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Science with AGILE

AGILE is an ASI Small Scientific Mission dedicated to high-energy astrophysics. The AGILE instrument is designed to detect and image photons in the 30 MeV–50 GeV and 10–40 keV energy bands, with excellent spatial resolution, timing capability, and an unprecedently large field of view covering $\sim 1/5$ of the entire sky at energies above 30 MeV. Primary scientific goals include the study of AGNs, Gamma-Ray Bursts, Galactic sources, unidentified gamma-ray sources, diffuse Galactic gamma-ray emission, high-precision timing studies, and Quantum Gravity testing.

AGILE is planned to be operational during the year 2005, and will be the only Mission entirely dedicated to high-energy astrophysics above 30 MeV to support multiwavelength studies during the period 2005-2007. The AGILE Science Program will be open to the international scientific community.

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1 Introduction

Gamma-rays of cosmic origin are a manifestation of the most energetic phenomena in our Universe. Many astrophysical sources emit gamma-rays including relativistic compact stars, massive black holes in Active Galactic Nuclei, Gamma-Ray Burst sources, and our Sun during intense flares. Energetic cosmic rays can be accelerated and eventually smash gaseous environments in our Galaxy producing a strong diffuse gamma-ray emission. Gamma-rays reach the Earth also from remote regions of the Universe, providing crucial information on the cosmological evolution of energetic sources. Many gamma-ray sources are transient, often on timescales of seconds/hours/days, showing a Universe in turmoil and subject to catastrophic events. Our understanding of many of these phenomena is preliminary, and a tremendous amount of observational and theoretical work is necessary to fully understand these energetic phenomena.

The space program AGILE (*Astro-rivelatore Gamma a Immagini LEggero*) was proposed in June 1997 to ASI for the Program for Small Scientific Missions as a powerful and cost-effective space mission dedicated to gamma-ray astrophysics (30 MeV–50 GeV) [18]. The mission was selected in December 1997 for a Phase A study that ended in October 1998 [19]. Subsequently, ASI selected (June 1999) AGILE as the first satellite of the Program of Small Scientific Missions. The Mission is a cornerstone of the ASI *Piano Spaziale Nazionale* formulated in mid-2002 and approved by the Italian Ministry of Research. AGILE is currently in Phase C/D [20, 5, 21]: the planned launch period is the second quarter of 2005.

The AGILE scientific instrument is based on the state-of-the-art and reliably developed technology of solid state silicon detectors developed by the Italian INFN laboratories [1, 2, 3, 4, 10]. The instrument is light ($\sim$ 130 kg) and effective in detecting and monitoring gamma-ray sources within a large field of view ($\sim$ 1/5 of the whole sky). The philosophy we adopted is to develop one integrated instrument made of three detectors with broad-band detection and imaging capabilities.

The AGILE **Gamma-Ray Imaging Detector (GRID)** is sensitive in the energy range $\sim$ 30 MeV–50 GeV. It is characterized by the smallest ever obtained deadtime for gamma-ray detection ($\lesssim$200 μs) and by a trigger based exclusively on Silicon plane detectors. GRID consists of a Silicon-Tungsten Tracker, a Cesium Iodide Mini-Calorimeter, an Anticoincidence system made of segmented plastic scintillators, and fast readout electronics and processing units[1]. The GRID is designed to achieve an optimal angular resolution (source location accuracy $\sim 5' - 20'$ for intense sources), an unprecedently large field-of-view ($\sim$ 3 sr), and a sensitivity comparable to that of EGRET for on-axis (and substantially better for off-axis) point sources.

AGILE will be greatly enhanced by its detection and imaging capabilities in the hard X-ray range (10-40 keV). The **Super-AGILE** detector consists of an additional plane of four Silicon square units positioned on top of the GRID Tracker plus an ultra-light coded mask structure with a top absorbing mask at the distance of 14 cm from the Silicon detectors. The main goals of Super-AGILE are the simultaneous gamma-ray and hard X-ray detection of astrophysical sources (unprecedented for gamma-ray instruments), optimal source positioning (1-3 arcmins, depending on intensity), fast gamma-ray burst and transient alert and

[1] In constrast with previous generation instruments (COS-B, EGRET), AGILE will not require gas operations and/or refilling, and will not require high-voltages.

on-board trigger capability.

The CsI **Mini-Calorimeter** (MC) will also detect and collect events independently of the GRID. The energy range for this non-imaging detector is 0.25–200 MeV, and it can be very useful to provide spectral and accurate timing information of transient events. The content of a cyclic MC event buffer will be transmitted to the ground for impulsive events (solar flares, GRBs, other transients).

AGILE with its combination of GRID, MC, and Super-AGILE is an innovative instrument, with an optimal expected performance for transients (gamma-ray bursts, solar flares, unidentified gamma-ray sources, AGNs) and steady sources (e.g., pulsars). The fast AGILE electronic readout and data processing (resulting in very small detectors' deadtimes) allow for the first time the systematic search for sub-millisecond gamma-ray transients [22]. Table (1) provides a schematic summary of the Mission science goals.

The AGILE Team currently includes scientists from the CNR Istituto di Astrofisica Spaziale and Fisica Cosmica (IASF), INFN laboratories, and the Universities of Trieste, Roma-Tor Vergata, and Roma-La Sapienza. The instrument development and scientific operations will take advantage of the work of the **AGILE Science Group** composed of scientists from the international community interested in correlated observations and theoretical investigations related with AGILE results.

Despite its simplicity and moderate weight and cost (compared to a typical NASA-SMEX program), AGILE is ideal to perform a large number of tasks: monitoring active galactic nuclei (AGNs), detecting gamma-ray bursts (GRBs) with high efficiency, mapping the diffuse Galactic and extragalactic emission, studying pulsed gamma-ray emission from radiopulsars, monitoring the many unidentified sources contributing to their unveiling, detecting energetic solar flares, carrying out high-precision timing and Quantum Gravity tests.

It is clear today that successful investigations of gamma-ray sources rely on coordinated space and ground-based observations. 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 the many space missions that will be operational during the first decade of the new Millenium (INTEGRAL, NEWTON, CHANDRA, SWIFT and others). Furthermore, it can support ground-based investigations in the radio, optical, and TeV bands. No other mission entirely dedicated to gamma-ray astrophysics above 30 MeV is being planned during the period 2005-2007. AGILE's technological and scientific development is strongly integrated towards GLAST (planned at the beginning of 2007). 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.

Table 1: **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 counterparts, 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
Solar flares	(1) Si-Tracker ratemeter transient detection ($\gtrsim$ 100 keV) (2) Mini-Calorimeter detection in the range 0.3 – 200 MeV
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

2 Instrument Overview

Fig. 4 shows schematically the AGILE baseline configuration of total weight of $\sim$ 130 kg including the Si-Tracker, Super-AGILE, Mini-Calorimeter, the Anticoincidence system and electronics. The AGILE instrument is made of the following elements.

- **Silicon-Tracker**, the gamma-ray pair-converter and imager is made of 12 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 (see Fig. 5). The adopted "floating readout strip" system has a total of 384 readout channels (readout pitch equal to 242 μm) and three readout TAA1 chips per Si-tile. Each Si-Tracker layer is made of 4×4 Si-tiles, for a total geometric area of 38×38 cm^2. The first 10 planes are made of three elements: a first layer of tungsten (0.07 X_0) for gamma-ray conversion, and two Si-layers with microstrips orthogonally configured (see Fig. 5). 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 the tungsten layers. The total readout channel number for the GRID Tracker is **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 GRID has an *on-axis* total radiation length near 0.8 X_0. 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. Fig. 6 schematically shows the layout and typical results of experimental tests carried out at CERN of the tracking performance of the AGILE Silicon detectors [6]. The positional resolution obtained by these detectors is excellent, being below 40 μm for a large range of photon incidence angles [14].

- **Super-AGILE**, made of properly arranged four square Silicon detectors ($19 \times 19\,\mathrm{cm}^2$ each, similar to those of the Tracker) and dedicated FEE placed on the first GRID tray plus an ultra-light collimator supporting a Tungsten mask placed at a distance of 14 cm from the Silicon detectors. The total number of readout channels is **6,144**. The scientific goals of Super-AGILE 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 at 15 keV 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)* burst alert and quick on-board positioning capability for transients and GRBs.

- **Mini-Calorimeter** (MC), made of 30 Cesium Iodide (CsI) bars arranged in two planes, 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 goals are: *(i)* obtaining additional information on the energy deposited in the CsI bars by particles produced in the Si-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. 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 ~ 200 MeV total energy collected in the MC.

- **Anticoincidence (AC) System**, 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 MC). 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 trigger logic ensure the large GRID field of view.

- **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 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 $\lesssim 200\ \mu$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. 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 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 200 MeV in the MC, the AC veto may 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 envisions a first "filtering" based on AC-veto signals, and pulse-height discrimination in the dedicated FEE (based on XA 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, of $\sim 4\,\mu$s deadtime each.

Given the relatively large number of readable channels in the Si-tracker and Super-AGILE (∼40,000), the instrument requires a very efficient readout system. 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 will be accommodated at the bottom of the instrument.

3 Scientific Performance

3.1 Angular resolution

Figs. 7 and 8 show the GRID Point Spread Function (PSF) and its dependence on the off-axis angle as obtained by Montecarlo simulations. The baseline GRID configuration will achieve a PSF with 67% containment radius better than $\sim 0.5°$ at E > 1 GeV allowing a gamma-ray source positioning with error box radius near $5' - 20'$ depending on source spectrum, intensity, and sky position.

Super-AGILE operating in the 10-40 keV band will have a spatial resolution of 6 arcminute (pixel size). This translates into a positional accuracy of 1-2 arcmins for transients at the Crab flux level.

