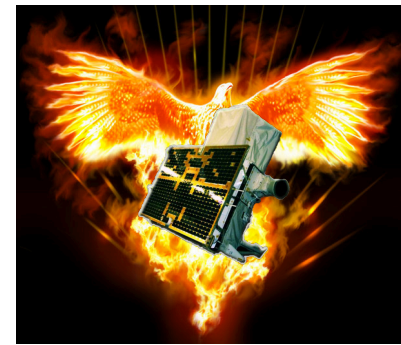
TARANIS

CNES \geq 2015



A new life for AGILE

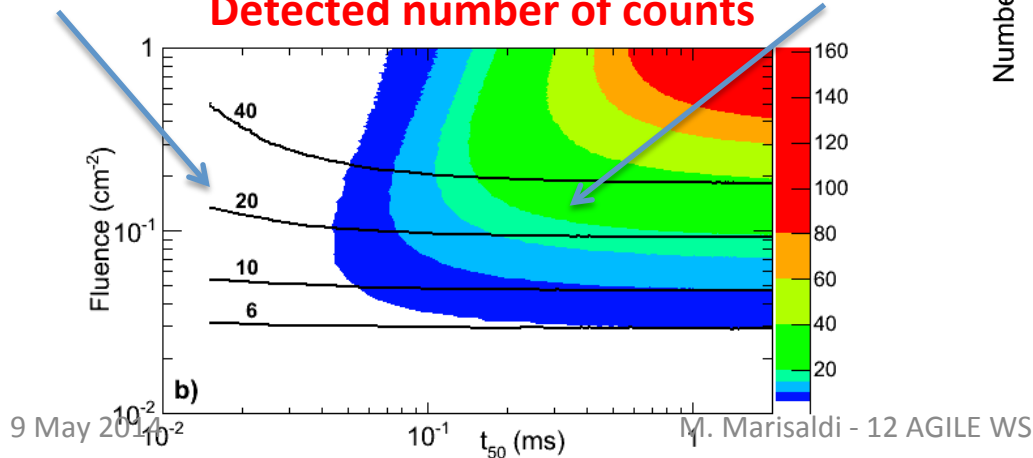
- Change of configuration: anticoincidence shield disabling for MCAL to reduce dead time and enhance short TGF detection



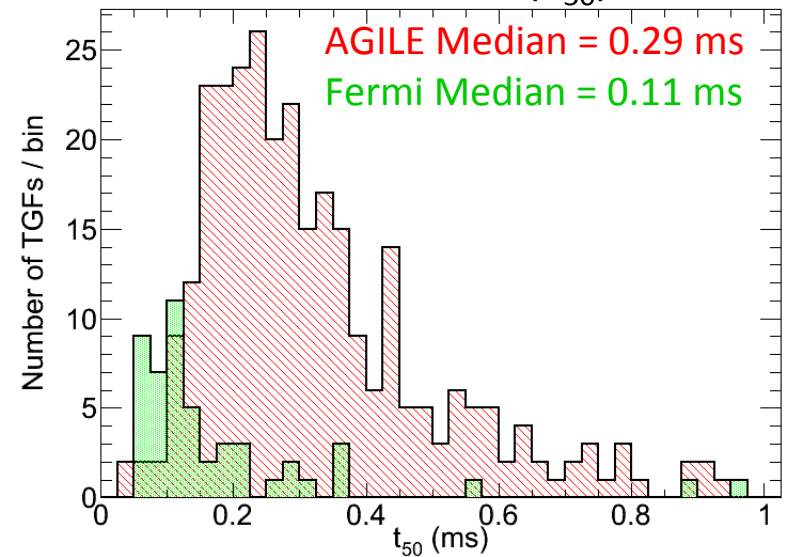
Without AC

With AC

Detected number of counts



TGF duration (T_{50})

