Terrestrial Gamma-ray Flashes

M. Marisaldi – INAF-IASF Bologna
On behalf of the AGILE TGF Team

AstroEarth

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

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

GRB

BATSE onboard CGRO 1991 – 2000 looking up to space...

TGF

Light Curve for a Terrestrial Gamma Flash

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TGFs 20\textsuperscript{th} birthday!


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

9 May 2014
What do we really know about TGFs?

Illustration: Hans Møller, mollers.dk

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


\[ F(eV/cm) \]

\[ E_c \sim 260 \text{ kV/cm} \]

\[ E_k \sim 32 \text{ kV/cm} \]

\[ E_{cr}^- \sim 12.5 \text{ kV/cm} \]

\[ E_{cr}^+ \sim 4.4 \text{ kV/cm} \]

\[ E_I \sim 2 \text{ kV/cm} \]

\[ E_I \sim 1 \text{ kV/cm (gaps > 30 m, Raizer, 1991, page 362)} \]

\[ \frac{E_c}{E_k} \sim 8 \]

\[ \frac{E_c}{E_I} \sim 130 \]

\[ \frac{E_k}{E_I} \sim 16 \]
Two competing models

Dwyer and Smith, Scientific American (2012)

Dwyer, Smith & Cummer (2012)

Celestin+ (2011)
TGF / lightning connection

Connaughton+ JGR (2013)

Cummer+ GRL (2011)
TGF / lightning connection

Ostgaard+2013

Credits: birkeland.uib.no
Observational breakthrough

TGF related publications (from ADS)

- TGF discovery by BATSE
- RHESSI
- AGILE
- Fermi

Association to lightning
- Cumulative spectrum
- Energy up to 20 MeV
- Production altitude < 20km

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

+ ground lightning location networks

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

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Operating TGF detectors

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

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AGILE contributions to TGF science

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

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

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

- The TGF / lightning flash ratio is not constant over different geographical regions:
AGILE contributions to TGF science

- TGFs can potentially affect aircrafts avionics:
  Tavani et al., NHESS 13 (2013)

- AGILE TGFs in the frame of current observational framework; delivery of the 1st AGILE TGF catalog:
Properties of terrestrial gamma ray flashes detected by AGILE MCAL below 30 MeV

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

TGF (E < 30 MeV) observed from March 2009 to July 2012
An interactive tool for the TGF community
Available at the ASI Science Data Center (ASDC) website: www.asdc.asi.it/mcaltgfcat

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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+)

Airplane

- ADELE (USA)
- ILDAS (NL)

Ground

- USA
- Japan
- Armenia

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What next?

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

**ASIM**
ESA >= 2014

**TARANIS**
CNES >= 2015

Listen to T. Neubert talk
A new life for AGILE

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

Detected number of counts

Without AC

With AC

TGF duration ($T_{50}$)

AGILE Median = 0.29 ms
Fermi Median = 0.11 ms

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.

Low energy TGFs
(max energy < 30 MeV)
1st AGILE TGF catalog
Data + cutoff powerlaw model

Complete sample

High energy events
(max energy > 30 MeV)
Data + broken powerlaw model

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