3.2 Energy resolution

The GRID is designed to achieve a nominal spectral resolution $\Delta E/E \sim 1$ near 200 MeV, and a much better resolution below 100 MeV. This result is obtained by combining the information on the particle energy deposited in the Si-Tracker and MC. Multiple scattering (particularly relevant for particle energies $\lesssim$ 300 MeV) also provides additional information on individual particle energies. Special algorithms will reconstruct the incoming photon energy by off-line data analysis.

Super-AGILE energy resolution in the 10-40 keV band will be near 3 keV.

Mini-Calorimeter events detected by CsI bars are of two spectral types. Low-energy events, for a single low-energy channel from 250 keV to 1 MeV (for 1-diode detections), and standard events, for an energy range from 1 to $\sim$ 100 MeV band with ∼1 MeV energy resolution (for 2-diode detections).

3.3 A comparison between AGILE and EGRET

Fig. 9 shows the *on-axis* AGILE-GRID and EGRET effective areas, A_{eff}, as a function of photon energy. Because of its improved angular resolution (and background rejection) AGILE's on-axis sensitivity for point sources is expected to be comparable to that of EGRET. The great advantage of the AGILE-GRID vs. EGRET will be its much larger field-of-view. Fig. 10 shows that AGILE will suffer a moderate loss of effective area at large incidence angles (up to $\sim 60°$). Fig. 11 and Fig. 12 show the AGILE sensitivity as a function of photon energy and off-axis angle, respectively. For each pointing, AGILE will therefore monitor a large fraction of the entire sky ($\sim 1/4$) searching for transients and accumulating photons for steady sources.

AGILE and EGRET are quite different: they are approximately twenty years apart in technological development. Table 2 shows several important characteristics of AGILE compared with those of EGRET. AGILE differs from EGRET in many ways: (1) it is a payload of mass $\sim$130 kg vs. an EGRET mass of 1.8 tons; (2) AGILE gamma-ray detection technique (based on Silicon detector tracking, analog and digital readout signals, and fast trigger electronics) is completely different from that of EGRET (based on spark chamber technology with time-of-flight background rejection); (3) AGILE's effective area on-axis is a factor of $\gtrsim 2$ smaller than EGRET's but its improved PSF results in a comparable sensitivity for detection of point-like sources; (5) AGILE source sensitivity is practically constant for sources at off-axis angles up to $\sim 60°$ whereas the EGRET field of view is limited to $\sim 25°$ off-axis; (6) the GRID deadtime ($\lesssim 200\,\mu$s) is three orders of magnitude better than that of EGRET: this opens the way to the discovery of sub-millisecond gamma-ray transients.

Table 2: **A COMPARISON BETWEEN AGILE/GRID AND EGRET**

	EGRET	AGILE
Mass	1830 kg	130 kg
Energy band	30 MeV – 30 GeV	30 MeV – 50 GeV
Field of view	$\sim$ 0.5 sr	$\sim$ 3 sr
PSF (68% containment radius)	5.5° 1.3° 0.5°	4.7° (@ 0.1 GeV) 0.6° (@ 1 GeV) 0.2° (@ 10 GeV)
Deadtime for γ-ray detection	$\sim$ 100 ms	$\lesssim 200\,\mu$s
Sensitivity for pointlike sources† ($\mathrm{ph\,cm^{-2}\,s^{-1}\,MeV^{-1}}$)	8×10^{-9} 1×10^{-10} 1×10^{-11}	6×10^{-9} (@ 0.1 GeV) 4×10^{-11} (@ 1 GeV) 3×10^{-12} (@ 10 GeV)
Required pointing reconstruction	$\sim$10 arcmin	$\sim$1 arcmin

(†) Obtained for a typical exposure time near 2 weeks for both AGILE and EGRET.

4 Science with AGILE

Currently, nearly 300 gamma-ray sources above 30 MeV were detected (with only a small fraction, 30%, identified as AGNs or isolated pulsars) [11, 24, 25, 26]. AGILE will nicely fit into the discovery path followed by previous gamma-ray missions, including SAS-2, COS-B, and EGRET.

4.1 Gamma-Ray Astrophysics with the GRID

GRID has been designed to obtain:

- **excellent imaging capability in the energy range 100 MeV-50 GeV**, improving the EGRET angular resolution by a factor of 2;
- **a very large field-of-view**, allowing simultaneous coverage of $\sim 1/4$ of the entire sky per each pointing (FOV larger by a factor of $\sim$6 than that of EGRET);
- **excellent timing capability**, with absolute time tagging of uncertainty near $1\,\mu$s and very small deadtimes ($\lesssim 200\,\mu$s for the Si-Tracker and $\sim 20\,\mu$s for each of the individual CsI bars);
- **a good sensitivity for point sources**, comparable to that of EGRET for *on-axis* sources, and substantially better for *off-axis* sources (see Figs. 10, 11 and 12);
- **excellent sensitivity to photons in the energy range $\sim$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.

4.1.1 Large FOV monitoring of gamma-ray sources

Figs. 17 and 18 show typical AGILE pointings. Relatively bright AGNs and Galactic sources flaring in the gamma-ray energy range above a flux of $10^{-6}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ can be detected within a few days by the AGILE Quicklook Analysis. We conservatively estimate that for a 3-year mission AGILE is potentially able to detect a number of gamma-ray flaring AGNs larger by a factor of several compared to that obtained by EGRET during its 6-year mission. Furthermore, the large FOV will favor the detection of fast transients such as gamma-ray bursts. 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.

4.1.2 Fast reaction to strong high-energy transients

The existence of a large number of variable gamma-ray sources (extragalactic and near the Galactic plane, e.g., [17]) 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

Table 3: **AGILE Scientific Performance**

Gamma-ray Imaging Detector (GRID)		
Energy Range	30 MeV – 50 GeV	
Field of view	$\sim$ 3 sr	
Sensitivity at 100 MeV (ph cm^{-2} s^{-1} MeV^{-1})	6×10^{-9}	(5σ in 10^6 s)
Sensitivity at 1 GeV (ph cm^{-2} s^{-1} MeV^{-1})	4×10^{-11}	(5σ in 10^6 s)
Angular Resolution at 1 GeV	36 arcmin	(68% cont. radius)
Source Location Accuracy	$\sim$5–20 arcmin	S/N$\sim$10
Energy Resolution	ΔE/E$\sim$1	at 300 MeV
Absolute Time Resolution	$\sim 1\,\mu$s	
Deadtime	$\sim 200\,\mu$s	
Hard X–ray Imaging Detector (Super-AGILE)		
Energy Range	10 – 40 keV	
Field of view	$107°\times68°$	FW at Zero Sens.
Sensitivity (at 15 keV)	$\sim$5 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	ΔE<4 keV	
Absolute Time Resolution	$\sim 4\,\mu$s	
Deadtime (for each of the 16 readout units)	$\sim 4\,\mu$s	
Mini-Calorimeter		
Energy Range	0.3 – 200 MeV	
Energy Resolution	$\sim$ 1 MeV	above 1 MeV
Absolute Time Resolution	$\sim 3\,\mu$s	
Deadtime (for each of the 30 CsI bars)	$\sim 20\,\mu$s	

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 $10^{-6}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$) will be ensured. Detection of short timescale (seconds/minutes/hours) transients (GRBs, SGRs, solar flares 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.

4.1.3 Accumulating exposure on Galactic and extragalactic sky areas

The AGILE average exposure per source will be larger by a factor of ~ 4 for a 1-year sky-survey program compared to the typical exposure obtainable by EGRET for the same time period (see Fig. 19). After a 1-year all-sky pointing program, AGILE average sensitivity to a generic gamma-ray source above the Galactic plane is expected to be better than EGRET by a factor conservatively given as ~ 2. Deep exposures for selected regions of the sky can be obtained by a proper program with repeated overlapping pointings. For selected regions, AGILE can achieve a sensitivity larger than EGRET by a factor of $\sim 4-5$ at the completion of its program. This can be particularly useful to study selected Galactic and extragalactic sources.

A direct comparision between the AGILE and EGRET whole-sky exposure can be obtained by computing the sky pointing distribution of the EGRET Cycle-1 with the AGILE one. Fig. 20 shows that after $\sim 10^7$ sec, the AGILE averaged exposure ($\sim 1.5 \times 10^9$ cm^2 s) which is a factor between 3 and 4 times larger than that of EGRET. For selected sky areas, AGILE can then achieve a flux sensitivity better than 5×10^{-8} ph cm^{-2} s^{-1} at the completion of its scientific program.

An interesting quantity representing the ability of the instrument to monitor a large field of view with an angle-dependent effective area is given by the product $A_{eff}(\theta) \times \Delta\,\Omega(\theta)$, $\Delta\,\Omega(\theta)$ being the bin-integrated solid angle centered at the off-axis angle θ. Fig. 21 shows the quantity $A_{eff}(\theta) \times \Delta\,\Omega(\theta)$ for EGRET (green curve) and AGILE (red curve). The comparison shows that despite a smaller *on-axis* effective area, the combination of the shallow AGILE A_{eff} and its large field-of-view produce a coverage of a wide portion of the sky by AGILE with good sensitivity.

4.1.4 High-Precision Timing

AGILE detectors will have optimal timing capabilities. The on-board GPS system allows to reach an absolute time tagging precision for individual photons near $2\,\mu$s. Depending on the detectors hardware and electronics, absolute time tagging can achieve values near $1-2\,\mu$s for the Silicon-tracker, and $3-4\,\mu$s for the individual detecting units of the Mini-Calorimeter and Super-AGILE.