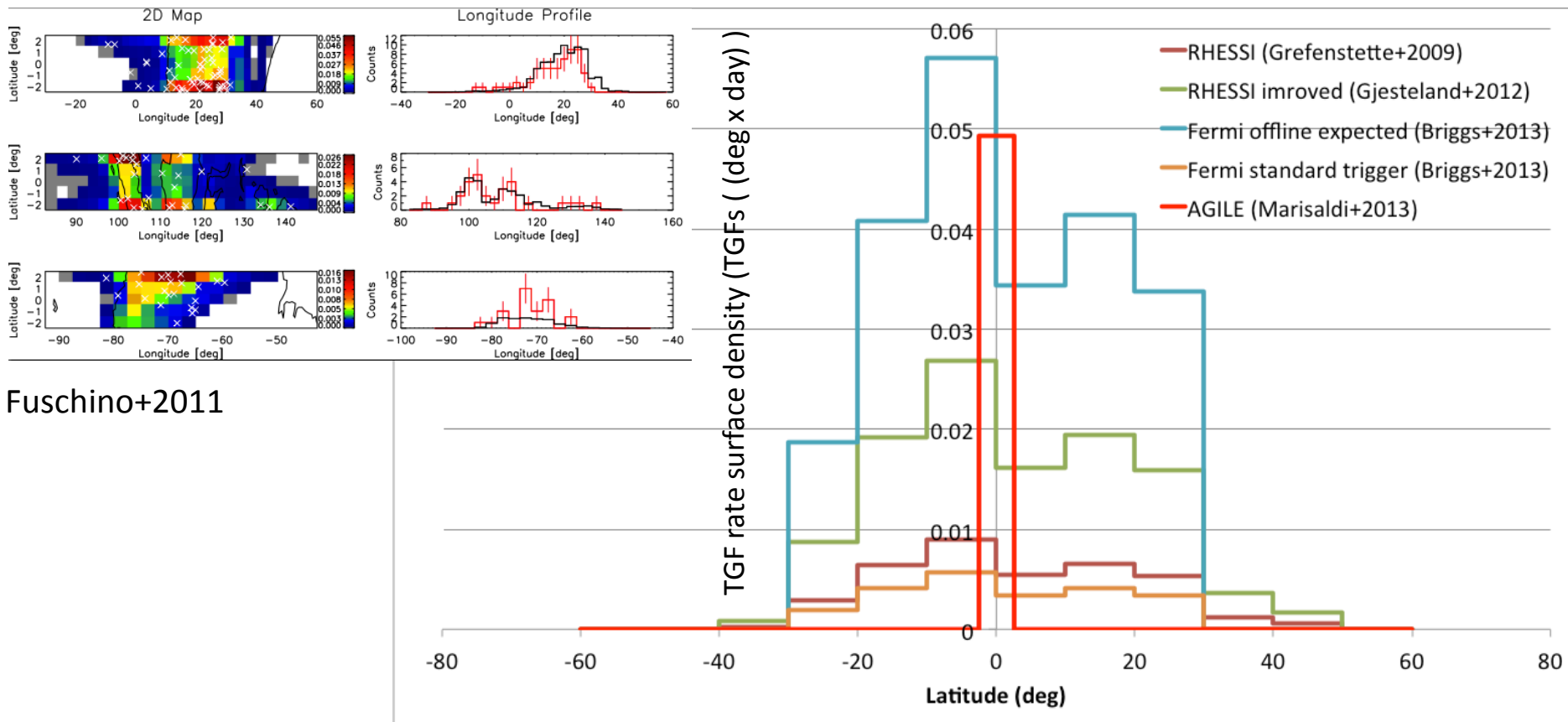


Marisaldi+2014

A new life for AGILE

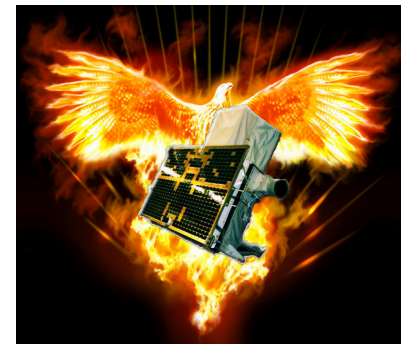


- Exploit AGILE peculiarities: the large TGF rate surface density above the equatorial region is fundamental to explore TGF / lightning flash asymmetric behavior

