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Science and Technology: The AGILE Scientific Instrument

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ABSTRACT

The Energetic Gamma Ray Experiment Telescope was the highest energy instrument on board the Compton Gamma Ray Observatory, and covered the broadest energy range, from 20 MeV to 30 GeV. It had a large field of view, good angular resolution and very low background. Because it was designed for high-energy studies, the detector was optimized to detect gamma rays when they interact by the dominant high-energy pair-production process which forms an electron and a positron pair within the EGRET spark chamber.

The AGILE scientific instrument is based on an innovative design based on three detecting systems: (1) a Silicon Tracker, (2) a Mini-Calorimeter, and (3) an ultralight coded mask system with Si-detectors (Super-AGILE). AGILE is designed to provide: (1) excellent imaging in the energy bands 30 MeV–50 GeV (5–10 arcmin for intense sources) and 10-40 keV (1–3 arcmin);, (2) optimal timing capabilities, with independent readout systems and minimal deadtimes for the Silicon tracker, Super-AGILE and Mini-Calorimeter; (3) large

fields of view for the gamma-ray imaging detector (~3 sr) and Super-AGILE (~1 sr).

Despite of its smaller dimensions AGILE will have comparable performances to EGRET on axis and substantially better off axis. The innovative technology will allow AGILE to achieve the smallest deadtime in high-energy astrophysics.

1 Introduction

The AGILE Mission is the first of the Italian Space Agency Small Scientific Missions 8). It is devoted to high-energy astrophysics and is currently planned to be operational in 2003. The AGILE scientific instrument 2, 9, 10) is based on the state-of-the-art technology of solid state Silicon detectors developed by INFN and CNR laboratories. The instrument is light (~ 80 kg) and very effective in detecting and monitoring hard X-ray/gamma-ray sources within a large field of view (FOV).

We adopted the philosophy of one integrated instrument made of three detectors with broad-band detection and imaging capabilities: the Gamma-Ray Imaging Detector (GRID) 4) sensitive in the energy range 30 MeV–50 GeV, the hard X-ray imager named Super-AGILE (SA) 6) sensitive in the energy range 10–40 keV, and a non-imaging CsI(Tl) Mini-Calorimeter (MC) 1) sensitive in the energy range 0.3–200 MeV. We briefly describe in these paper the main instrument's characteristics.

The use of the state of the art technology allows AGILE to reach scientific performances better than EGRET.

2 The EGRET experiment

EGRET was sensitive to gamma rays in the energy range from about 30 MeV to 30 GeV. In the mode used for most of the observations, the effective area of the telescope is about 1000 cm^2 at 150 MeV, 1500 cm^2 around 0.5-1 GeV, decreasing gradually at high energies to about 700 cm^2 at 10 GeV for targets near the center of the field of view. EGRET's effective area is maximum when the target is on axis and falls to approximately 50% of this value when the angular offset reaches 18°.

The instrument had components typically used in the high energy gamma-ray telescopes until the 1990's; an anticoincidence system to discriminate against charged particle radiation, a multilevel thin-plate spark chamber system to convert gamma rays and determine the trajectories of the secondary electron-positron pair, a triggering telescope that detects the presence of the pair with the correct direction of the motion, and an energy measuring calorimeter, which in the case of EGRET is a NaI(Tl) crystal. Descriptions of the instrument and details of the instrument calibration, both before and after launch, could be found in [12, 7]. The instrument was carefully designed to be essentially free of internal background, and calibration tests verified that the internal background was at least an order of magnitude below the extragalactic diffuse gamma radiation.

The scientific goals of the mission included the study of the high energy transfers in neutron stars, other galactic objects, and active galaxies, the galactic and extragalactic high-energy gamma-ray diffuse radiation, energetic solar phenomena, cosmic rays and supernovae, and the high-energy gamma-ray emission of the gamma ray bursts.

