

## AGILE, a satellite for high energy Gamma Ray Astrophysics: Prospects for the MiniCalorimeter

E. Celesti<sup>1</sup>, A. Bulgarelli<sup>1</sup>, G. di Cocco<sup>1</sup>, M. Galli<sup>2</sup>, F. Gianotti<sup>1</sup>, C. Labanti<sup>1</sup>, M. Marisaldi<sup>1,3</sup>,  
A. Mauri<sup>1</sup>, E. Rossi<sup>1</sup>, A. Traci<sup>1</sup>, M. Trifoglio<sup>1</sup>, M. Tavani<sup>4</sup>, A. Argan<sup>5</sup>

1 - IASF/CNR Sezione di Bologna, Via Gobetti 101, 40129, Bologna (Italy)

2 - ENEA, Via Don Fiammelli 2, 40129, Bologna (Italy)

3 - Università di Bologna - Dipartimento di Fisica, viale C. Berti Pichat 6/2, 40127, Bologna (Italy)

4 - IASF/CNR Sezione di Roma, Via del fosso del Cavaliere 100, Roma (Italy)

5 - IASF/CNR Sezione di Milano, Via Bassini 15, 20133, Milano (Italy)

### Abstract

AGILE is an ASI (Italian Space Agency) small space mission for high energy astrophysics in the gamma ray energy range 30MeV–50GeV, and in the X-ray band 10keV–40keV. AGILE is composed of three scientific detectors: a Tungsten-Silicon Tracker, a CsI Mini-Calorimeter and a Silicon based X-ray detector (Super-Agile), moreover an anticoincidence system carries out background rejection. The satellite's payload will have good imaging performances (with angular resolution of a few arc-minutes in the gamma ray band), good timing resolution and a large field of view (about 1/5 of the sky). AGILE detection principle is based on the pair production process that arises from the interaction between high energy photons and the Tungsten layers of the Silicon Tracker. The Silicon Tracker is designed to determine the direction of the incoming radiation, while the Mini-Calorimeter evaluates the energy of the interacting photons. The Mini-Calorimeter can also work as a stand-alone gamma ray detector in the energy range 250keV–250MeV, with no imaging capabilities, for the detection of transients and gamma ray burst events (in cooperation with Super-Agile) and for the evaluation of gamma ray background fluctuations. In this paper a description of the Mini-Calorimeter is done.

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### 1. Introduction

AGILE (“Astrorivelatore Gamma ad Immagini LEggero”, [1, 2]) is a small ASI (Italian Space Agency) mission, aimed to the observation of the high energy gamma ray sky in the energy range 30MeV–50GeV. Agile will have a large field of view (~3 sr), combined with good angular resolution (a few arc minutes of source pointing accuracy), good sensitivity and an unprecedented low dead time for gamma rays (lower than 200ms). Furthermore AGILE will give simultaneous information in the X-Ray and Gamma Ray bands thanks to the Superagile instrument [3]. AGILE is planned to be operational during the years 2005-2007. No other mission dedicated to gamma-ray astrophysics in the same energy band will be operational during that period.

The Agile payload (weighting ~130 kg, see figure 1) is composed of three scientific instruments: the Silicon Tracker [4], that is made of 12 layers of Silicon strip detectors (with a pitch of 120mm between strips and thickness of 410mm) interleaved with 10 plates of tungsten (0.07 radiation length  $X_0$  each) for gamma ray interaction. The MiniCalorimeter (MCAL) [5, 6], which is placed below the Tracker and is made of two planes of 15 CsI(Tl) bars each. Due to payload weight constraints, MCAL is just 1.5  $X_0$ ; it will collect energy information on particles converted in the Silicon Tracker (with energy between 1MeV and 500MeV), and will also monitor the Gamma Ray sky for transients (in the energy range 250keV–250MeV). Above the Tracker is placed a silicon X-ray detector (sensitive to X-rays with energy between 10keV and 40keV) which will give further information on gamma ray sources

observed, and will look for X-ray transients as well. Surrounding the payload is an Anti Coincidence system, aimed at charged particle background rejection; it is made of plastic scintillators (with thickness of 0.5cm to 0.6cm) with photo multiplier readout. A Data Handling system (DH) will process the detected events both for impulsive events detection and for effective particle background rejection [7, 8, 9].