Instrumental deadtimes will be unprecedently small for gamma-ray detection. The GRID deadtime will be lower than $200\,\mu$s (improving by three orders of magnitude the performance of previous spark-chamber detectors such as EGRET). The deadtime of MC single CsI bars is near $20\,\mu$s, and that of single Super-AGILE readout units is $\sim 5\,\mu$s. Taking into account the segmentation of the electronic readout of MC and Super-AGILE detectors (30 MC elements and 16 Super-AGILE elements) the effective deadtimes will be much less than those for individual units.

Furthermore, the MC 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 is crucial for AGILE high-precision timing investigations.

Figs. 25 and 26 show the AGILE timing performance compared to other gamma-ray missions. Fast AGILE timing will, for the first time, allow investigations and searches for sub-millisecond transients in the gamma-ray energy range.

4.1.5 AGILE and GLAST

It is useful to compare the capabilities of AGILE vs. GLAST from the point of view of detection of new gamma-ray transients flaring with timescales of hours-days and then fading away (typical of AGN γ-ray flaring). We consider the AGILE-GRID and the GLAST Large Area Telescope (LAT) detector whose performance (see [12] for details) can be considered separately for the upper portion (the "Upper-LAT" being the gamma-ray imager with optimal PSF, with $A_{eff} \simeq 3500$ cm^2 at 100 MeV, and equivalent grammage equal to $\sim 0.4\,X_0$), and the whole LAT (made of the Upper-LAT plus four additional Tracker planes with $0.18 X_0$ each, with $A_{eff} \simeq 7000$ cm^2 at 100 MeV, and total equivalent grammage equal to $\sim 1.1\,X_0$). Fig. 24 shows the square-root of the on-source integrated exposures (at 100 MeV) as a function of orbital phases for the same portion of the sky assuming: (1) a fixed AGILE pointing at an unocculted sky region (celestial South pole), and (2) a sky scanning mode to be adopted during the first year of the GLAST Mission.

4.2 Super-AGILE

An imaging coded mask detector system (Super-AGILE) in addition to the GRID will provide a unique tool for the study of high-energy sources. The Super-AGILE FOV is planned to be ~ 0.8 sr. Super-AGILE can provide important information including:

- **source detection and spectral information in the energy range ∼10-40 keV** to be obtained simultaneously with gamma-ray data (5 mCrab sensitivity at 15 keV ($5\,\sigma$) for a 50 ksec integration time);
- **accurate localization (∼2-3 arcmins) of GRBs and other transient events** (for typical transient fluxes above ∼1 Crab); the expected GRB detection rate is $\sim 1-2$ per month;
- **excellent timing**, with absolute time tagging uncertainty and deadtime near $4\,\mu$s for each of the 16 independent readout units of the Super-AGILE Si-detector;
- **long-timescale monitoring (∼2 weeks) of hard X-ray sources**;
- **hard X-ray response to gamma-ray transients detected by the GRID**, obtainable by slight repointings of the AGILE spacecraft (if necessary) to include the gamma-ray flaring source in the Super-AGILE FOV.

The combination of simultaneous hard X-ray and gamma-ray data will provide a formidable combination for the study of high-energy sources. Given the sensitivities of the GRID and Super-AGILE, simultaneous hard X-ray/gamma-ray information is anticipated to be obtainable for: (1) GRBs, (2) blazars with strong X-ray continuum such as 3C 273 and Mk 501, (3) Galactic jet-sources with favorable geometries, (4) unidentified variable gamma-ray sources. Figs. 27,28,29 show the expected scientific performance of Super-AGILE.

4.3 Scientific Objectives

We summarize here the main AGILE's scientific objectives (listed without any meaning to the ordering, Table 1 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; (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.

• **Gamma-ray bursts**. About ten GRBs were detected by the EGRET spark chamber during $\sim$ 7 years of operations [15]. This number was limited by the EGRET FOV and sensitivity and not by the GRB emission mechanism. GRB detection rate by the 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$ 1000 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 [13] is of great importance to model burst acceleration processes. AGILE is expected to be highly 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 is given to fast timing allowing the detection of sub-millisecond GRB pulses independently detectable by the Si-Tracker, MC and Super-AGILE.

• **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 searching for time variability of pulsar wind/nebula interactions, e.g., as in the Crab nebula. Particularly interesting for AGILE are the $\sim$ 30 new young PSRs discovered [8] 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 [17].

• **Galactic sources, new transients**. A large number of gamma-ray sources near the Galactic plane are unidentified, and sources such as 2CG 135+1 can be monitored on timescales of months/years. Also 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 [22]. The existence of sub-millisecond GRB pulses lasting hundreds of microseconds [7] 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 [22].

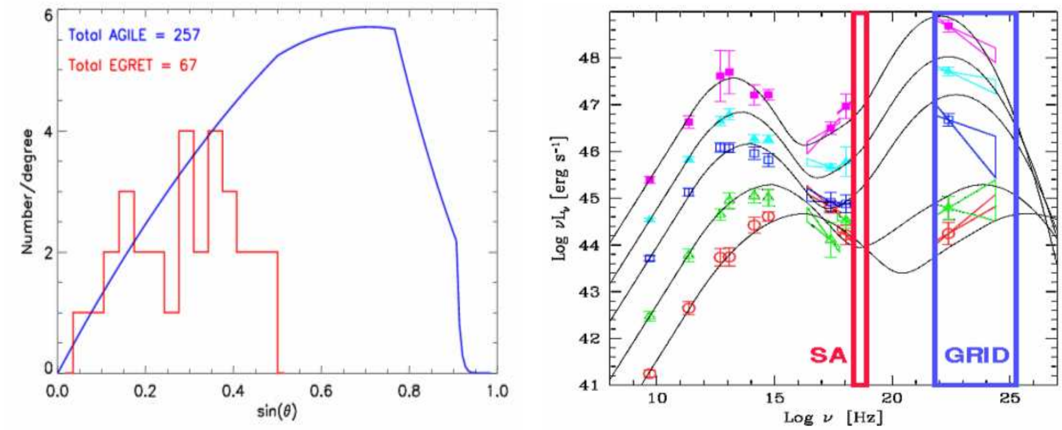

Figure 1: (**Left panel:**) Simulation of the EGRET and AGILE detectable blazar distribution as a function of the sine of the off-axis angle θ. (**Right panel:**) Broad-band spectral coverage of AGILE compared to different classes of blazar emission.

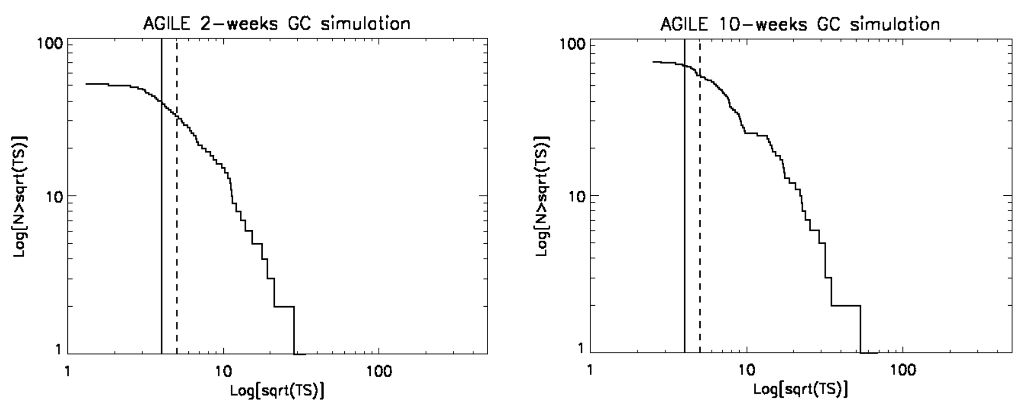

Figure 2: Simulation of the logN-log$\sqrt{\mathrm{TS}}$ distribution of gamma-ray sources detectable by the AGILE GRID based on the 3EG Catalog and GRID detection capabilities for a 2-week exposure (left panel) and 10-week exposure (right panel) of the Galactic Center region. The square root of the Test Statistic (TS) of the likelihood algorithm determines the statistical significance of source detection in terms of standard deviations. Vertical lines indicate the required significance of $\sqrt{\mathrm{TS}} = 4 - 5$ for source detection. The strong diffuse gamma-ray emission from the Galaxy is included in the calculation.

5 Mission

5.1 Satellite

The AGILE scientific Instrument (developed by the Science Team Institutes, and by LABEN and Oerlikon-Contraves Italia as main industrial contractors) will be integrated with a spacecraft of the MITA class developed by Carlo Gavazzi Space (CGS) as prime contractor. AGILE satellite pointing is envisioned to be obtained by a 3-axis stabilization system with an accuracy near 0.5–1 degree. Pointing reconstruction reaching an accuracy of $\sim$1 arcmin will be obtained by a set of two Star Sensors. A GPS transceiver will also ensure on-board timing accuracy within 1-2 microseconds. The satellite downlink telemetry rate is 512 $\mathrm{kbit\,s^{-1}}$, resulting in an average on-board acquisition rate of $\sim$ 50 kbit/s, that turns out to be adequate for AGILE and Super-AGILE data acquisition for a single contact per equatorial orbit. Relevant spacecraft and satellite characteristics are given in Table 4.

The fixed solar panels configuration of the satellite 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. A typical 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 envisioned for events of major scientific relevance detected by other observatories (within 1 day).

5.2 Orbit and Launch Possibilities

The optimal orbital parameters for the AGILE mission are given in Table 4. A low earth orbit (LEO) of small inclination is clearly preferred because of the reduced background and the possibility of using the ASI ground base at Malindi (Kenya). Because of the relatively small weight and dimensions of the AGILE satellite, launching possibilities also include being a partner in a shared launch. ASI is currently finalizing the launch contract for AGILE.

