The AGILE Mission and its Scientific Instrument

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ABSTRACT

The AGILE Mission will explore the gamma-ray Universe with a very innovative instrument combining for the first time a gamma-ray imager (sensitive in the range 30 MeV - 50 GeV) and a hard X-ray imager (sensitive in the range 15-45 keV). An optimal angular resolution and a large field of view are obtained by the use of state-of-the-art Silicon detectors integrated in a very compact instrument. AGILE will be operational at the beginning of 2007 and it will provide crucial data for the study of Active Galactic Nuclei, Gamma-Ray Bursts, unidentified gamma-ray sources, Galactic compact objects, supernova remnants, TeV sources, and fundamental physics by microsecond timing.

Keywords: Space instrumentation, gamma-rays, X-rays

1. INTRODUCTION

The space program AGILE (*Astro-rivelatore Gamma a Immagini LEggero*) is a high-energy astrophysics Mission supported by the Italian Space Agency (ASI) with scientific and programmatic participation by INAF, INFN and several Italian universities.[25] The industrial team includes Carlo Gavazzi Space, Alcatel-Alenia-Space-Laben, Oerlikon-Contraves, and Telespazio.

The main scientific goal of the AGILE program is to provide a powerful and cost-effective mission with excellent imaging capability simultaneously in the 30 MeV-50 GeV and 15-45 keV energy ranges with a very large field of view.[7,26,27] AGILE is currently (June 2006) carrying out the satellite qualification tests after having completed the gamma-ray calibration in November 2005. The Indian rocket PSLV is planned to launch AGILE during the fourth quarter of 2006/beginning of 2007.

Paper presented at the SPIE Conference n. 6266, Orlando, May 24, 2006; to be published in the Conf. Proceedings.
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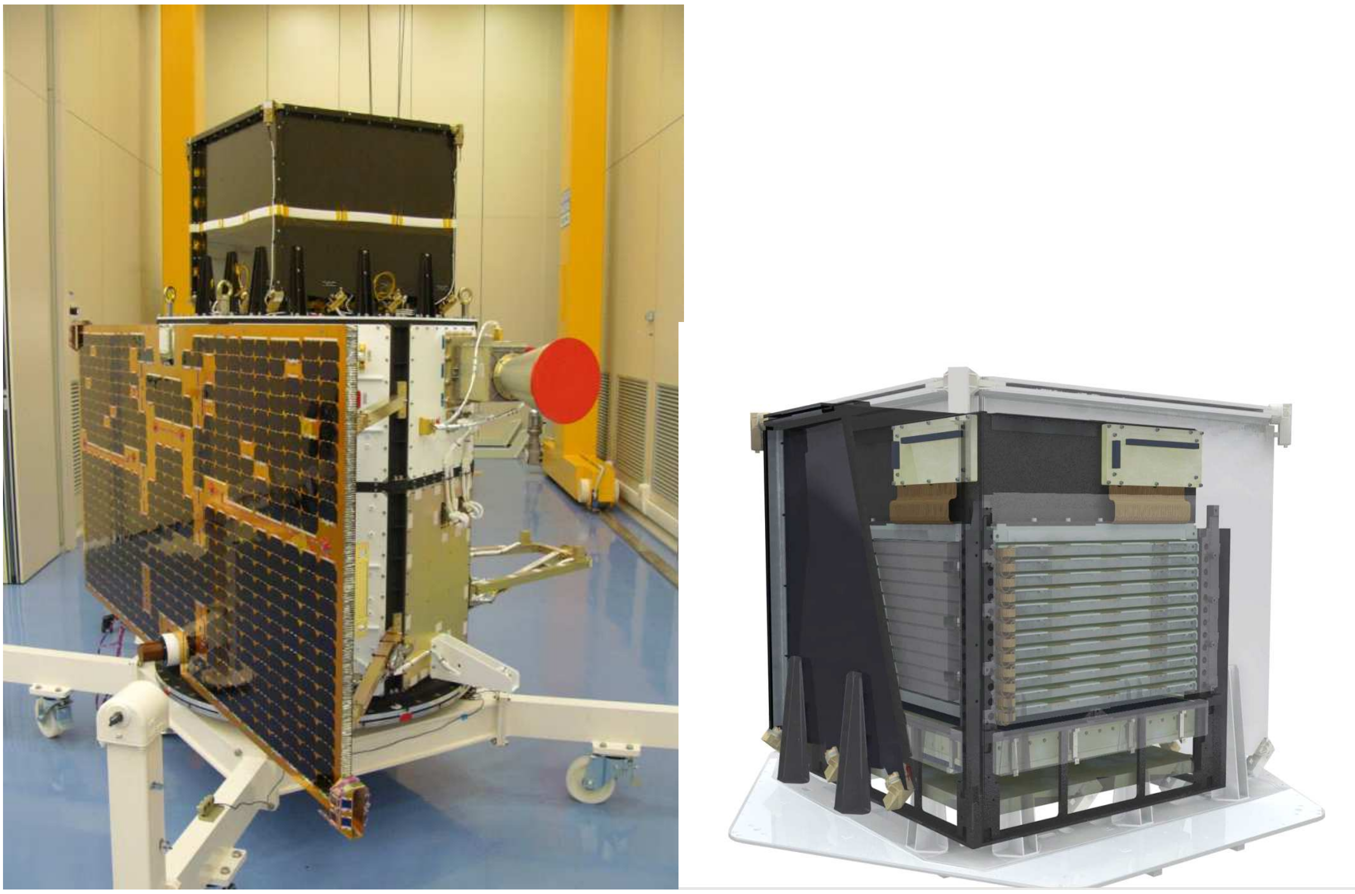

Figure 1. *Left panel*: The integrated AGILE satellite in its final configuration. The total satellite mass is equal to 350 kg. *Right panel*: the AGILE scientific instrument showing the hard X-ray imager, the gamma-ray Tracker, and Calorimeter. The Anticoincidence system is partially displayed, and no lateral electronic boards and harness are shown for simplicity. The AGILE instrument "core" is approximately a cube of about 60 cm size and of weight equal to 100 kg.

The AGILE instrument design is innovative and based on the state-of-the-art technology of solid state Silicon detectors and associated electronics developed in Italian laboratories.[3–6, 15] The instrument is very compact (see Fig. 1) and light ($\sim$ 120 kg) and it is aimed at detecting new transients and monitoring gamma-ray sources within a very large field of view (FOV $\sim 1/5$ of the whole sky). The total satellite mass is equal to 350 kg.