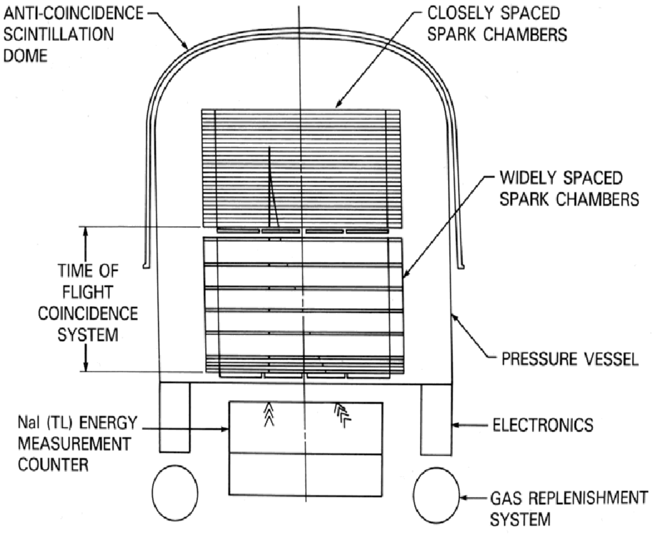

Figure 1: *Schematic view of the EGRET instrument*

3 The AGILE Instrument

Fig. 2 shows the AGILE instrument configuration of total weight of $\sim$ 80 kg including the Si-Tracker, Super-AGILE, Mini-Calorimeter, the Anticoincidence system and electronics. The baseline AGILE instrument is made of the following elements.

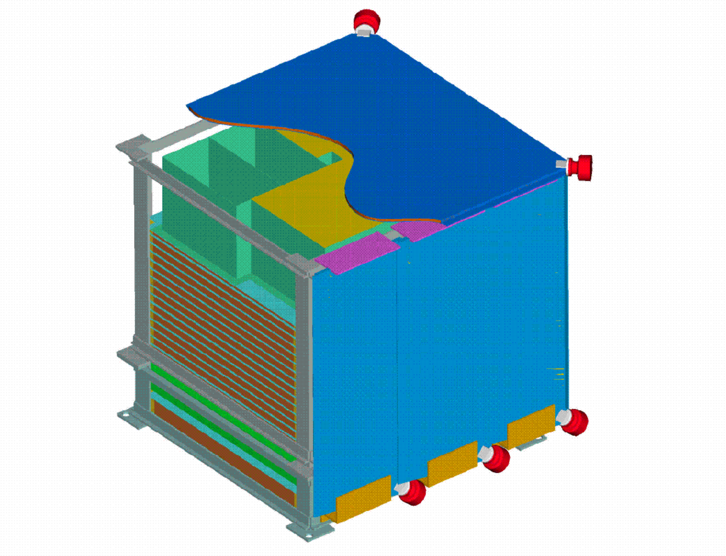

Figure 2: *Schematic view of the AGILE instrument*

- **Silicon-Tracker**, a gamma-ray pair-converter and imager made of 14 planes, with two Si-layers per plane providing the X and Y coordinates of interacting charged particles. The fundamental Silicon detector unit is a tile of area 9.5×9.5 cm^2, microstrip pitch equal to 121 μm, and thickness 410 μm. The adopted "floating readout strip" system has a total of 384 readout channels (readout pitch equal to 242 μm) and three readout TA1 chips per Si-tile. Each Si-Tracker layer is made of 4×4 tiles, for a total geometric area of 38×38 cm^2 and 1,536 readout channels. The first 12 planes are made of three elements: a first layer of Tungsten (0.07 X_0) for gamma-ray conversion, and two Si-layers (views) with microstrips orthogonally positioned. For each plane there are then $2 \times 1,536$ readout microstrips. Since the GRID trigger requires at least three Si-planes to be activated, two more Si-planes are inserted at the bottom of the Tracker without Tungsten layers. The total readout channel number of for the GRID Tracker is $\sim 43,000$. Both digital and analog information (charge deposition in Si-microstrip) is read by TA1 chips. These channels are individually read by state-of-the-art electronic devices (front-end-electronics, FEE). The distance between mid-planes equals 1.6 cm (optimized by Montecarlo simulations). Special algorithms applied off-line to telemetered data will allow optimal background subtraction and reconstruction of the photon incidence angle. Both digital and analog information are crucial for this task. The positional resolution obtained by these detectors in recent beam tests at CERN is excellent, being below 40 μm for a large range of photon incidence angles $^{3)}$. More information on the Silicon Tracker can be found in Refs. $^{4)}$.