5.3 Mission Cost

The current costing plan for the AGILE Mission (44 Million euros) includes Payload design and development, spacecraft development and satellite integration, Mission management, launch, commissioning, and 2-year Mission Operations Center support. Instrument support, Scientific Ground Segment activities and AGILE science Team activities are calculated to cost about 1.5 million euros per year.

Table 4: **THE AGILE MISSION**

Required orbit	Equatorial (i = 0-6 degrees, 550 km)
Ground base	Malindi (Kenya)
Payload and bus shell mass	$\sim$ 160 kg
Spacecraft mass	140-170 kg
Total mass	300-330 kg
Payload absorbed power	$\sim$ 130 W
Downlink telemetry rate	512 kbit/sec
Pointing configuration	3 - axes
Pointing accuracy	$0.5^\circ - 1^\circ$
Pointing reconstruction	1 arcmin
Mass memory	500 Mbit
Positioning	GPS, $\sim$ 50 m
Satellite time	GPS, $\sim 1\,\mu$s
Satellite expected life	$\gtrsim$ 3 years

6 The AGILE Science Program

The scientific program of the Mission is regulated by the AGILE Science Management Plan approved by ASI and agreed upon by the Science Team. AGILE is a Small Mission with a Science Program open to the international scientific community. The AGILE Mission Board (AMB) will determine the pointing strategy, appoint a Data Allocation Committee, and decide on Target of Opportunity (TOO) observations in case of exceptional transients.

Part of the AGILE GRID Data will be available for Guest Observers from the international community on a competitive basis.

6.1 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 ASDC will ensure the data communication to the AGILE Data Center Unit at ASDC between two successive orbits. 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.

Data analysis of AGILE data at ASDC can be summarized as follows. After preprocessing, AGILE science data (level-1) will be corrected for satellite attitude data and processed by dedicated software produced by the AGILE Science Team in collaboration with ASDC personell. 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 science 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.

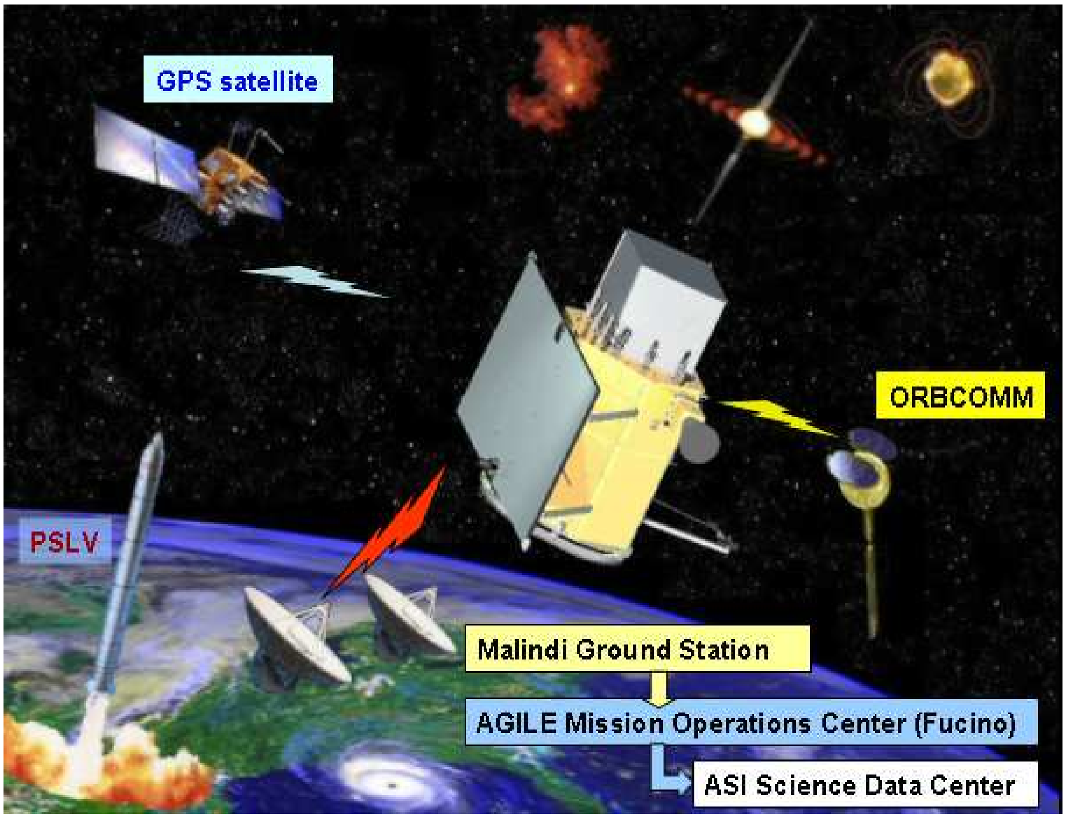

Figure 3: Artist's view of the AGILE operations and Ground Segment. A PSLV rocket is planned to launch the satellite in an equatorial orbit. The ASI ground station at Malindi (Kenya) will receive the satellite and science data at every satellite passage. The AGILE satellite is capable of obtaining GPS timing information by a dedicated on-board receiver. It is also able to communicate GRB essential data (time, coordinates, flux) within a few seconds since the event through a special transceiver connected with the constellation of ORBCOMM communication satellites. AGILE data are transferred from Malindi to the Mission Operations Center at Fucino through ASINET. Data are subsequently transferred to the ASI Science Data Center (ASDC) for processing, Quicklook Analysis, data distribution to the science community and archiving.

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 are:

- **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**, as regulated by the ASMP;
- **web-availability of the standard analysis results of the hard X-ray monitoring program by Super-AGILE**.

6.2 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. AGILE will be the only mission entirely dedicated to gamma-ray astrophysics in the energy band above 30 MeV during the period 2005–2007. The AGILE Science Program will then overlap and be complementary to those of many other high-energy space Missions (INTEGRAL, XMM, CHANDRA, ASTRO-E2, SWIFT, GLAST) and ground-based instrumentation.

The AGILE Science Program emphasizes the quick reaction to transients and the rapid communication of crucial data allowing fast follow-up observations. Past experience shows that in many occasions there was no fast reaction to 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. SA will obtain arcminute positioning for relatively bright transients emitting also in the hard X-ray band above a few tens of mCrab. In some cases this might lead to unambiguous identifications of gamma-ray sources. However, this may not be enough. In order to systematically identify the gamma-ray transient counterparts the Program needs a coordinated program for follow-up observations.

The AGILE Science Program will involve a very large astronomy and astrophysics community. We summarize here the ground-based and space instruments that will benefit from the AGILE Science Program for the study of high-energy sources. For all of these instruments, AGILE will provide a unique set of data.

- **Radio observations**
  - *Blazar flux monitoring:* carried out routinely at diffent radio observatories (including Michigan and Metsahovi).
  - *Blazar long-timescale imaging programs:* carried out at **VLBI** and **VLBA** facilities.
  - *Pulsar detection and monitoring:* carried out at several radio telescopes (**Parkes, Jodrell Bank, Green Bank (GB), Arecibo, Sardinian Radio Telescope (SRT)** and others).
  - *Transient reaction:* possible at **VLA, GB, Medicina, SRT** and other radio-telescopes.
- **Optical/IR observations**
  - *AGN monitoring:* carried out systematically by many individual telescopes and telescope networks (e.g., **WEBT**) around the world.
  - *Transient reaction:* to be carried out to study GRB afterglows and other transients (involving robotic and medium-size telescopes for fast reaction, e.g., **REM, ROTSE**, and others).
- **X-ray observations**
  - *Transient reaction:* possible through TOO observations by **CHANDRA, NEWTON, ASTRO-E2**.
  - *Simultaneous GRB detections:* obtained by a program of overlapping pointings of **SWIFT** and AGILE.
- **Gamma-ray observations below 30 MeV**
  - *Transient reaction:* possible through TOO observations by **INTEGRAL**.
- **TeV observations**
  - *Source monitoring:* carried out by new generation Cherenkov telescopes around the world (**HESS, Whipple-VERITAS, CANGAROO, MAGIC, STACEE**) as well as by large area detectors (**ARGO, MILAGRO**).
  - *Transient reaction:* possible for AGN flaring and other transients.

The **AGILE Science Group (ASG)** was constituted in 2001 with the aim at favoring and coordinating the effort for multiwavelength observations based on the AGILE detections and alerts. The ASG is open to the international astrophysics community and consists of the AGILE Science Team and qualified researchers contributing with their data and expertise in optimizing the scientific return of the Mission on a variety of crucial science topics: blazars, GRBs, pulsars, Galactic compact objects. A series of dedicated science workshops are being dedicated to these topics to foster an open scientific collaboration. The Italian community will play a major role in the ASG, favoring coordinated programs between INAF, Italian universities and ASI.