AGILE is expected to substantially advance our knowledge in several research areas including the study of Active Galactic Nuclei and massive black holes, Gamma-Ray Bursts (GRBs), the unidentified gamma-ray sources, Galactic transient and steady compact objects, isolated and binary pulsars, pulsar wind nebulae (PWNae), supernova remnants, TeV sources, and the Galactic Center. Furthermore, the fast AGILE electronic readout and data processing (resulting in detectors' deadtimes smaller than $\sim$ 200 μsec) allow for the first time a systematic search for sub-millisecond gamma-ray/hard X-ray transients that are of interest for both Galactic objects (searching outburst durations comparable with the dynamical timescale of $\sim 1\,M_\odot$ compact objects) and quantum gravity studies[30] .

The AGILE Science Program will be focused on a prompt response to gamma-ray transients and alert for follow-up multiwavelength observations. AGILE will provide crucial information complementary to several space missions (Chandra, INTEGRAL, XMM-Newton, SWIFT, Suzaku) and it will support ground-based investigations in the radio, optical, and TeV bands. Part of the AGILE Science Program will be open for Guest Investigations on a competitive basis. Quicklook data analysis and fast communication of new transients will be implemented as an essential part of the AGILE Science Program.

2. THE SCIENTIFIC INSTRUMENT

The AGILE scientific payload is made of three detectors combined into one integrated instrument with broad-band detection and imaging capabilities. The Anticoincidence and Data Handling systems complete the instrument. Table 1 summarizes the instrument scientific performance.

The Gamma-Ray Imaging Detector (GRID) is sensitive in the energy range $\sim$ 30 MeV–50 GeV, and consists of a Silicon-Tungsten Tracker, a Cesium Iodide Calorimeter, and the Anticoincidence system*. It is characterized by a very fine spatial resolution (obtained by a special arrangement of Silicon microstrip detectors and analog signal storage and processing) and by the smallest ever obtained deadtime for gamma-ray detection ($\lesssim$200 μs). The GRID is designed to achieve an optimal angular resolution (source location accuracy $\sim 15'$ for intense sources), an unprecedentedly large field-of-view ($\sim$ 2.5 sr), and a sensitivity comparable to that of EGRET for sources within 10-20 degree off-axis (and substantially better for larger off-axis angles).

The hard X-ray imager (Super-AGILE) is the unique characteristic of the AGILE instrument. This imager is placed on top of the gamma-ray detector and is sensitive in the 15-45 keV band. It has an optimal angular resolution (6 arcmin) and a good sensitivity over a $\sim$ 1 sr field of view. The main characteristic of AGILE will be then the possibility of simultaneous gamma-ray and hard X-ray source detection with arcminute positioning and on-board GRB/transient source alert capability.

A Mini-Calorimeter operating in the "burst mode" is the third AGILE detector. It is part of the GRID, but also is capable of independently detecting GRBs and other transients in the 300 keV - 100 MeV energy range with optimal timing capabilities.

Fig. 1 shows the integrated AGILE satellite and a representation of the instrument. We briefly describe here the main detecting units of the AGILE instrument; more detailed information will be presented elsewhere.[28]

- **The Silicon-Tracker** (ST) providing the gamma-ray imager is based on photon conversion into electron-positron pairs. It consists of a total of 12 trays with a repetition pattern of 1.9 cm. The first 10 trays are capable of converting gamma-rays by a Tungsten layer. Tracking of charged particles is ensured by high-resolution Silicon microstrip detectors that are configured to provide the two orthogonal coordinates for each element (point) along the track. 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 AGILE ST readout system is capable of detecting and storing the energy deposited by the penetrating particles for half of the Silicon microstrips. This implies an alternating readout system characterized by "readout" and "floating" strips. The analog signal produced in the readout strips is read and stored for further processing. The fundamental element is a Silicon tile with a total of 384 readout channels (readout pitch equal to 242 μm) and 3 TAA1 chips required to process independently the analog signal from the readout strips. Each Si-Tracker layer is made of 4×4 Si-tiles, for a total geometric area of 38×38 cm^2. The first 10 trays are equipped with a Tungsten layer of 245 μm (0.07 X_0) positioned in the lower part of the tray. The Silicon detectors providing the two orthogonal coordinates are positioned at the very top and bottom of these trays. For each tray there are $2 \times 1,536$ readout microstrips. Since the ST trigger requires at least three planes to be activated, two more trays are inserted at the bottom of the Tracker without the Tungsten layers. The total readout channel number for the GRID Tracker is then $36,864$. Both digital and analog information (charge deposition in Si-microstrip) is read by TAA1 chips. The distance between mid-planes equals 1.9 cm (optimized by Montecarlo simulations). The ST has an *on-axis* total radiation length near 0.8 X_0. Special trigger logic algorithms implemented on-board (Level-1 and Level-2) lead to a substantial particle/albedo-photon background subtraction and a preliminary on-board reconstruction of the photon incidence angle. Both digital and analog information are crucial for this task. Fig. 3 shows an example of gamma-ray events detected by the GRID during the integrated satellite tests. The positional resolution obtained by the ST is excellent, being below 40 μm for a large range of particle incidence angles.[?]

*In contrast with previous generation instruments (COS-B, EGRET), AGILE does not require gas operations and/or refilling, and does not require high-voltages.

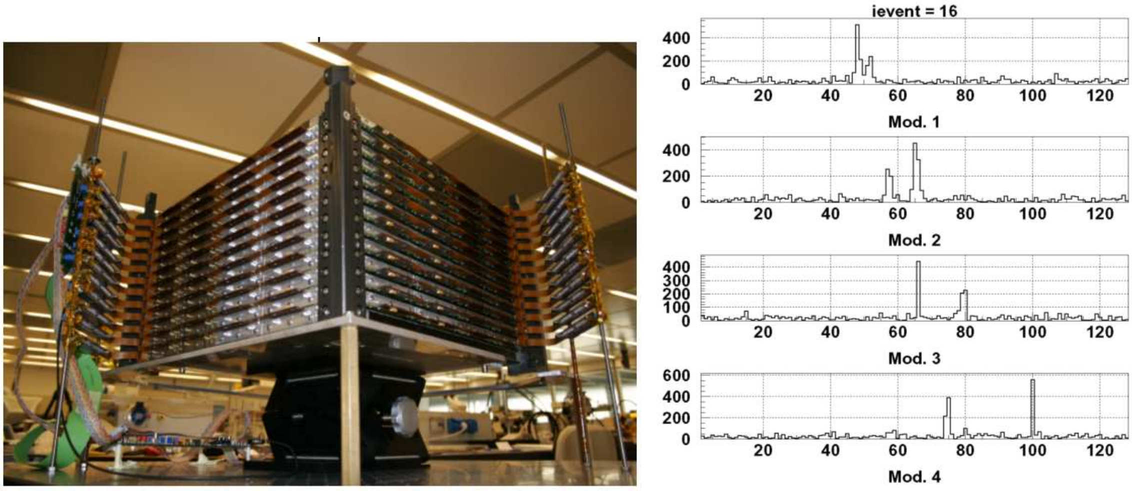

Figure 2. *Left panel*: the assembled AGILE Silicon Tracker developed by the INFN laboratories of Trieste before being integrated with the rest of the instrument (June 2005). *Right panel*: an example of an "environmental" gamma-ray event produced by cosmic-rays and detected by the Tracker with its characteristic pattern of released energy in clusters of hit readout Silicon microstrips (August 2005).