- **Super-AGILE**, made of four square Silicon detectors ($19 \times 19\,\mathrm{cm}^2$ each) and associated FEE placed on the first GRID tray plus an ultra-light coded mask system supporting a Tungsten mask placed at a distance of 14 cm from the Silicon detectors. Super-AGILE tasks are: *(i)* photon-by-photon detection and imaging of sources in the energy range 10-40 keV, with a field-of-view (FOV) of $\gtrsim 0.8$ sr, good angular resolution (1-3 arcmins, depending on source intensity and geometry), and good sensitivity ($\sim$ 5 mCrab for 50 ksec integration, and $\lesssim 1$ Crab for a few seconds integration); *(ii)* simultaneous X-ray and gamma-ray spectral studies of high-energy sources; *(iii)* excellent timing ($\lesssim 4\,\mu$s); *(iv)* burst trigger for the GRID and MC; *(v)* GRB alert and quick on-board positioning capability. Refs. $^{6)}$ describe the Super-AGILE structure and scientific capabilities.

- **Mini-Calorimeter** (MC), made of two planes of Cesium Iodide (CsI) bars, for a total (on-axis) radiation length of 1.5 X_0. The signal from each CsI bar is collected by two photodiodes placed at both ends. The MC tasks are: *(i)* obtaining additional information on the energy of particles produced in the Si-Tracker; *(ii)* detecting GRBs and other impulsive events with spectral and intensity information in the energy band $\sim 0.3 - 100$ MeV. We note that the problem of "particle backsplash" for AGILE is much less severe than in the case of EGRET. AGILE allows a relatively efficient detection of (inclined) photons near 10 GeV and above also because the AC-veto can be disabled for events with more than $\sim$ 100 MeV total energy collected in the MC. Ref. $^{1)}$ describes the MC characteristics.

- **Anticoincidence System**, aimed at both charged particle background rejection and preliminary direction reconstruction for triggered photon events. The AC system surrounds all AGILE detectors (Super-AGILE, Si-Tracker and MC). Each lateral face is segmented with three plastic scintillator layers (0.6 cm thick) connected to photomultipliers placed at their bottom. A single square plastic scintillator layer (0.5 cm thick) constitutes the top-AC layer whose signal is read by four photomultipliers placed at the four corners.

- **Data Handling System**, for fast processing of the GRID, Mini-Calorimeter and Super-AGILE events. The GRID trigger logic for the acquisition of gamma-ray photon data and background rejection is structured in two main levels: Level-1 and Level-2 trigger stages. The Level-1 trigger is fast ($\lesssim 5\mu s$) and requires a signal in at least three out of four contiguous tracker planes, and a proper combination of fired TA1 chip number signals and AC signals. An intermediate Level-1.5 stage is also envisioned (lasting $\sim 20\ \mu s$), with the acquisition of the event topology based on the identification of fired TA1 chips. Both Level-1 and Level-1.5 have a hardware-oriented veto logic providing a first cut of background events. Level-2 data processing includes a GRID readout and pre-processing, "cluster data acquisition" (analog and digital information), and processing by a dedicated CPU. The Level-2 processing is asynchronous (estimated duration $\sim$ a few ms) with the actual GRID event processing. The GRID deadtime turns out to be $\sim 100\ \mu s$ and is dominated by the Tracker readout.