7 Documentation

Updated documentation on the AGILE Mission can be found at the web site

`http://agile.mi.iasf.cnr.it`

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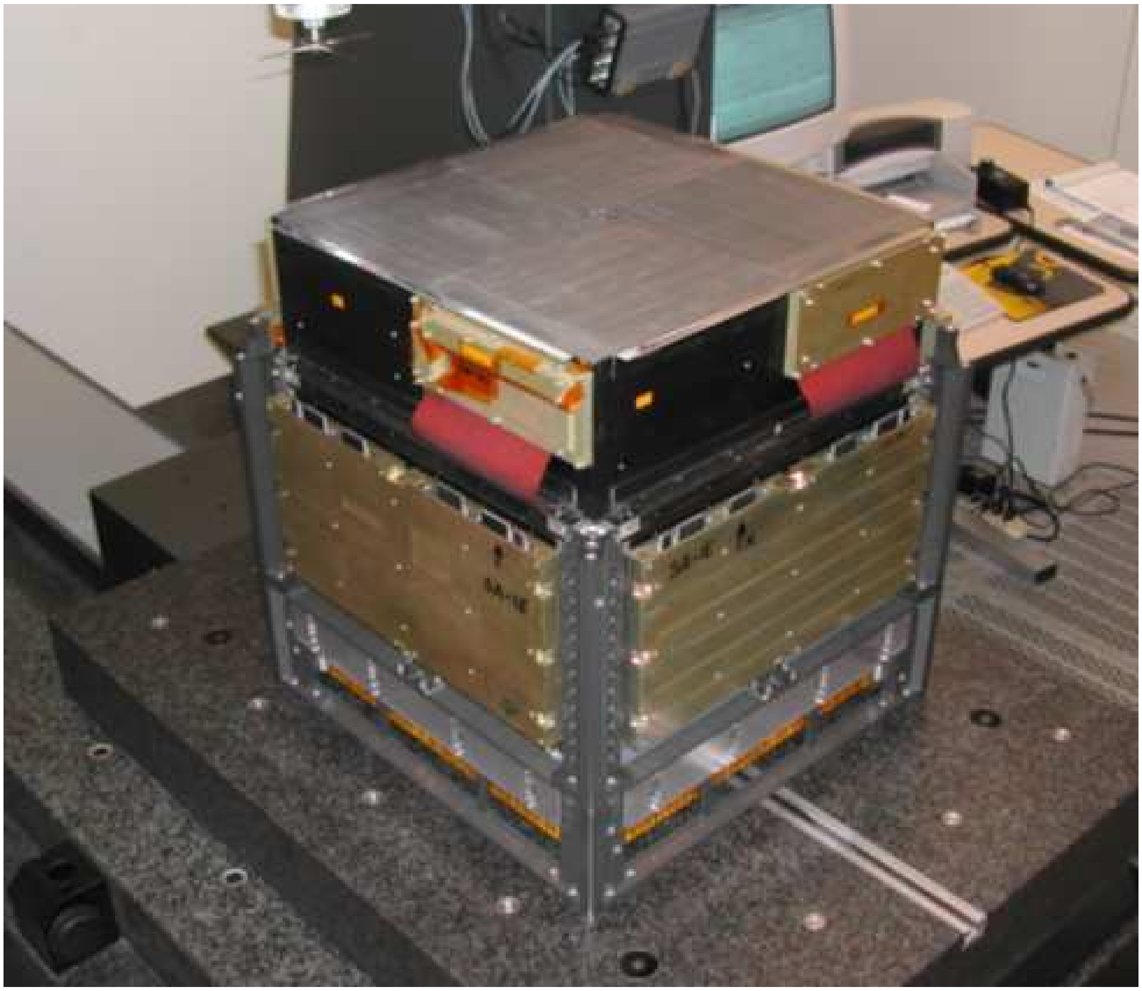


Figure 4: Engineering Model of the AGILE instrument (AC system not displayed). The GRID is made of 12 Silicon-Tungsten planes and the Mini-Calorimeter positioned at the bottom of the istrument. Super-AGILE with its 4 Si-detectors and the ultra-light coded mask system is positioned on top of the first GRID tray. The istrument size is $\sim 63 \times 63 \times 58\,\mathrm{cm}^3$, including the AC system for a total weight of the external envelope of $\sim$ 100 kg.

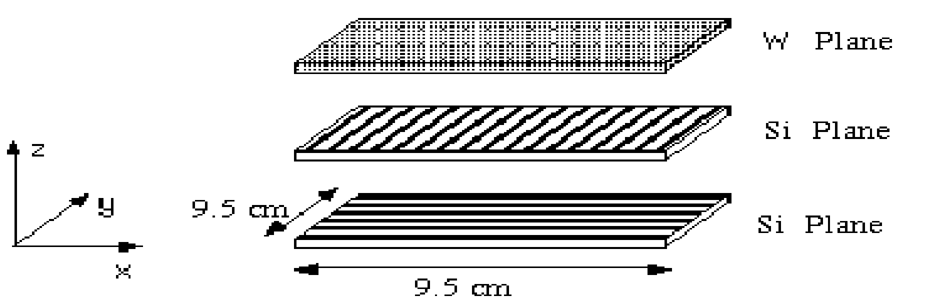


Figure 5: Schematic layout of the fundamental $9.5 \times 9.5\,\mathrm{cm}^2$ unit (tile) of the AGILE Silicon Tracker. The Silicon microstrip pitch is 121 μm, for a floating strip readout system of 242 μm pitch. Each Si-tile has 384 readout channels read by 3 TA1 chips.

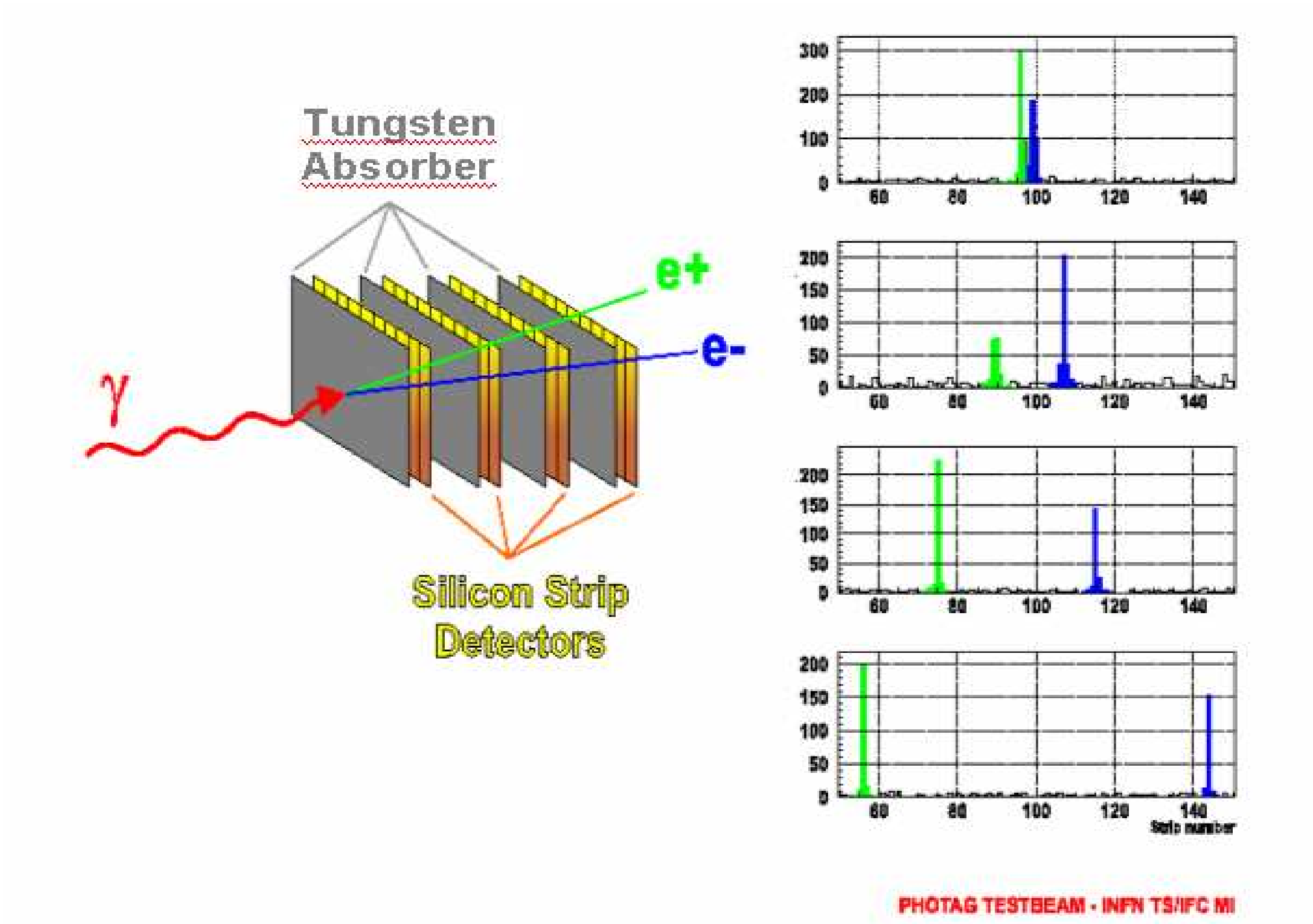


Figure 6: Schematic representation and typical results of beamtests carried out at CERN. The right panel shows the results of the AGILE beamtest carried out in August, 2000 at the CERN T11 beamline (East Hall, CERN PS). A photon beam (of energy range $\sim 30-500$ MeV) was produced by Bremsstrahlung of electrons of momentum ranging from 0.15 to 1 GeV/c hitting a thin lead target. The electron beam was deviated by a magnet spectrometer, and tagged by two delay wire chambers and a lead glass calorimeter. A typical gamma-ray photon event detected by 4 Silicon detectors spaced with lead converters (each of $\sim$0.07 radiation length) is shown on the right. The histograms represent the charge collected on the readout strips configured with the baseline AGILE tracker layout (Silicon microstrip pitch of 121 μm, for a floating strip readout system of 242 μm pitch). The spatial resolution achieved by this readout configuration is excellent (below 40 μm for a wide range of photon incidence angles, [14]). Data from [6].

