The observation of gamma ray bursts and terrestrial gamma-ray flashes with AGILE


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A B S T R A C T
Since its early phases of operation, the AGILE mission is successfully observing Gamma Ray Bursts (GRBs) in the hard X-ray band with the SuperAGILE imager and in the MeV range with the Mini-Calorimeter. Up to now, three firm GRB detections were obtained above 25 MeV and some bursts were detected with lower statistical confidence in the same energy band. When a GRB is localized, either by SuperAGILE or Swift/BAT or INTEGRAL/IBIS or Fermi/GBM or IPN, inside the field of view of the Gamma Ray Imager of AGILE, a detection is searched for in the gamma ray band or an upper limit is provided. A promising result of AGILE is the detection of very short gamma ray transients, a few ms in duration and possibly identified with Terrestrial Gamma-ray Flashes. In this paper we show the current status of the observation of Gamma Ray Bursts and Terrestrial Gamma-ray Flashes with AGILE.

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1. Introduction

The italian small satellite mission AGILE (see Ref. [1] for further information) has been designed, developed and produced having in mind the Gamma Ray Bursts (GRBs) as one of the most important scientific objectives. For this reason the X-ray monitor SuperAGILE (see Ref. [2] for a complete description of the instrument) and the non-imaging Mini-Calorimeter (described by Ref. [3]) are equipped with on-board trigger algorithms and dedicated telemetry data packets (see Refs. [4,5] for a complete description). Similar methods are used in the ground based analysis in order to detect GRBs.

At the time of writing, that is in two years of operations including the Commissioning and Science Verification Phase (until November 2007), the whole Cycle One (December 2007–November 2008) and more than one half of the Cycle Two...
The prompt emission of GRB 090401B is characterized by a multipeak structure, detected up to 2.8 MeV by MCAL (see Fig. 2) and spanning about 10 s. As shown in the figure, in this case the majority of the photons in gamma rays (76%) is emitted simultaneously with the X-rays, while only a small fraction (24%) is found after the end of the prompt phase.

The extended emission of gamma rays is particularly evident in the case of GRB 090510, that is also the first short GRB with a gamma ray emission detected by AGILE. As shown in Fig. 3, the prompt emission is composed of a narrow and hard peak, of about 200 ms duration and very clearly seen by MCAL up to tens of MeV energy. In this case the gamma rays are not simultaneous with the prompt emission while their detection starts just at the end (see Fig. 3). GRB 090510 has been localized by Swift/BAT [12] and detected also by Fermi/LAT [13]. The redshift has been measured spectroscopically by VLT/FORS2 and is 0.903 [14].

Up to now AGILE has detected five GRBs in the gamma ray band in around two years of observation while the Fermi satellite mission has reported in the GCNs nine detections in about one year. If we sum the detection rate of the two missions we obtain a total rate of about one GRB per month in gamma rays. Since the two instruments, GRID and LAT, have similar fields of view, we may take into account the results of both satellites in order to obtain an overall detection rate. It seems that the phenomenon of the extended emission is a distinctive feature of the GRBs emitting in the gamma-ray band. In fact the same property has
been detected, for example, by Fermi in the lightcurve of GRB 080916C [15].

### 3. Terrestrial gamma-ray flashes

Terrestrial Gamma-ray Flashes (TGFs) are short and intense bursts with typical emission in the MeV region and duration of few ms, discovered by BATSE on CGRO (see [16]). The spectrum is harder than that of cosmic GRBs and the incoming direction is compatible with the Earth atmosphere. In nine years of operations BATSE detected only 78 TGFs mainly because of limitations in the trigger logic architecture. The sample statistics was greatly increased by RHESSI [17], whose first catalogue (see Ref. [18]) contains 820 TGFs detected between 2002 and 2008. The association between TGFs and atmospheric lightning and thunderstorm activity has been proven by Refs. [19,20] by means of temporal and spatial correlation with lightning strokes localized by their signature at VLF frequencies (sferics).