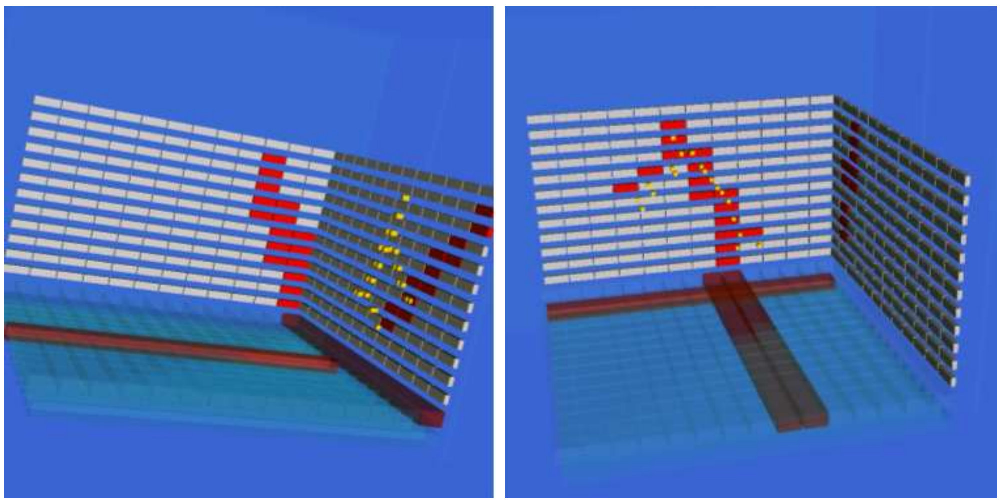

Figure 3. *Left and right panels*: an example of two "environmental" gamma-ray events produced by cosmic-rays and detected by the AGILE-GRID during the integrated satellite scientific acquisition runs with the whole ST trigger logic implemented (May 2006).

- **Super-AGILE** (SA), the ultra-compact and light hard-X-ray imager of AGILE is a coded-mask system made of a Silicon detector plane and a thin Tungsten mask positioned 14 cm above it. The detector plane is organized in four independent square Silicon detectors ($19 \times 19\,\mathrm{cm}^2$ each, similar to those of the ST) plus a dedicated front end electronics based on the XAA1.2 chips (suitable in the SA energy range). The total number of SA readout channels is 6,144. The detection cabability of SA includes: (1) photon-by-photon transmission and imaging of sources in the energy range 15-45 keV, with a large field-of-view (FOV ~ 1 sr); (2) a good angular resolution (6 arcmin); (3) a good sensitivity (~ 10 mCrab between 15-45 keV for 50 ksec integration, and $\lesssim 1$ Crab for a few seconds integration). The hard-X-ray imager is aimed at the simultaneous X-ray and gamma-ray detection of high-energy sources with excellent timing capabilities (a few microsecond deadtime for individual detectors). The AGILE satellite is equipped with an ORBCOMM transponder capable of trasmitting GRB coordinates to the ground within a few 1-2 min.

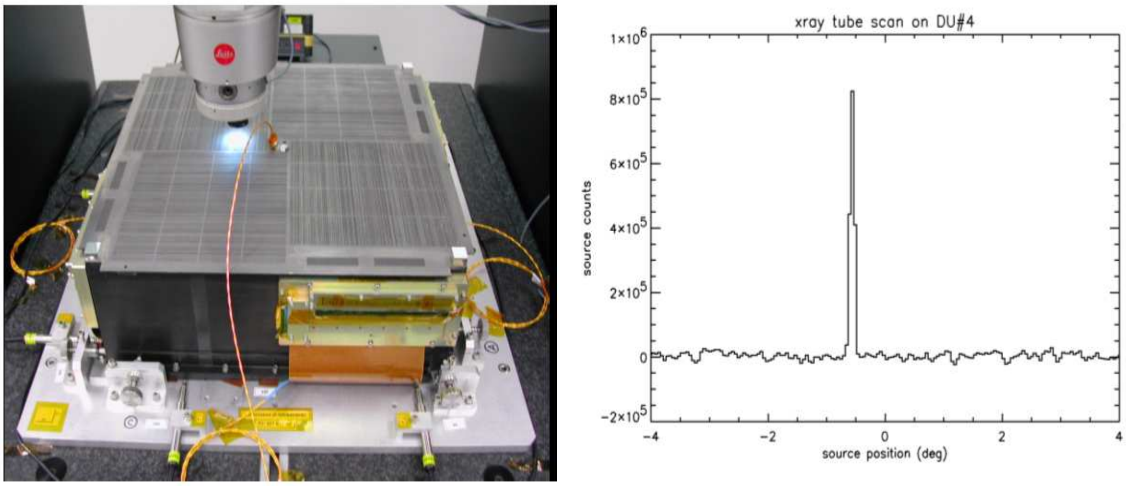

Figure 4. *Left panel*: The Super-AGILE detector during metrology measurements (March 2005). *Right panel*: deconvolved "image" of Super-AGILE obtained by an experimental set-up reproducing with a sequence of parallel beams a hard X-ray source at infinity (May 2005).

- **The Mini-Calorimeter** (MCAL) is made of 30 Thallium activated Cesium Iodide (CsI(Tl)) bars arranged in two planes, for a total (on-axis) radiation length of 1.5 X_0[19] . The signal from each CsI bar is collected by two photodiodes placed at both ends. The MCAL aims are: *(i)* obtaining additional information on the energy deposited in the CsI bars by particles produced in the Silicon Tracker (and therefore contributing to the determination of the total photon energy); *(ii)* detecting GRBs and other impulsive events with spectral and intensity information in the energy band $\sim 0.3 - 100$ MeV. An independent burst search algorithm is implemented on board with a wide dynamic range for the MCAL independent GRB detection.

- **The Anticoincidence (AC) System** is aimed at both charged particle background rejection and preliminary direction reconstruction for triggered photon events. The AC system completely surrounds all AGILE detectors (Super-AGILE, Si-Tracker and MCAL). Each lateral face is segmented in three plastic scintillator layers (0.6 cm thick) connected with photomultipliers placed at the bottom. A single plastic scintillator layer (0.5 cm thick) constitutes the top-AC whose signal is read by four light photomultipliers placed externally to the AC system and supported by the four corners of the structure frame. The segmentation of the AC System and the ST trigger logic contribute to produce the very large field of view of the AGILE-GRID.