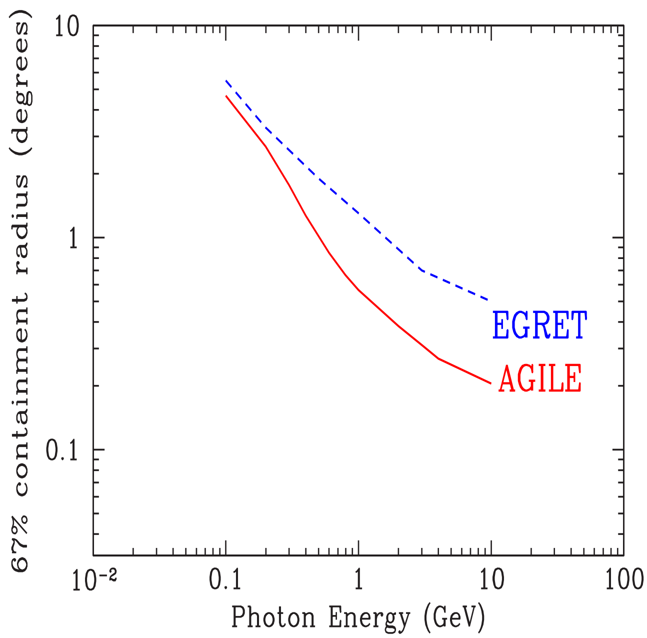


Figure 7: Three dimensional Point Spread Function (PSF) (67% containment radius) vs. photon energy for AGILE-GRID and EGRET.

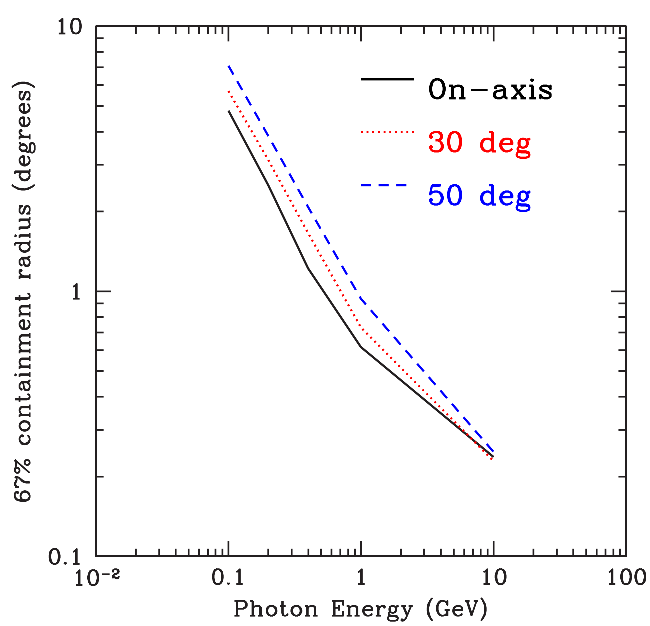


Figure 8: The AGILE-GRID three-dimensional PSF (67% containment radius) as a function of photon energy for 0°, 30° and 50° off-axis.

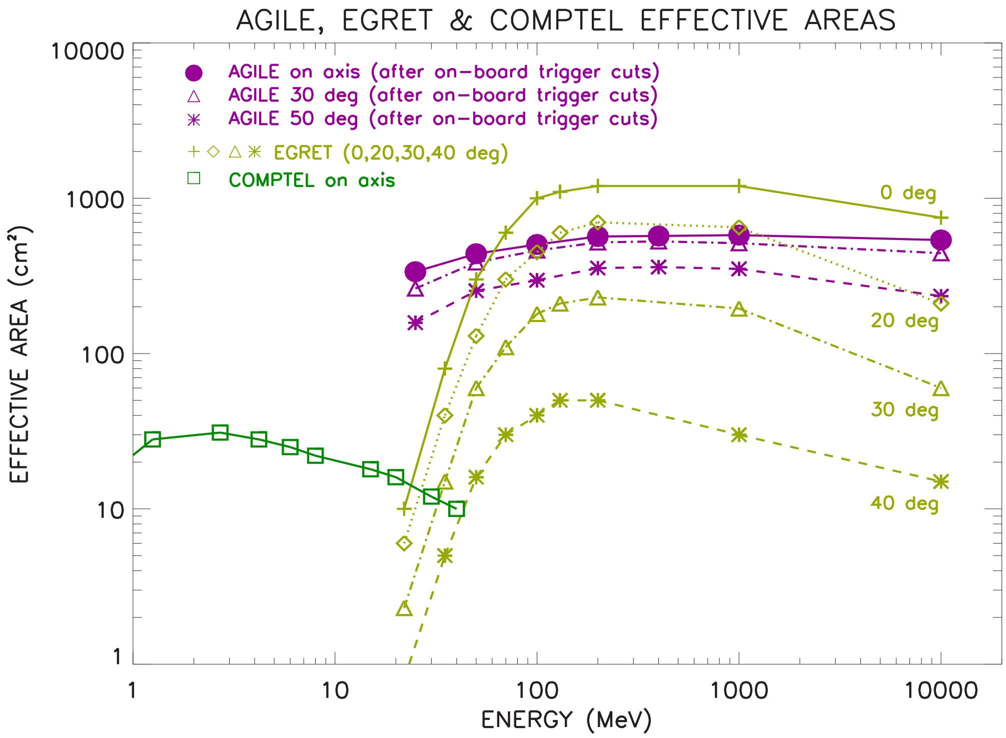


Figure 9: Effective area as a function of photon energy for the AGILE-GRID, EGRET [23], and COMPTEL [16].

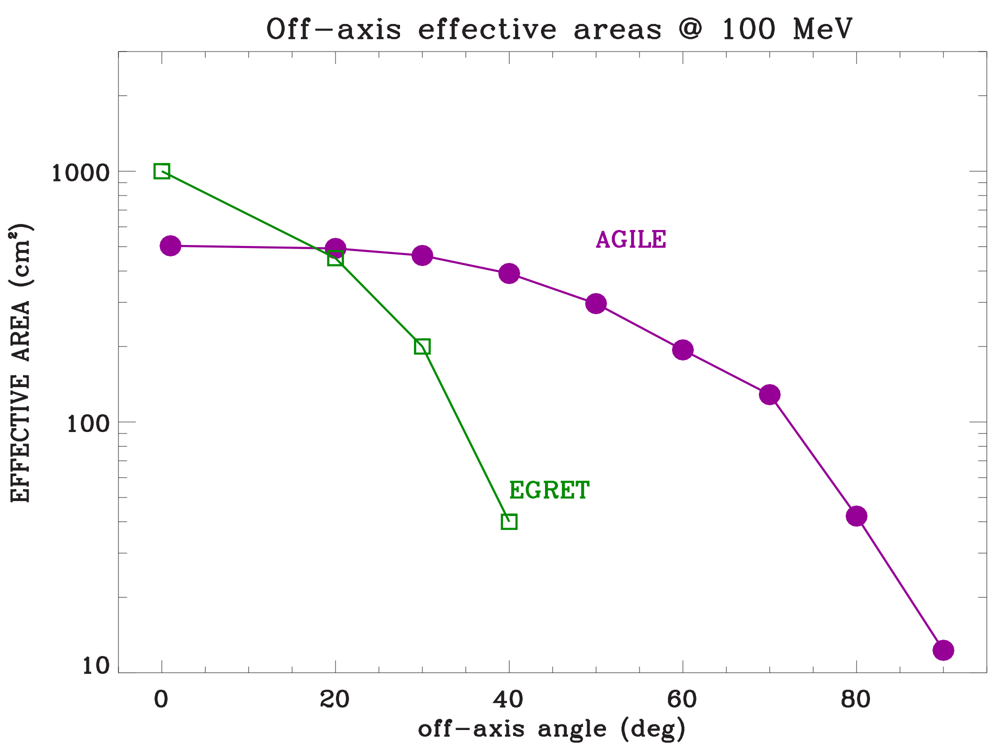


Figure 10: Effective area at 100 MeV as a function of photon incidence angle for the AGILE-GRID and EGRET.

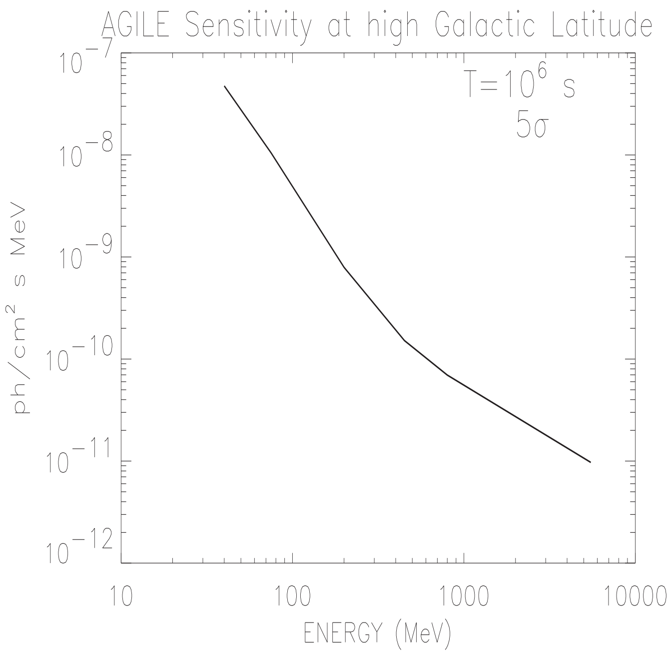


Figure 11: Expected point source sensitivity of AGILE-GRID for an effective exposure time of 10^6 s (corresponding to a 2-week viewing period, for a typical observing efficiency). Only the extragalactic diffuse gamma-ray background has been considered, therefore this figure refers to the sensitivity for sources outside the galactic plane.