The observation of TGFs takes advantage of the MCAL on-board trigger logic, that is active on several timescales ranging between 285 μs and 8 s and allows to send to telemetry photon-by-photon data in a time window of 60 s centered at the trigger time (including the energy information and a time tag with 1 μs accuracy) in case a trigger is issued. It is the first time that a timescale as short as 285 μs is used in a space mission.

On the time scale of 16 ms or shorter, the average rate of the MCAL detections is 6.8 triggers per orbit, corresponding to about 95 triggers per day. In order not to miss any faint event, we decided to keep deliberately as low as possible the threshold of their signature at VLF frequencies (sferics).

The geographical coordinates of each TGF are derived from the footprint of AGILE at the trigger time. Since AGILE is on an equatorial orbit with ~2.5° of inclination, only a very narrow region across the Equator is span and no high latitude coverage can be obtained. The geographical distribution of the MCAL dataset is shown in Fig. 4. In the figure the clustering of the TGFs above Africa, with about half of the events ranging in the longitude interval from 0° to 30°, and South-East Asia, with about one third of the triggers in the interval between 90° and 120°, is clearly seen. The AGILE TGFs geographical and local time distributions well match those for the RHESSI TGFs, when a consistent cut in latitude is applied.

The sum of the net exposure of all the TGFs in the MCAL sample amounts to 51 ms. The dataset shows a total number of 47 photons with energy higher than 10 MeV and 8 photons above 20 MeV. These number are highly significant since, in the same energy intervals, the expected background counts are 2.3 and 1.3, respectively. The highest photon’s energy detected is larger than 40 MeV. The cumulative spectrum can be well fitted with a power law with exponential cutoff, with a cutoff energy of about 9 MeV. The same spectral model closely match also the RHESSI cumulative spectrum, with a difference in the normalization factor of about a factor 2. This difference in normalization may be ascribed both to calibration issues and to dead time effects. The effects of dead time were proven to be of particular importance for RHESSI and BATSE as shown in Ref. [21] and are still under evaluation for what concerns MCAL. Ref. [22] reports a detailed description of the selection criteria and the TGF candidate properties, as well as the comparison of the AGILE sample with the RHESSI one.

### 4. Discussion and conclusions

The observation of GRBs by Fermi and AGILE missions is showing that the emission of gamma rays from this class of sources is rather uncommon, with a detection rate of about one event per month. The continuing observation will allow to increase the statistic of the data sample and may help to find correlations between the detection of gamma rays and other features of the GRBs. So far the gamma rays are detected mainly during the prompt phase of the GRBs and usually belong to an extended emission, lasting longer than the prompt emission in hard X-rays. The fraction of gamma rays in the extended emission may vary, depending on the position of the peaks in the
lightcurve. Another important property, reported in the case of GRB 080514B, is that the fluence in gamma rays is found on the extrapolation of the spectrum of the prompt emission detected up to the MeV region. A similar feature has been found in the spectrum of GRB 080916C, detected by Fermi/LAT [15]. The analysis of the energetics of other gamma ray emitting bursts is still in progress. Up to now no peculiar feature is found in the X-ray afterglow of gamma ray emitting GRBs but the sample is still small.

After the onset of the timescale shorter than 64 ms on the on-board trigger of the AGILE MCAL, the instrument is detecting a population of short and intense bursts with properties compatible with those of TGFs. Both the geographical and local time distributions as well as the cumulative spectrum of the AGILE TGF sample well match the same distributions for the RHESSI sample, confirming that AGILE is actually detecting TGFs and the goodness of the selection criteria applied. Improvements in the selection strategy and trigger logic are expected to increase the TGF detection rate. Thanks to the almost equatorial orbit, AGILE can provide a continuous monitoring of the equatorial region, especially concerning central Africa and South East Asia, where some of the most severe TGF-producing thunderstorms develop.

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