AGILE observation of TGFs

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In this topical lecture I will review the results on the science of Terrestrial Gamma-ray Flashes (TGFs) obtained by the AGILE satellite. AGILE is one of the few operating missions capable of TGF observation from space. Each of these missions has peculiar characteristics (orbit inclination, operative modes, detector and electronics design) that influence the characteristics of the observed TGF samples. In this lecture I will describe the AGILE payload and its potential for TGF detection, then focus on AGILE results in TGF science, in the context of the current observational framework. The properties of TGFs collected in the 1st AGILE TGF catalog will be reviewed, including duration, intensity, cumulative spectrum, multiple peaks and correlation with sferics detected by ground-based lightning detection networks.

1. The AGILE mission

Astrorivelatore Gamma a Immagini Leggero (AGILE) is a space mission of the Italian Space Agency (ASI) devoted to astrophysics in the gamma ray energy range from 30 MeV to 30 GeV, with a monitor in the X-ray band 18–60 keV [1] AGILE was launched on 23 April 2007 in a low-Earth orbit at 550 km altitude with 2.5° inclination and it is still operating. The main AGILE instruments suitable for TGF observation are: (1) the Gamma-Ray Imaging Detector (GRID), based on a tungsten-silicon tracker (ST) [2] , with imaging capabilities in the 30 MeV - 30 GeV range; (2) the minicalorimeter (MCAL) [3] , a CsI(Tl) scintillator detector sensitive in the range 300 keV - 100 MeV, without imaging capabilities. MCAL can work as an independent gamma-ray transient detector, equipped with a dedicated trigger logic [4] acting on several time scales spanning four orders of magnitude between 290 μs and 8 s.

2. AGILE TGF detection capabilities

The AGILE payload is well suited for TGF detection thanks to the following strength points [5] :

1. MCAL effective area peaks in the MeV range, where most of the TGF energy is radiated.
2. MCAL energy range is extended up to 100 MeV, allowing to probe the high energy tail of the TGF spectrum.
3. The MCAL trigger logic acts on time scales as short as 1 ms and 290 μs, well matching the TGF typical time scale.
4. Time-tagged event data with 2 μs timing accuracy are available for triggered events.
5. Absolute timing accuracy better than 100 μs allows precise timing for correlation with on-ground observation of sferic waves associated to lightning.
6. The AGILE-GRID trigger logic is sufficiently flexible to collect also high-energy photons coming from the Earth.
7. The AGILE orbit with 2.5° inclination is optimal for mapping the equatorial region, where most of the TGFs take place, with exposure larger than other missions.

All detectors that observed TGFs up to now are substantially affected by dead time, i.e., the time during which a detector is not responsive to input pulses because busy in processing previous events. Dead time is a specific characteristic of each instrument, mostly depending on design choices, therefore it affects observations differently for each detector. In the case of MCAL the dead time contribution is mostly due to the anti-coincidence (AC) shield surrounding the instrument and designed for charged particle rejection. The effects of dead time on MCAL, described in details in [6] , substantially limit the detection of short (<100 μs) TGFs and affects the observed intensity distribution.

3. Contribution to TGF science

The main AGILE contributions to TGF science are the following:

a. In [7] it was first reported that the TGF spectrum extends at least up to 40 MeV, with a spectral shape compatible with that of RHESSI, but with a maximum energy well above the previous 20 MeV limit set by that experiment.
b. In [8] we report that the high-energy tail of the observed TGF spectrum is harder than expected

and cannot be easily explained by previous theoretical models.

c. In [9] we report the first direct TGF localization from space in gamma-rays, using high-energy photons detected by the AGILE silicon tracker.

d. In [10] we show that TGFs are not a random sub-sample of global lightning activity as detected from space; moreover, significant regional differences exist, both in the degree of correlation and in the TGF/flash ratio, as confirmed both by RHESSI and, recently, by *Fermi* data.

e. In [11] we show that the high-energy photons in TGF spectrum can potentially affect the avionics of aircrafts flying close to the TGF production region.

f. In [6] we describe and discuss the properties of a sample of 308 TGFs with maximum photon energy < 30 MeV, which constitutes the 1st AGILE TGF catalog. An online version of the catalog is accessible as an interactive web table from the ASI Science Data Center website http://www.asdc.asi.it/mcaltgfcat/.

4. Properties of AGILE TGFs

The main properties of AGILE TGFs, as reported in [6] , are the following:

A. The average detection rate is ~0.3 TGFs/day, when the AGILE exposure is properly accounted for.

B. The AC-induced dead time is a key factor to understand important TGF properties such as duration and intensity distributions. The dead time model explains also why no Terrestrial Electron Beam has been detected by AGILE.

C. The duration distribution is biased toward larger values than RHESSI and *Fermi*-GBM because of the AC-induced dead time, which prevents the detection of TGFs shorter than ≈ 100 μs.

D. The intensity distribution is consistent with a power law fluence distribution with index $\lambda \approx 2.4$ for large fluences, compatible with previous studies based on RHESSI and *Fermi* data. Remarkably, all three operating TGF detectors, with different characteristics and different analysis methods, point toward consistent results.

E. The number of AGILE TGFs made of multiple peaks separated by a few milliseconds is about 2% of the sample. This fraction may be even larger if low-intensity peaks, not recognized as independent TGFs by the selection algorithm, are considered.

F. The cumulative spectrum can be fit with a power law with exponential cutoff model and is quite in agreement with RHESSI results, further supporting, with an independent data set, the scenario of low-altitude production. However, the spectrum is harder than RHESSI-simulated spectrum, suggesting a possible selection bias toward harder events.

G. No sferics detected by the World Wide Lightning Location Network (WWLLN) simultaneous to TGFs were detected. This is consistent with the fact that the detection of TGFs shorter than ≈ 100 μs, for which the probability of a simultaneous sferic is larger, is suppressed by dead time effects.

H. Despite the lack of simultaneous sferics, we used the number of WWLLN sferics detected in a spatial region and temporal interval centered at the subsatellite point and TGF time as an estimator of the overall lightning activity of the thunderstorm system conducive to TGF production. As far as this parameter is concerned, AGILE and RHESSI TGF samples are compatible with the same parent distribution.

5. References

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