The Data Handling (DH) and power supply systems complete the instrument. The DH is optimized for fast on-board processing of the GRID, Mini-Calorimeter and Super-AGILE data. Given the relatively large number of readable channels in the ST and Super-AGILE (~40,000), the instrument requires a very efficient on-board data processing system. 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 TAA1 chip number signals and AC signals. An intermediate Level-1.5 stage is also envisioned (lasting ~ 20 μs), with the acquisition of the event topology based on the identification of fired TAA1 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). 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 $\lesssim 200$ μs 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. 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 $\sim$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 MCAL 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 ST. For events depositing more than 200 MeV in the MCAL, the AC veto may be disabled to allow the acquisition of gamma-ray photon events with energies larger than 1 GeV.

A special set of memory buffers and burst search algorithms are implemented to maximize data acquisition for transient gamma-ray events (e.g., GRBs) in the ST, Super-AGILE and Mini-Calorimeter, respectively. The Super-AGILE event acquisition envisions a first "filtering" based on AC-veto signals, and pulse-height discrimination in the dedicated front end electronics (based on XA1 chips). The events are then buffered and transmitted to the CPU for burst searching and final data formatting. The four Si-detectors of Super-AGILE are organized in sixteen independent readout units, resulting in a $\sim 5\ \mu$s global deadtime[23].

In order to maximize the detecting area and minimize the instrument weight, 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 are positioned at the bottom of the instrument within the spacecraft body.

Table 1. AGILE Scientific Performance

Gamma-ray Imaging Detector (GRID)		
Energy Range	30 MeV – 50 GeV	
Field of view	$\sim$ 2.5 sr	
Flux sensitivity ($E > 100$ MeV) (ph cm^{-2} s^{-1})	3×10^{-7}	(5σ in 10^6 s)
Angular Resolution at 400 MeV	1.2 degrees	(68% cont. radius)
Source Location Accuracy (high Gal. latitudes)	$\sim$15 arcmin	(90% C.L.)
Energy Resolution	ΔE/E$\sim$1	at 400 MeV
Absolute Time Resolution	$\sim 2\,\mu$s	
Deadtime	$100 - 200\,\mu$s	
Hard X–ray Imaging Detector (Super-AGILE)		
Energy Range	15 – 45 keV	
Single (mono-dimensional) detector field of view	$107^\circ\times68^\circ$	FW at Zero Sens.
Combined (bi-dimensional) detector field of view	$68^\circ\times68^\circ$	FW at Zero Sens.
Sensitivity (at 15-45 keV)	$\sim$ 10 mCrab	(5σ in 1 day)
Angular Resolution (pixel size)	$\sim$ 6 arcmin	
Source Location Accuracy	$\sim$2-3 arcmin	S/N$\sim$10
Energy Resolution (FWHM)	ΔE$<$ 8 keV	
Absolute time accuracy	$\sim 4\,\mu$s	
Mini-Calorimeter		
Energy Range	0.3 – 100 MeV	
Energy Resolution	13% FWHM	at 1.3 MeV
Absolute Time Resolution	$\sim 3\,\mu$s	
Deadtime (for each of the 30 CsI bars)	$\sim 20\,\mu$s	

3. THE GAMMA-RAY CALIBRATION

The AGILE instrument was calibrated at the INFN National Laboratory of Frascati (LNF) during the month of November 2005. We used the Beam Test Facility (BTF) providing a collimated beam of electrons and positrons in the energy range 30-650 MeV. Gamma-rays in the energy range of interest to the AGILE-GRID were produced

Figure 5. *Left panel*: AGILE calibration at Beam Test Facility of LNF (photo courtesy: G. Mazzitelli, INFN). Several pieces of equipment are visible: the (orange) deflecting magnet, the AGILE Photon Tagging System installed around the magnet, and the mechanical ground support equipment supporting the AGILE instrument positioned in the γ-ray photon beam direction. *Right panel*: the AGILE instrument positioned along the gamma-ray photon beam in the BTF (November 2005).

by electron Bremsstrahlung in a thin Silicon target; a magnet subsequently deviated the charged particles leaving the gamma-rays interacting with the AGILE instrument. Our Team developed and installed in the the BTF area a photon-tagging system[20] and a ground support equipment[35] that were used for the AGILE gamma-ray calibration. More than 10^5 tagged gamma-rays were produced in 18 days of round-the-clock runs. They were made interact with the AGILE instrument positioned in different interaction geometries for a set of relevant incident directions and off-axis angles. We also used the direct electron and positron beams at different energies to study the effect of the particle background on the instrument. A detailed analysis of the results is beyond the scope of this paper and it will be presented elsewhere.

4. SCIENCE WITH AGILE

This section summarizes the main features of the AGILE scientific capability. The AGILE instrument has been designed and developed to obtain:

- **excellent imaging capability in the energy range 100 MeV-50 GeV**, improving the EGRET angular resolution by a factor of 2, see Fig. 7;
- **a very large field-of-view** for both the gamma-ray imager (2.5 sr) and the hard X-ray imager (1 sr), (FOV larger by a factor of $\sim$6 than that of EGRET);
- **excellent timing capability**, with overall photon absolute time tagging of uncertainty below $2\,\mu$s and very small deadtimes ($\lesssim 200\,\mu$s for the GRID, $\sim 5\,\mu$s for the sum of the SA readout units, and $\sim 20\,\mu$s for each of the individual CsI bars);
- **a good sensitivity for point sources**, comparable to that of EGRET in the gamma-ray range for sources within 20 degrees off-axis (except a central region of smaller effective area), and very flat up to 50-60 degrees off-axis. Depending on exposure and the diffuse background , the flux sensitivity threshold can reach values of $(10-20) \times 10^{-8}$ ph.cm^{-2} s^{-1} above 100 MeV. The hard X-ray imager sensitivity is between 10 and 20 mCrab at 20 keV for a 1-day integration over a field of view near 1 sr;

- **good sensitivity to photons in the energy range ∼30-100 MeV**, with an effective area above 200 cm^2 at 30 MeV;
- **a very rapid response to gamma-ray transients and gamma-ray bursts**, obtained by a special quicklook analysis program and coordinated ground-based and space observations.
- **accurate localization (∼2-3 arcmins) of GRBs and other transient events** obtained by the GRID-SA combination (for typical hard X-ray transient fluxes above ∼1 Crab); the expected GRB detection rate is $\sim 1-2$ per month;
- **long-timescale continuous monitoring (∼2-3 weeks) of gamma-ray and hard X-ray sources**;
- **satellite repointing after special alerts** (∼1 day) in order to position the source within the Super-AGILE FOV to obtain hard X-ray data for gamma-ray transients detected by the GRID in the external part of its FOV or by other high-energy missions (e.g., GLAST).