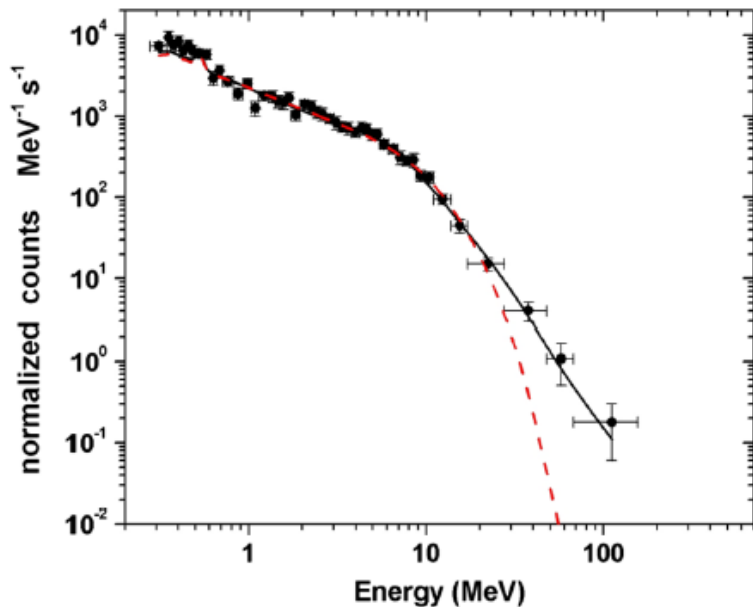


Fuschino+2011

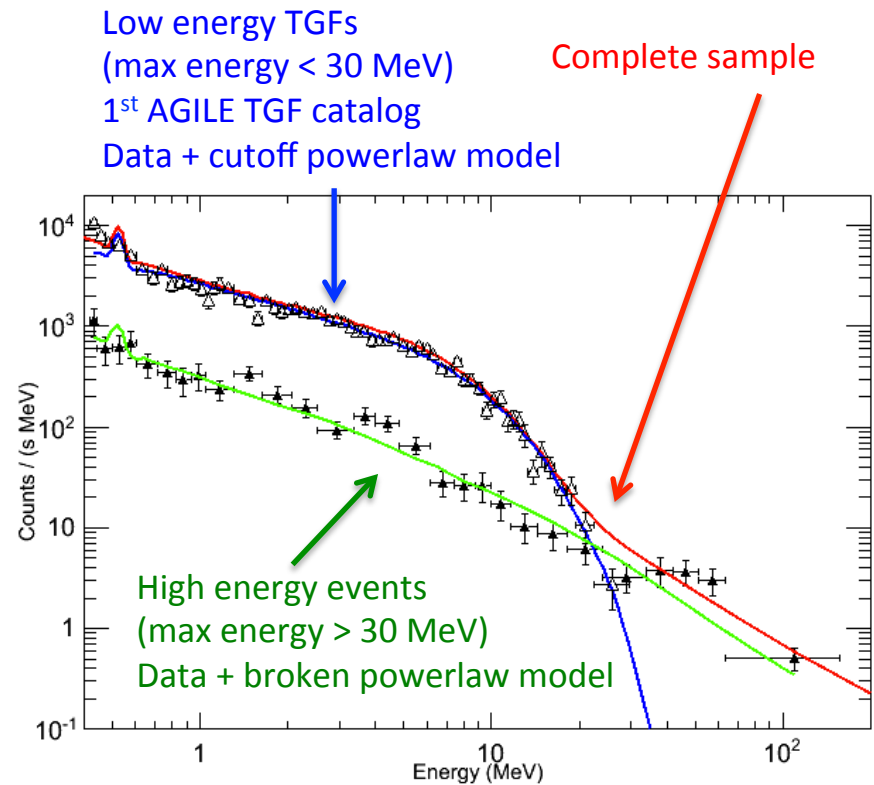
A new life for AGILE



- ❑ Exploit AGILE peculiarities: the extended energy range is fundamental to probe the emission models



Tavani+2011



Marisaldi+ in preparation

Conclusions / outlook

- ❑ TGFs are the manifestation of the most energetic natural particle accelerators on Earth
- ❑ After 20 years, lots of questions still do not have answers
- ❑ TGFs and radiation from atmospheric electricity is a fast growing scientific field
- ❑ European and American institutions are investing lots of efforts in this field
- ❑ AGILE can still give significant contribution in the field
- ❑ The AGILE Team and collaborators are the only Italian group in the field, BUT this position must be supported to be consolidated and maintained in the future