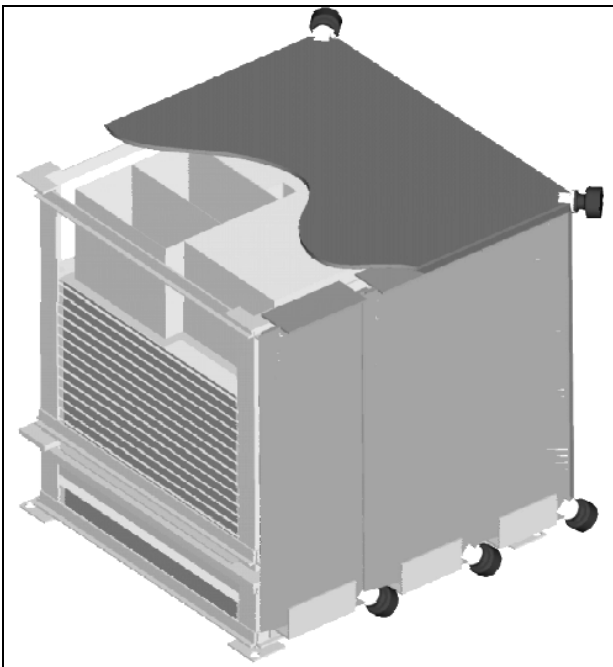


Fig. 1. Drawing of the Agile payload.

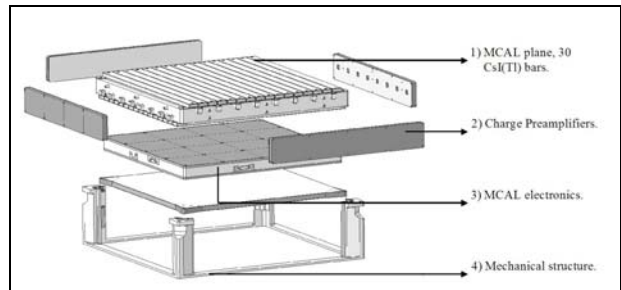
## 2. The MCAL Instrument

The Agile MiniCalorimeter (see figure 2) is basically composed of a detection plane and of a Front End Electronics (FEE), all contained in an unique mechanical structure. The MCAL functions will be the following:

i) To obtain additional information on the energy of particles converted in the Tracker

and interacting on MCAL, and therefore contributing in the energy determination of primary photons. In this case MCAL works in GRID (Gamma Ray Imaging Detector) mode, and it is a slave of the Silicon Tracker.

ii) To detect gamma ray impulsive events in the energy range 250keV–250MeV. In this case MCAL works in BURST mode, as a burst monitor detector.



The detection plane of MCAL consists of two planes of 15 CsI(Tl) bars each. The bars, which dimensions are 15mm x 23mm x 375mm, exhibit a low light attenuation combined with high light output. The readout of the scintillation light is accomplished by 2 custom PIN Photodiodes (area 15mm x 23mm, thickness 2mm, active area  $\sim 256\text{mm}^2$ ) coupled one at each side of the bar by means of a siliconic glue. To maximize the light output and to keep the light attenuation within an optimal range of values, the bars surfaces are polished and the bars are wrapped with a thin reflective coating.

Signals from PDs (Photodiodes) are collected by means of low noise charge preamplifiers, and then conditioned by a dedicated FEE. The front end electronics has been optimized for best noise performance, fast response, combined with low power consumption and a wide dynamic range. The FEE is made of 60 analogue electronic channels, one for each PD. The electronic channels used are the same for

the BURST and for the GRID chains up to the stretchers, where the signal is split and sent to the two analogue to digital conversion circuitries independently.

The BURST chains include discriminators on the signals coming from each side of each bar and on the sum of the two signals; the sparse read-out of triggered bars will minimize dead time, and the time resolution for BURST events is as low as  $\sim 2$ ms. The noise of the electronic chain is of  $\sim 800e^-_{\text{rms}}$ . The FEE is responsible for analogue to digital conversion of signals that will be sent to the DH system, where a burst search algorithm will compare the time of arrival of detected events with background fluctuations in order to detect impulsive events and then trigger a burst alert.

Mechanically, each bar, complete with its own 2 PDs, is hosted in a dedicated carbon fiber housing 1 mm thick, that provides rigidity and modularity to the MCAL detection plane. The 30 housings are mounted on to an aluminum frame, 15 in the upper side and 15 in the lower side. The frame containing the detection plane is joined to the lower part of the MCAL main frame; below the detector plane are placed the two FEE electronic boards contained in an aluminum box.