The combination of simultaneous hard X-ray and gamma-ray data will provide a formidable combination for the study of high-energy sources. We briefly address here some of the relevant features of the expected scientific performance.

4.1. Angular resolution

Figs. 7 shows and example of the expected positioning of a gamma-ray source in the Galactic plane. The GRID configuration will achieve a PSF with 68% containment radius better within $1° - 2°$ at E > 300 MeV allowing a gamma-ray source positioning with error box radius near $10^{'} - 20^{'}$ depending on source spectrum, intensity, and sky position. Super-AGILE operating in the 15-45 keV band has a spatial resolution of 6 arcminute (pixel size). This translates into a positional accuracy of 1-3 arcmins for relatively strong transients at the Crab flux level.

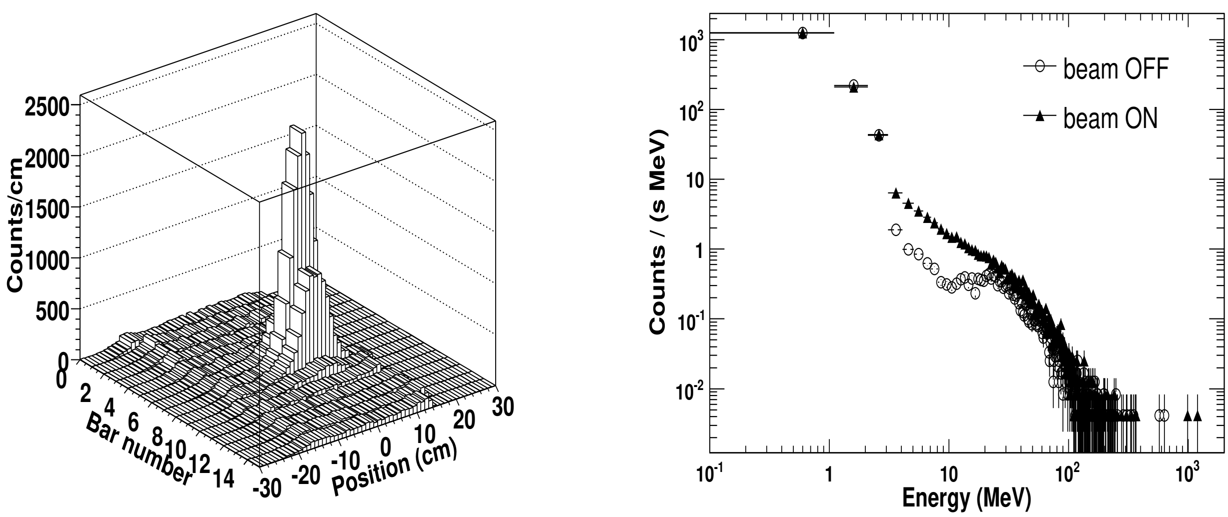

Figure 6. *Left panel*: AGILE Mini-Calorimeter data obtained during the AGILE LNF-BTF calibration, showing the 1-10 MeV "spot" of the γ-ray photon beam obtained by the MCAL "positioning" capability ($\sim$ 0.9 cm) of a gamma-ray/particle interaction along the CsI bars. *Right panel*: MCAL spectrum obtained with the gamma-ray photon beam off (lower data points, open circles) and on (upper data points, filled triangles) (November 2005).

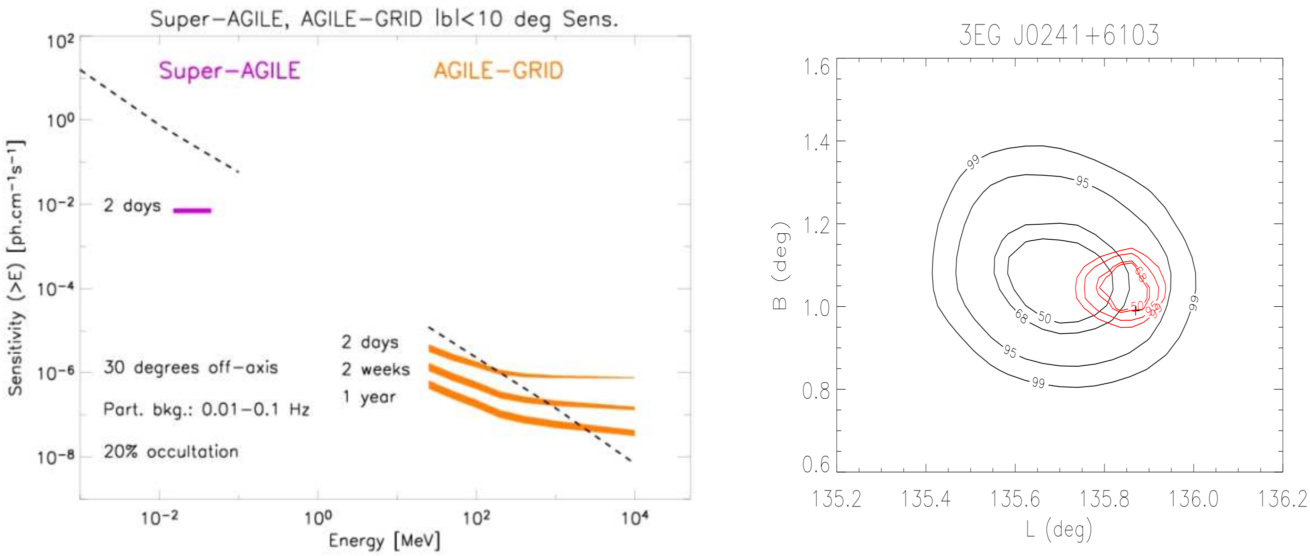

Figure 7. *Left panel*: simulated integrated flux sensitivity of AGILE (GRID and SA) as a function of energy for a 30-degree off-axis source in the Galactic plane. The Crab spectrum is shown by the dotted line. *Right panel*: simulated positioning of a gamma-ray source in the Galactic plane obtained by the AGILE Likelihood and diffuse gamma-ray background processing. The (more compact) red contours show the 50, 68, 95, 99 percent confidence levels obtained for the AGILE-GRID; the black contours show the confidence levels obtained with the EGRET likelihood analysis.