The charged particle and albedo-photon background passing the Level-1+1.5 trigger level of processing is simulated to be $\lesssim 100$ events/sec for the nominal equatorial orbit of AGILE [5]. The on-board Level-2 processing has the task of reducing this background by a factor between 3 and 5. Off-line processing of the GRID data with both digital and analog information is being developed with the goal to reduce the particle and albedo-photon background rate above 100 MeV to ~ 0.01 events/sec.

In order to maximize the GRID FOV and detection efficiency for large-angle incident gamma-rays (and minimize the effects of particle backsplash from the MC and of "Earth albedo" background photons), the data acquisition logic uses proper combinations of top and lateral AC signals and a coarse on-line direction reconstruction in the Si-Tracker. For events depositing more than ~ 100 MeV in the MC, the AC veto can be disabled to allow the acquisition of gamma-ray photon events with energies larger than 1 GeV.

Appropriate data buffers and burst search algorithms are envisioned to maximize data acquisition for transient gamma-ray events (e.g., GRBs) in the Si-Tracker, Super-AGILE and Mini-Calorimeter, respectively.

The Super-AGILE event acquisition is conceptually simple. After a first "filtering" based on AC-veto signals and pulse-height discrimination in the dedicated FEE (XAA1 chips), the events are buffered and transmitted to the CPU for burst searching and final data formatting. The 4 Si-detectors of Super-AGILE are organized in 16 independent readout units, of $\sim 5\ \mu s$ deadtime each.

Given the relatively large number of readable channels in the Si-Tracker and Super-AGILE ($\sim 50,000$ channels), the instrument requires a very efficient readout system. In order to maximize the detecting area and minimize the instrument weight and absorbed power, the GRID and Super-

AGILE front-end-electronics is partly accommodated in special boards placed externally on the Tracker lateral faces. Electronic boxes, P/L memory (and buffer) units will be accommodated at the bottom of the instrument. Ref. $^{11)}$ describes the AGILE Data Handling System.

Table 1 summarizes the main characteristics of the AGILE gamma-ray instrument and its performance compared to that of EGRET. We assumed a typical 2-week pointing duration and a $\sim 50\%$ exposure efficiency.

Table 1: **A COMPARISON BETWEEN EGRET AND AGILE**

	EGRET	AGILE
Mass	1830 kg	80 kg
Gamma-ray energy band	30 MeV – 30 GeV	30 MeV–50 GeV
Field of View	~ 0.5 sr	~ 3 sr
PSF	5.5°	4.7° (@ 0.1 GeV)
(68% containment radius)	1.3°	0.6° (@ 1 GeV)
	0.5°	0.2° (@ 10 GeV)
Deadtime for γ-ray detection	$\gtrsim 100$ ms	$\lesssim 100\,\mu$s
Sensitivity	8×10^{-9}	6×10^{-9} (@ 0.1 GeV)
for pointlike sources	1×10^{-10}	4×10^{-11} (@ 1 GeV)
($\mathrm{ph\,cm^{-2}\,s^{-1}\,MeV^{-1}}$)	1×10^{-11}	3×10^{-12} (@ 10 GeV)
Required pointing reconstruction	~10 arcmin	~1 arcmin

4 Conclusions

The AGILE scientific instrument is innovative in many ways, and is designed to obtain an optimal gamma-ray detection performance despite its relatively small mass and absorbed power. The refined readout of the Silicon Tracker allows to reach an excellent spatial resolution ($\sim 40\,\mu$m) that is crucial for gamma-ray imaging. The combination of hard X-ray (Super-AGILE) and gamma-ray imaging capabilities in a single integrated instrument is unique to AGILE. We anticipate a crucial role of Super-AGILE for studies of AGNs, GRBs, and Galactic sources. Positioning better than ~ 6 arcmin can be obtained for sources detectable in the hard X-ray range. Instrumental deadtimes for the different detectors are unprecedently small for gamma-ray instruments, and microsecond photon timing can be achieved. An optimal Burst Search Procedure is implemented in the on-board Data Handling System allowing a GRB search for a broad dynamic range of durations from milliseconds to hundreds of seconds.

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