### 3. Bar prototypes

The earlier bar prototypes had dimensions of 15mm x 25mm x 400mm, this allowed for two commercial PDs (with dimensions 14.5mm x 12.7mm x 2mm, active area 100mm<sup>2</sup> each) to be coupled at each bar end. This lead to results comparable with the definitive configuration of

only one PD per side. The bars main characteristics are shown in table 1 and table 2.

**Table 1.** Detector characteristics.

Energy (MeV)	Energy Resolution (%)	Position Resolution (mm)
1	22-24	15
100	0.7	2

**Table 2.** Bars characteristics.

Bar id	Light output @1cm (e <sup>-</sup> /kev)		Attenuation (cm <sup>-1</sup> )	
	Side A	Side B	Side A	Side B
1	11.6	11.1	0.009	0.009
2	11.3	11.8	0.021	0.021
3	10.9	11.6	0.016	0.018
4	15.6	15.2	0.042	0.044
5	12.6	11.4	0.017	0.013
6	14.5	17.9	0.037	0.061
7	15.6	15.1	0.043	0.045
8	12.0	11.3	0.049	0.037
9*	20.9	-	0.009	-

\* Bar dimensions 15mm x 23mm x 375mm

New bar prototypes, that have the dimensions of the flight model and are coupled with a flight model PD, show an higher light output and a lower attenuation (see bar 9 in table 2), which means lower energy threshold and higher efficiency in the detection of low energy gamma rays. A light output of 15e<sup>-</sup>/keV, with the current level of noise, corresponds to a lower detection threshold of about 280keV @1cm from the PD. Rising the light output to 20e<sup>-</sup>/keV can drop the energy threshold to about 210keV @1cm from the PD. This means higher chances to detect gamma ray bursts with

gamma ray emission above 300keV. Lowering the light attenuation along the bar yields to an higher ability of bars to detect faint gamma rays interacting far from the PD, but the energy and position resolution drops as well.

A Montecarlo simulation has been developed to evaluate the efficiency of MCAL bars to photons produced during gamma ray bursts. Two kinds of spectrums has been considered in the simulation: a medium energy burst spectrum and a high energy burst spectrum. According to Band's formula [10]:

$$N(E) = A \left( \frac{E}{100} \right)^\alpha \exp\left( -\frac{E}{E_0} \right) \quad \text{if } E \leq (\alpha - \beta) \cdot E_0$$

$$N(E) = B \left( \frac{E}{100} \right)^\beta \quad \text{if } E > (\alpha - \beta) \cdot E_0$$

And considering the following values:

- Medium energy burst:

$$\alpha = -1.00 \quad \beta = -2.30 \\ E_0 = 300\text{keV} \quad A = 0.05 \quad B = 0.08$$

- High energy burst:

$$\alpha = -0.67 \quad \beta = -2.30 \\ E_0 = 700\text{keV} \quad A = 0.6 \quad B = 6.2$$

The calculated detection efficiencies are listed below, showing that, for both medium and high energy gamma ray bursts, optimal values for the light attenuation coefficients are around 0.009 cm<sup>-1</sup>.

tion coefficients, exposed to medium and high energy gamma ray burst.

Light Attenuation (cm <sup>-1</sup> )	Efficiency to Medium Energy Bursts	Efficiency to High Energy Bursts
0.002	0.11	0.016
0.009	0.14	0.024
0.024	0.11	0.016
0.042	0.096	0.014

#### 4. Front End Electronics SEM prototype

Front End Electronics SEM prototype

A SEM (Simplified Engineering Model) prototype of the MCAL FEE has been available at IASF-Bologna in the March 2003. This prototype is composed of two electronic boards, each one can read the input signals coming from up to 4 bars. It includes 16 electronic chains (compared to 60 of the flight model), can handle events both in GRID and BURST mode and performs signal conditioning and analogue to digital conversion of the analogue signals. Each one of the 16 analogue chains collects the signal from the respective PD, and is composed of:

- An amplification stage;
- A signal shaper, with shaping time of about 3 msec;
- A baseline restorer;
- A programmable threshold discriminator, used to enable zero crossing discriminator circuitry (used by the BURST chain);
- A zero crossing discriminator (used by the BURST chain);
- Two signal stretchers, one for the GRID chain and one for the BURST chain.