4.2. Large FOV monitoring of gamma-ray sources

A crucial feature of AGILE is its large field of view for both the gamma-ray and hard X-ray detectors. Fig. 8 shows typical gamma-ray FOVs obtained for a sequence of AGILE pointings. Relatively bright AGNs and Galactic sources flaring in the gamma-ray energy range above a flux of 10^{-6} ph cm^{-2} s^{-1} can be detected within a few days by the AGILE Quicklook Analysis. We conservatively estimate that for a 2-year mission AGILE is potentially able to detect hundreds of gamma-ray flaring AGNs and other transients. The very large FOV will also favor the detection of GRBs above 30 MeV. Taking into account the high-energy distribution of GRB emission above 30 MeV, we conservatively estimate that $\sim$1 GRB/month can be detected and imaged in the gamma-ray range by the GRID. Super-AGILE will be able to detect about 30% of the sources detected by INTEGRAL;[10] about 10 hard X-ray sources per day are expected to be detected by SA for typical pointings of the Galactic plane.

4.3. Fast reaction to strong high-energy transients

The existence of a large number of variable gamma-ray sources (extragalactic and near the Galactic plane[24]) makes necessary a reliable program for quick response to transient gamma-ray emission. Quicklook Analysis of gamma-ray data is a crucial task to be carried out by the AGILE Team. Prompt communication of gamma-ray transients (that require typically 2-3 days to be detected with high confidence for sources above 10^{-6} ph cm^{-2} s^{-1}) will be ensured. Detection of short timescale (seconds/minutes/hours) transients (GRBs, SGRs, and other bursting events) is possible in the gamma-ray range. A primary responsibility of the AGILE Team will be to provide positioning of short-timescale transient as accurate as possible, and to alert the community though dedicated channels.

4.4. Accumulating exposure on Galactic and extragalactic sky areas

The AGILE average exposure per source will be larger by a factor of $\sim$ 4 for a 1-year sky-survey program compared to the typical exposure obtainable by EGRET for the same time period. Deep exposures for selected regions of the sky can be obtained by a proper program with repeated overlapping pointings. This can be particularly useful to study selected Galactic and extragalactic sources.

4.5. High-Precision Timing

AGILE detectors have optimal timing capabilities. The on-board GPS system allows to reach an absolute time tagging precision for individual photons better than $2\,\mu$s. Depending on the event characteristics, absolute time tagging can achieve values near $1-2\,\mu$s for the Silicon-Tracker, and $3-4\,\mu$s for the Mini-Calorimeter and Super-AGILE.

Instrumental deadtimes will be unprecedentedly small for gamma-ray detection. The GRID deadtime will be lower than $200\,\mu$s (improving by almost three orders of magnitude the performance of previous spark-chamber detectors such as EGRET). Taking into account the segmentation of the electronic readout of MCAL and Super-AGILE detectors (30 MCAL elements and 16 Super-AGILE elements) the MCAL and SA effective deadtimes will be less than those for individual units. We obtain $\sim 2\,\mu$s for MCAL, and $5\,\mu$s for SA. Furthermore, a special memory will ensure that MCAL events detected during the Si-Tracker readout deadtime will be automatically stored in the GRID event. For these events, precise timing and detection in the $\sim$ 1–200 MeV range can be achieved with temporal resolution well below $100\,\mu$s. This may be crucial for AGILE high-precision timing investigations.

4.6. AGILE and GLAST

AGILE and GLAST[14] are complementary missions in many respects: we briefly outline here some important points, postponing a more general discussion.[29] The GLAST gamma-ray instrument covers a broad spectrum and is especially optimized in the high energy range above 1 GeV . On the other contrary, AGILE is optimized in the range below 1 GeV with emphasis to the simultaneous hard X-ray/gamma-ray imaging with arcminute angular resolution. The GLAST large gamma-ray effective area allows deep pointings and good imaging within a few arcminutes for strong gamma-ray sources. AGILE has a gamma-ray effective area near 100 MeV smaller by a factor of ~ 4 compared to the upper portion of the LAT instrument on board of GLAST. However, it can reach arcminute positioning of sources because of Super-AGILE. Furthermore, the GLAST sky-scanning mode adopted during the first phase of the mission, and the AGILE fixed pointing strategy offer a way for joint investigations. In the overlapping pointed regions, strong time variability of gamma-ray sources can be simultaneously studied by the two missions in a complementary way. AGILE with its hard X-ray imager can provide very useful and independent information.

The most relevant feature of AGILE is its unique combination of a large-FOV hard X-ray imager together with a gamma-ray imager. AGILE will be able to reach arcminute positioning of sources emitting in the hard X-ray range above 10 mCrab. Furthermore, AGILE can react to transients, and can point at gamma-ray sources detected by other missions to position the source within the FOV of both the GRID and SA. Interesting gamma-ray transients detected by GLAST might then be pointed by AGILE for a broad-band study of their temporal and spectral properties.

5. SCIENTIFIC OBJECTIVES

Currently, nearly 300 gamma-ray sources above 30 MeV were detected (with only a small fraction, 30%, identified as AGNs or isolated pulsars).[16, 32–34] AGILE will nicely fit into the discovery path followed by previous gamma-ray missions (SAS-2, COS-B, and EGRET) and be complementary to GLAST. We summarize here the main AGILE's scientific objectives (Table 2 provides a schematic summary).

• **Active Galactic Nuclei**. For the first time, simultaneous monitoring of a large number of AGNs per pointing will be possible. Several outstanding issues concerning the mechanism of AGN gamma-ray production and activity can be addressed by AGILE including: (1) the study of transient vs. low-level gamma-ray emission and duty-cycles;[36] (2) the relationship between the gamma-ray variability and the radio-optical-X-ray-TeV emission; (3) the correlation between relativistic radio plasmoid ejections and gamma-ray flares; (4) hard X-ray/gamma-ray correlations. A program for joint AGILE and ground-based monitoring observations is being planned. On the average, AGILE will achieve deep exposures of AGNs and substantially improve our knowledge on the low-level emission as well as detecting flares. We conservatively estimate that for a 3-year program AGILE will detect a number of AGNs 2–3 times larger than that of EGRET. Super-AGILE will monitor, for the first time, simultaneous AGN emission in the gamma-ray and hard X-ray ranges.