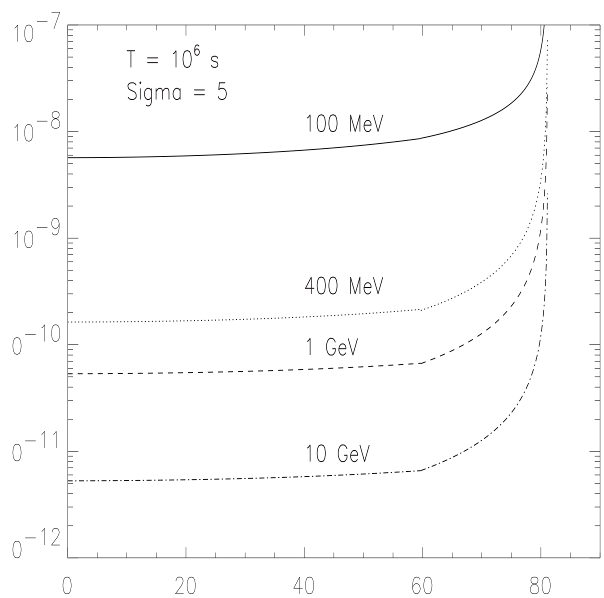


Figure 12: Expected point source sensitivity of the AGILE-GRID detector for an effective exposure time of 10^6 s as a function of the off-axis angle.

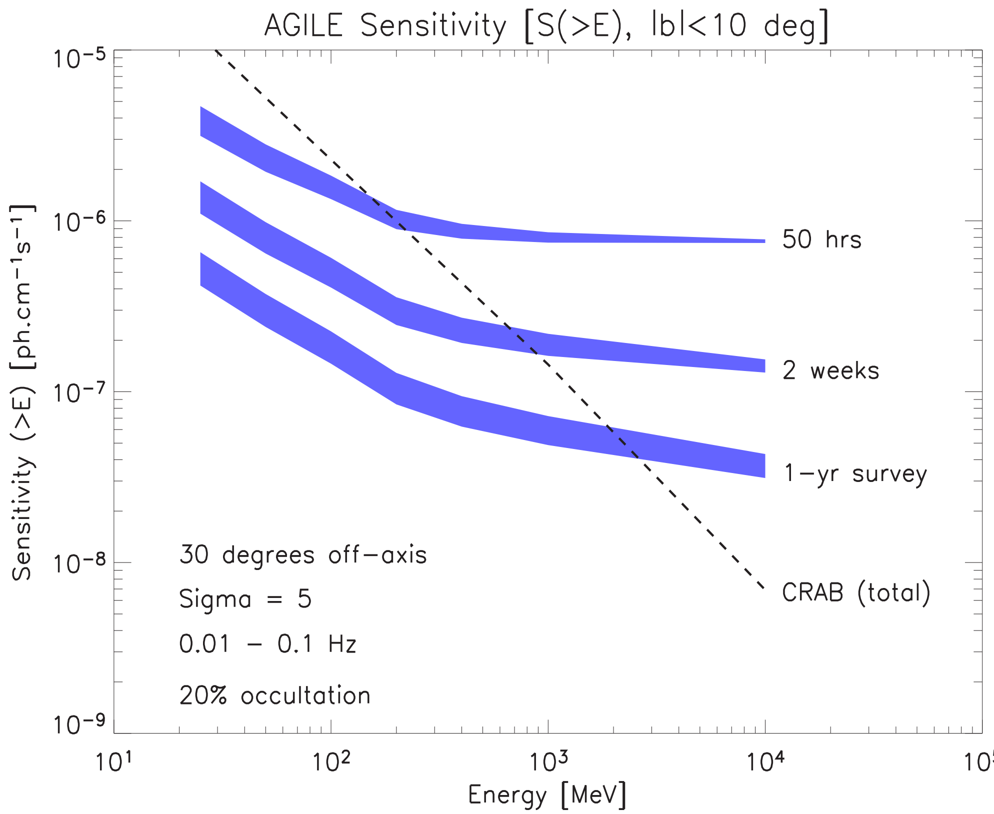


Figure 13: Simulated point source sensitivity (integral flux) of the AGILE-GRID detector for a typical source in the Galactic plane anticenter, and an average off-axis angle of 30 degrees. The dotted lines shows the integral gamma-ray flux from the Crab Nebula. The lower and upper curves defining the colored bands indicate the sensitivities obtained for a residual particle background of 0.01 Hz and 0.1 Hz, respectively.

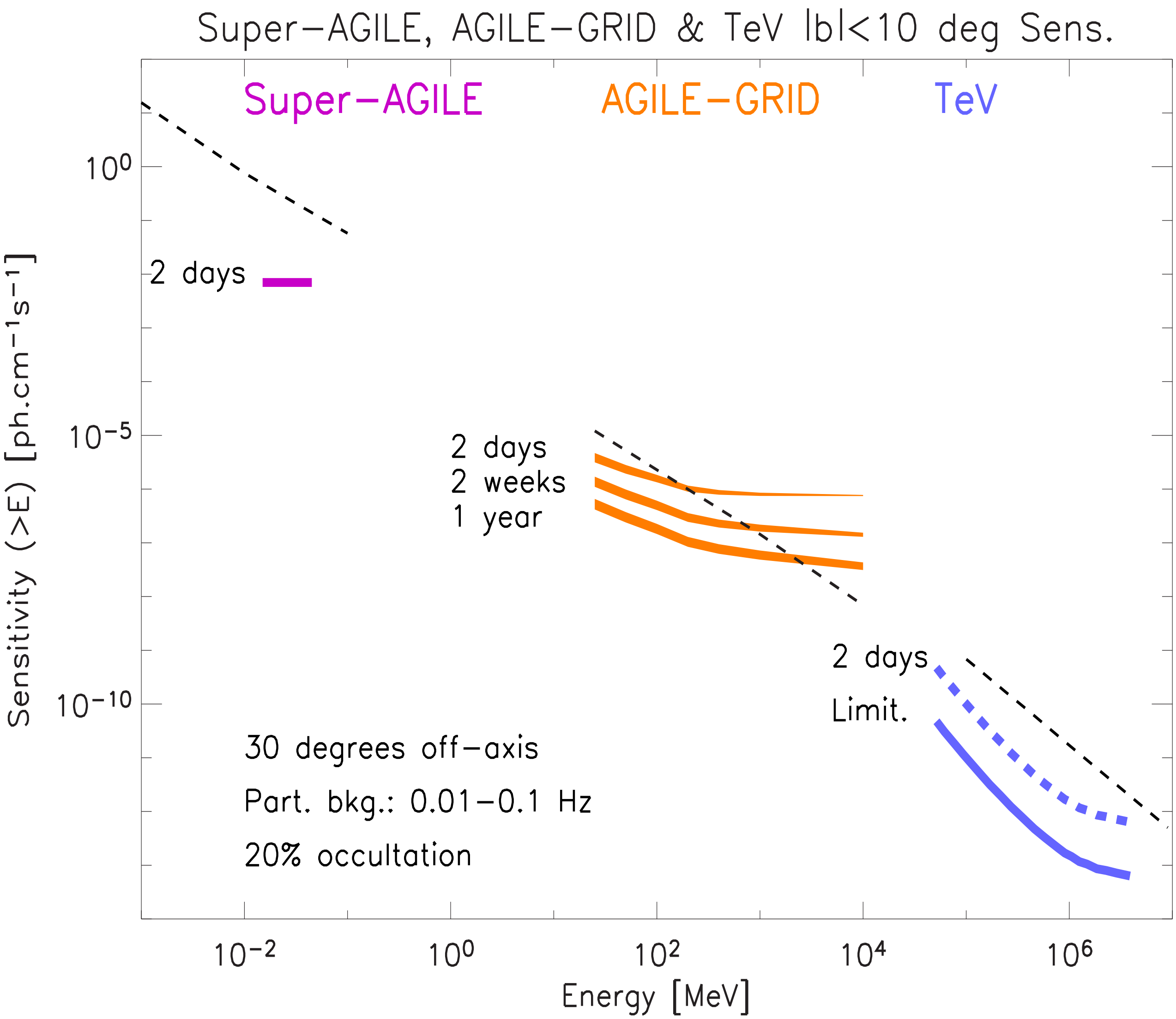


Figure 14: Simulated point source sensitivity (integral flux) of the AGILE instrument (GRID and Super-Agile) detector for typical source in the Galactic plane anticenter, and an average off-axis angle of 30 degrees. The dotted lines shows the integral gamma-ray flux from the Crab Nebula.