**Table 1.** Detection efficiencies (detected photons / total incoming photons) of four sample bars with different light attenua-

The signal in output from the stretchers is multiplexed separately for the BURST and GRID chains and is sent to separate ADCs with 12 bit precision. GRID and BURST chains can acquire data simultaneously.

In BURST mode, the triggers generated by signals above threshold are sent to an FPGA, that is in charge to send a conversion command to the stretchers of single bars in case the trigger is not vetoed. Only bars with valid triggers are converted. An AC input signal can inhibit BURST data acquisition.

In GRID mode, signals are converted when a trigger from the data handling system is received. Moreover, a trigger pulse is generated by the FEE when the total energy released in the whole MCAL exceeds a predefined threshold (programmable via Tele-Command, starting from 10 MeV). Such an amount of energy released in the Agile MCAL, actually could cause a backplash of particles triggering the AC system, that in this case will be momentarily disabled.

Digitized data is stored in a de-randomizing FIFO, while a dedicated interface manages the I/O of stored data and Tele-Commands (TC) to/from a Test Equipment simulating the Agile data handling. A set of ratemeters on the two boards keep track of the trigger rate of the BURST discriminators.

## **5. Front End Electronics Test Equipment and Science Console**

A dedicated FEE Test Equipment (TE) and Science Console has been realized for the SEM prototype. The former is composed of a host computer, running Linux, connected to a rack containing a number of boards installed on a

VME bus. The purpose of the TE is to control the instrument configuration and to acquire the instrument data, through the custom made VME boards. A GUI (Graphical User Interface), based on the QT library, provides the operator with the current status of the instrument and graphical widgets for the generation of the Tele-Commands.

Three VME boards simulate the Agile Data Handling Unit, providing the acquisition of the events, the on-board time clock for events time tag, the digital House-Keepings acquisition and the generation of the Tele-Commands which write/read the status and the FEE configuration registers.

The Host Computer is able to archive data on local disc and to forward all the telemetry and TC data packets to the Science Console through a TCP/IP connection.

In near real time, the raw data packets are archived by the Science Console, which extracts the events list and archives it in FITS format. The FITS archive is accessed by the Quick-Look and On-Line Analysis software, in order to produce the events list histograms for each electronic chain (GRID and BURST) and the count rate time profile, with user adjustable parameters.

## **6. Preview of tests performed on prototypes**

A test session has been carried out at CERN laboratories in summer 2003, using the Mini-Calorimeter and Ground Support Equipment prototypes in a configuration similar to the one described above. The MCAL prototypes were used together with those of the Agile Silicon Tracker and of the Anticoincidence system. The system was the target of a beam consisting

of high energy charged particles and photons, produced by bremsstrahlung. A sample spectrum obtained in BURST mode by the MCAL prototype is shown in figure 3, where the Landau shaped behavior of energy deposits on the bars is due to interaction with high energy charged particles.

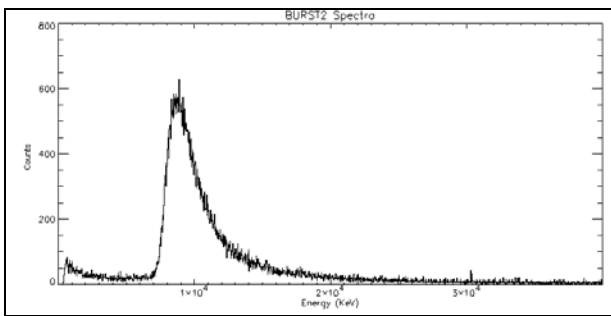


Fig. 3. Sample spectrum, obtained in a BURST mode acquisition, of the bar n. 2 (ref. table 2), showing the energy deposit in the crystal resulting from high energy particles interactions. Test campaign at CERN, June/July 2003.

## 7. Conclusions

The MCAL instrument is going to carry out a relevant role in the AGILE satellite, both in the energy estimation of GRID events (originating from the interaction of high energy photons in the silicon tracker), and in the detection of gamma ray transients coming from the whole sky. Its main characteristics are good signal to noise ratio and low dead time, combined with good timing resolution for BURST events. Prototypes have been realized for the bars, Front End Electronics and Ground Support Equipment, and have been tested at CERN.

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