Table 2. OVERVIEW OF AGILE's SCIENTIFIC GOALS

Active Galactic Nuclei	(1) Wide field-of-view survey (2) Deep exposure by repeated pointings (3) Quick reaction to transients (4) Super-AGILE monitoring in the hard X-rays band (5) Correlative observations in the radio, optical, X-ray, TeV ranges
Gamma-Ray Bursts	(1) Expected detection rate above 50 MeV: 5-10 events/year (2) Study of the initial impulsive phase (GRID deadtime $\lesssim 200\,\mu$s) (3) Broad-band spectral information (~10 keV –30 GeV) (4) Super-AGILE imaging ($\sim 1' - 2'$ for intense GRBs) (5) Super-AGILE study of gamma-ray vs. hard X-ray emission (6) Search for sub-millisecond GRB pulses (7) Rapid communication of GRB coordinates and quicklook results
Pulsars	(1) High-resolution timing of known gamma-ray pulsars (2) Period Searches for Galactic unidentified sources (3) Millisecond pulsars
Unidentified Sources	(1) Deep exposure, variability studies (2) Refined positions, search for γ-ray periodicity, e.g., 2CG 135+01 (3) Long-term study of variable sources near the Galactic plane (4) Search for new transients and quicklook alert (5) Super-AGILE imaging of new transients
Supernova Remnants	(1) Search and precise imaging with deep exposures (2) Monitoring of plerions (Crab, Vela, etc.) in SNRs (3) Gamma-ray/TeV studies
Binary Systems	(1) Neutron star binaries (2) Black hole systems: microquasars (3) Interacting binaries, study of stellar winds (4) Binary plerions (e.g., PSR 1259-63) (5) Super-AGILE monitoring and simultaneous detection
Diffuse emission	(1) Deep exposure and precise mapping of Galactic emission (2) Study of cosmic ray origin and propagation
Galaxies	(1) Deep pointings at the SMC and LMC (2) Testing dark matter models by deep exposures of Andromeda (3) Super-AGILE search for transients from Andromeda (4) Deep exposures of clusters of galaxies
Fundamental Physics	(1) Quantum Gravity tests for sub-ms GRB pulses (2) High-precision pulsar timing and Quantum Gravity effects (3) MACHO emission from our and nearby galaxies

• **Gamma-ray bursts**. A few GRBs were detected by the EGRET spark chamber.[21] This number appears to be limited by the EGRET FOV and sensitivity and probably not by the intrinsic GRB emission mechanism. GRB detection rate by the AGILE-GRID is expected to be at least a factor of ~ 5 larger than that of EGRET, i.e., $\geq$5–10 events/year). The small GRID deadtime ($\sim$ 500 times smaller than that of EGRET) allows a better study of the initial phase of GRB pulses (for which EGRET response was in many cases inadequate). The remarkable discovery of 'delayed' gamma-ray emission up to $\sim$ 20 GeV from GRB 940217[17] is of great importance to model burst acceleration processes. AGILE is expected to be efficient in detecting photons above 10 GeV because of limited backsplashing. Super-AGILE will be able to locate GRBs within a few arcminutes, and will systematically study the interplay between hard X-ray and gamma-ray emissions. Special emphasis will be given to the search for sub-millisecond GRB pulses independently detectable by the Si-Tracker, MCAL and Super-AGILE.

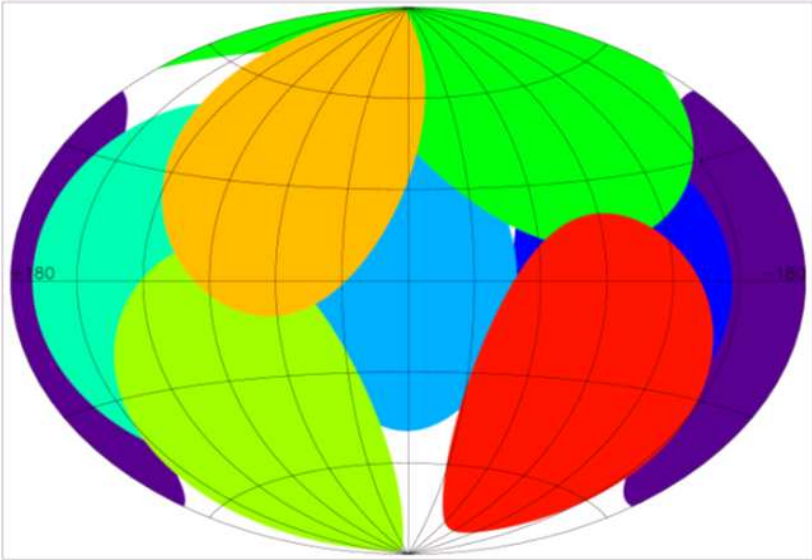

Figure 8. An example of a sequence of AGILE pointings showing the very large gamma-ray field of view (in Galactic coordinates). Typical AGILE pointings will last 3 weeks and are subject to solar panel constraints.

• **Diffuse Galactic and extragalactic emission**. The AGILE good angular resolution and large average exposure will further improve our knowledge of cosmic ray origin, propagation, interaction and emission processes. We also note that a joint study of gamma-ray emission from MeV to TeV energies is possible by special programs involving AGILE and new-generation TeV observatories of improved angular resolution.

• **Gamma-ray pulsars**. AGILE will contribute to the study of gamma-ray pulsars (PSRs) in several ways: (1) improving timing and lightcurves of known gamma-ray PSRs; (2) improving photon statistics for gamma-ray period searches; (3) studying unpulsed gamma-ray emission from plerions in supernova remnants and studying pulsar wind/nebula interactions, e.g., as in the Galactic sources recently discovered in the TeV range.[1] Particularly interesting for AGILE are the ~ 30 new young PSRs discovered[18] in the Galactic plane by the Parkes survey.

• **Search for non-blazar gamma-ray variable sources in the Galactic plane**, currently a new class of unidentified gamma-ray sources such as GRO J1838-04.[24]

• **Galactic sources, new transients**. A large number of gamma-ray sources near the Galactic plane are unidentified, and sources such as 2CG 135+1/LS I 61 +61 303 can be monitored on timescales of months/years. Cyg X-1 will be also monitored and gamma-ray emission above 30 MeV will be intensively searched. Galactic X-ray jet sources (such as Cyg X-3, GRS 1915+10, GRO J1655-40 and others) can produce detectable gamma-ray emission for favorable jet geometries, and a TOO program is planned to follow-up new discoveries of *micro-quasars*.

• **Fundamental Physics: Quantum Gravity**. AGILE detectors are suited for Quantum Gravity studies.[30] The existence of sub-millisecond GRB pulses lasting hundreds of microseconds[9] opens the way to study QG delay propagation effects by AGILE detectors. Particularly important is the AGILE Mini-Calorimeter with independent readout for each of the 30 CsI bars of small deadtime ($\sim 20\,\mu$s) and absolute timing resolution ($\sim 3\,\mu$s). Energy dependent time delays near $\sim 100\,\mu$s for ultra-short GRB pulses in the energy range 0.3–3 MeV can be detected. If these GRB ultra-short pulses originate at cosmological distances, sensitivity to the Planck's mass can be reached.[30]

Table 3. THE AGILE MISSION

Payload mass	120 kg
Spacecraft mass	230 kg
Total satellite mass	350 kg
Payload absorbed power	$\sim$ 130 W
Downlink telemetry rate	512 kbit/sec
Sat. pointing configuration	3 - axes
Pointing accuracy	$0.5° - 1°$
Req. pointing reconstruction	1 arcmin
Mass memory	500 Mbit
Positioning	GPS, $\sim$ 50 m
On-board Satellite time	GPS, $< 2\,\mu$s
Required orbit	Equatorial (i = 0-3 degrees, 550 km)
Ground base	Malindi (Kenya)
Satellite expected life	$\gtrsim$ 3 years

6. THE MISSION

6.1. Satellite operations

Table 3 summarizes the main features of the AGILE satellite. The AGILE spacecraft is of the MITA class and is developed by Carlo Gavazzi Space (CGS) as prime contractor and by Oerlikon-Contraves. The spacecraft provides a 3-axis stabilization with an accuracy near 0.5–1 degree. The final satellite pointing reconstruction is required to reach an accuracy of $\sim$1 arcmin by a set of two Star Sensors. A GPS transceiver will also ensure an on-board timing accuracy within 2 microseconds. The AGILE scientific instrument generates under normal conditions a telemetry rate of $\sim$ 50 kbit/s. The satellite downlink telemetry rate is 512 kbit s^{-1}, that is adequate to transmit at every passage over the ground station all the satellite and scientific data.

The fixed solar panels configuration and the necessity to have them always exposed to the Sun imposes some constraints on the AGILE pointing strategy. However, in practice the AGILE large FOV does not sensibly limit the accessible sky: only the solar and anti-solar directions are excluded from direct pointings. The AGILE Pointing Plan is being finalized and will be ready in advance before the start of Cycle-1 (first year). The typical AGILE pointing duration is envisioned to be 2-3 weeks. AGILE might react to transient events of great importance occurring outside the accessible FOV. For transients detected by the AGILE-GRID and not by Super-AGILE, a minor re-pointing (20-30 degrees) is envisioned to allow the coverage of the gamma-ray transient also by the X-ray imager within 1 day. A drastic re-pointing strategy (Target-of-Opportunity, TOO) is foreseen for events of major scientific relevance detected by other observatories.

6.2. The Orbit

The AGILE orbit will be quasi equatorial, with an inclination required to be within 3 degrees from the Equator. A low earth orbit (LEO) of small inclination is clearly preferred because of the reduced particle background and the crucial use of the ASI communication ground base at Malindi (Kenya).

7. THE AGILE SCIENCE PROGRAM

AGILE is a Small Scientific Mission with a science program open to the international scientific community. The AGILE Mission Board (AMB) oversees the scientific program, determines the pointing strategy, and authorizes Target of Opportunity (TOO) observations in case of exceptional transients. A substantial fraction of the gamma-ray data will be available for the AGILE Guest Observer Program (AGOP) that will be open to the international community on a competitive basis.

7.1. Data Analysis and Scientific Ground Segment

AGILE science data (about 300 Mbit/orbit) will be telemetered from the satellite to the ASI ground station in Malindi (Kenya) at every satellite passage (about 90 minutes). A fast ASINET connection between Malindi and the Telespazio Satellite Control Center at Fucino and then between Fucino and the ASI Science Data Center (ASDC) will ensure the data transmission every orbit. The AGILE Mission Operations Center is located at Fucino and will be operated by Telespazio with scientific and programmatic input by ASI and the AGILE Science Team through the ASDC.

Scientific data storage, quicklook analysis and the AGOP will be carried out at ASDC. After pre-processing, scientific data (level-1) will be corrected for satellite attitude data and processed by dedicated software produced by the AGILE Team in collaboration with ASDC personnel. Background rejection and photon list determination are the main outputs of this first stage of processing. Level-2 data will be at this point available for a full scientific analysis. Gamma-ray data generated by the GRID will be analyzed by special software producing: (1) sky-maps, (2) energy spectra, (3) exposure, (4) point-source analysis products, and (5) diffuse gamma-ray emission. This software is aimed to allow the user to perform a complete science analysis of specific pointlike gamma-ray sources or candidates. This software will be available for the AGOP. Super-AGILE data will be deconvolved and processed to produce 2-D sky images through a correlation of current and archival data of hard X-ray sources. GRB data will activate dedicated software producing lightcurves, spectra and positioning both in the hard X-ray (15 – 45 keV) and gamma-ray energy (30 MeV – 30 GeV) ranges. The AGILE data processing goals can be summarized as follows:

- **Quicklook Analysis (QA)** of all gamma-ray and hard X-ray data, aimed at a fast scientific processing (within a few hours/1 day depending on source intensity) of all AGILE science data.
- **web-availability of QA results** to the international community for alerts and rapid follow-up observations;
- **GRB positioning and alerts through the AGILE Fast Link**, capable of producing alerts within 1-2 minutes since the event;
- **standard science analysis of specific gamma-ray sources open to a Guest Observer Program**;
- **web-availability of the standard analysis results of the hard X-ray monitoring program by Super-AGILE**.

7.2. Multiwavelength Observations Program

The scientific impact of a high-energy Mission such as AGILE (broad-band energy coverage, very large fields of view) is greatly increased if an efficient program for fast follow-up and/or monitoring observations by ground-based and space instruments is carried out. The AGILE Science Program will overlap and be complementary to those of many other high-energy space Missions (INTEGRAL, XMM-Newton, Chandra, SWIFT, Suzaku , GLAST) and ground-based instrumentation.

The AGILE Science Program will involve a large astronomy and astrophysics community and emphasizes a quick reaction to transients and a rapid communication of crucial data. Past experience shows that in many occasions there was no fast reaction to γ-ray transients (within a few hours/days for unidentified gamma-ray sources) that could not be identified. AGILE will take advantage, in a crucial way, of the combination of its gamma-ray and hard X-ray imagers.

The AGILE Science Group (ASG) (established in 2001) aims at favoring the scientific collaboration between the AGILE Team and the community especially for coordinating multiwavelength observations based on AGILE detections and alerts. The ASG is open to the international astrophysics community and consists of the AGILE Team and qualified researchers contributing with their data and expertise in optimizing the scientific return of the Mission. Several working groups are operational on a variety of scientific topics including blazars, GRBs, pulsars, and Galactic compact objects. The AGILE Team is also open to collaborations with individual observing groups.

Updated documentation on the AGILE Mission can be found at the web site http://agile.iasf-roma.inaf.it.

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ACKNOWLEDGMENTS

The AGILE program is developed under the auspices of the Italian Space Agency with co-participation by the Italian Institute of Astrophysics (INAF) and by the Italian Institute of Nuclear Physics (INFN). Research partially supported under the grant ASI-I/R/045/04. We acknowledge the crucial programmatic support of the ASI Directors of the *Observation of the Universe* Unit (S. Di Pippo) and of the *Small Mission* Unit (F. Viola), as well as of P. Giommi and G. Guarrera.