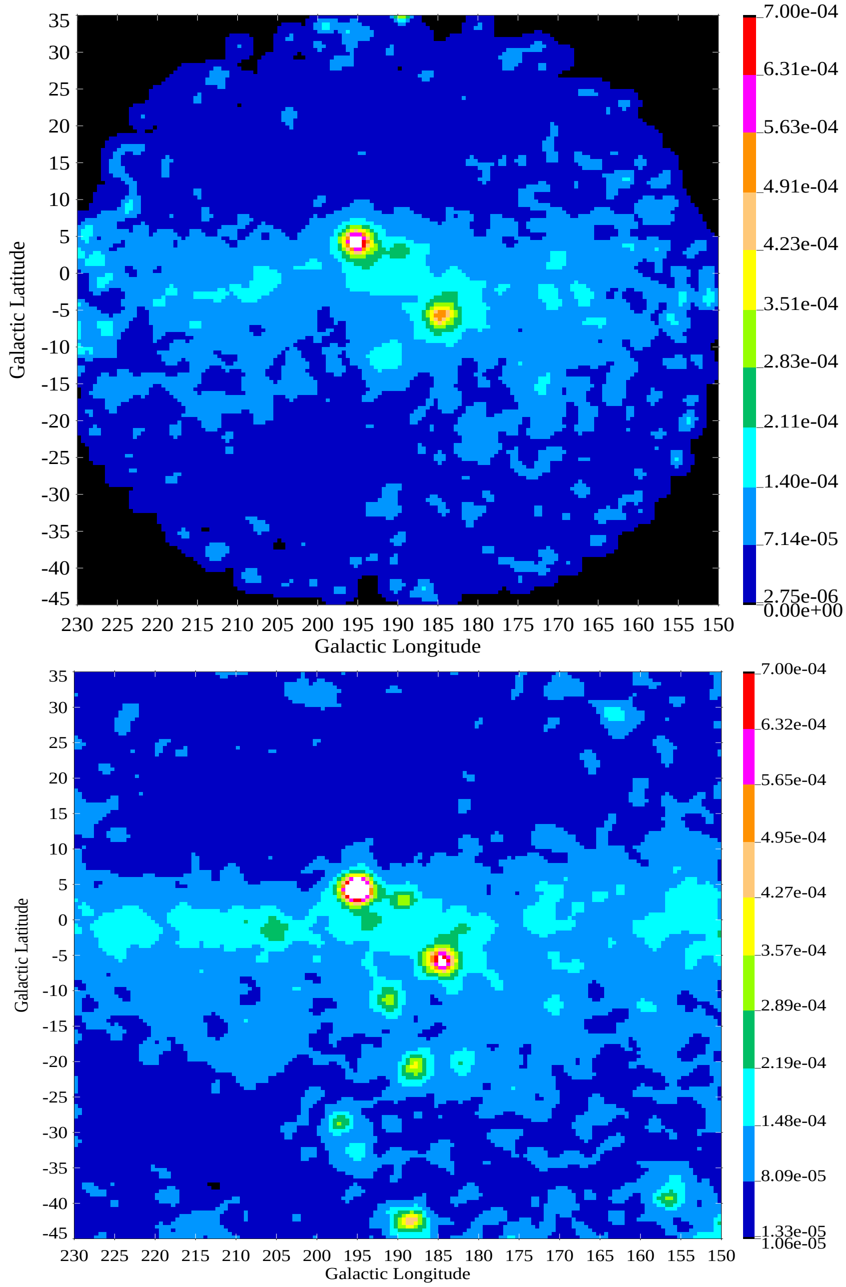
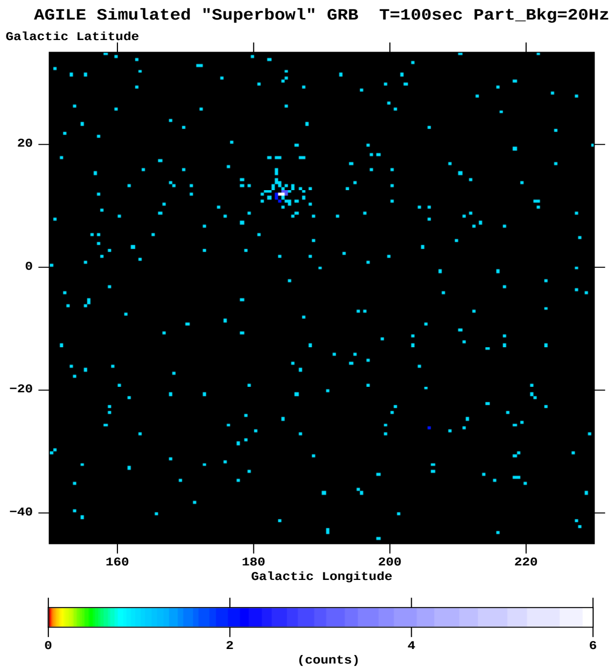
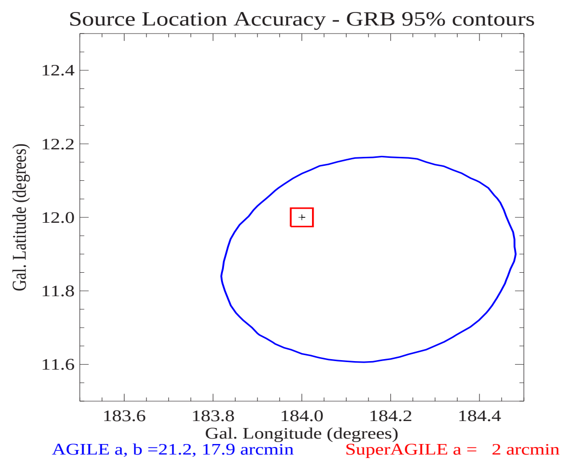


Figure 15: *Top Panel:* EGRET intensity map (E > 100 MeV) of the Galactic anti-center region for EGRET's Viewing Period 1 (effective on-source time of approximately 7 days). Color code in units of photons $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$. The Geminga pulsar (above the Galactic plane) and the Crab pulsar (below the plane) are clearly detectable above the Galactic diffuse background. *Bottom Panel:* simulated AGILE-GRID intensity map (E > 100 MeV) of the Galactic anti-center region for an effective on-source time of 7 days. Color code in units of photons $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$. Several other sources (considering the fluxes measured in the highest statistically significant detections as listed in the EGRET Third Catalog) are potentially detectable in addition to the Geminga and Crab pulsars.





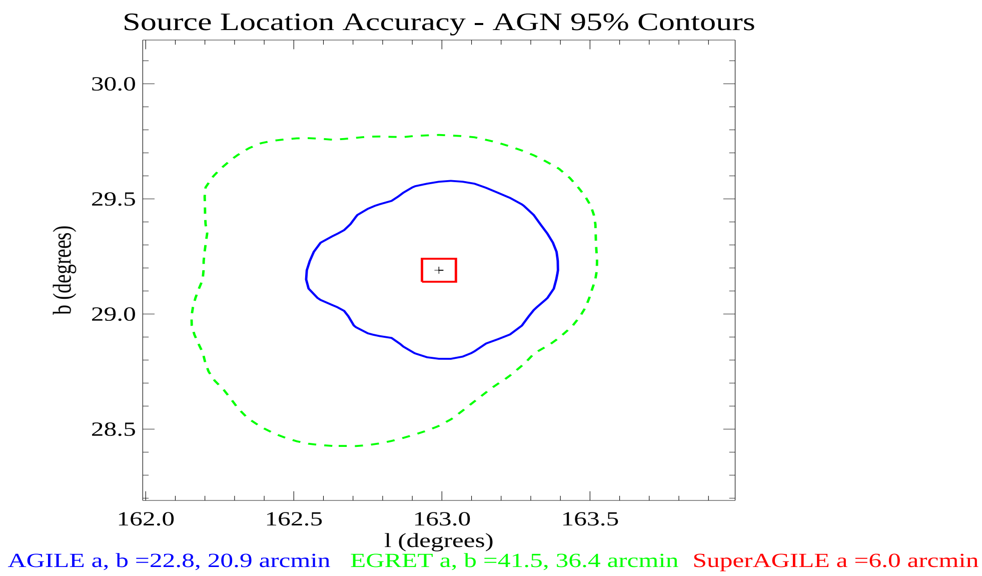


Figure 16: **Top Panel:** AGILE counts map above 100 MeV (*left*) and source location accuracy 95% contour (*right*) as obtained by the simulation of a GRB as intense as GRB 930131 (*Superbowl Burst*). AGILE can localize such a GRB within $\sim$ 20 arcmin for a Level-2 Trigger background rate of $\sim$ 20 Hz. Even at the edge of its field of view, Super-AGILE will be able to localize such a burst ($F_{10-40\,\mathrm{keV}} \sim$ Crab) within 2'–3'. **Bottom panel:** AGILE source location accuracy 95% contour as obtained by the simulation of an AGN ($F_{E>100\,\mathrm{MeV}} \sim 30 \times 10^{-8}\,\mathrm{ph\,cm^{-2}s^{-1}}$) placed at the edge of Super-AGILE field of view.

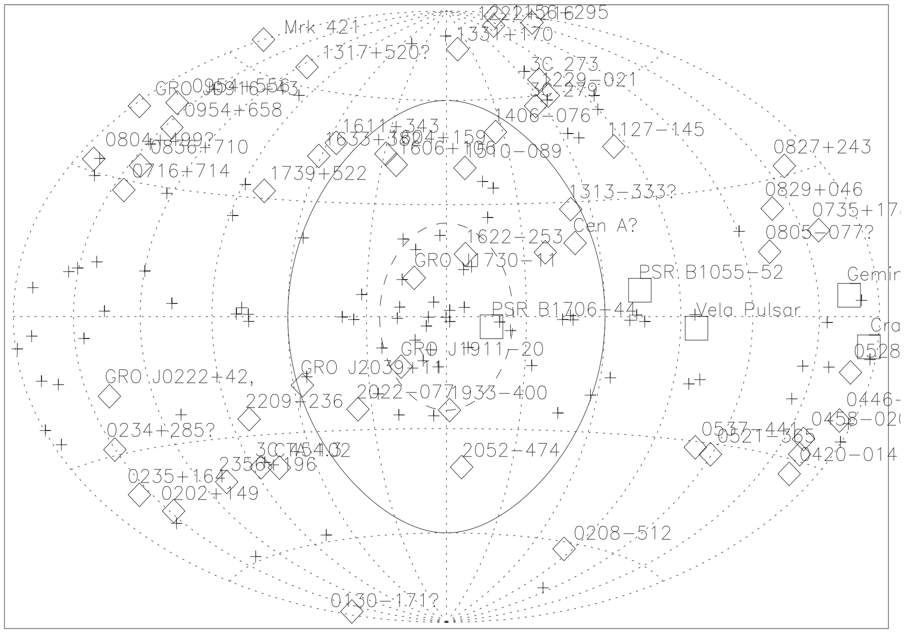


Figure 17: Comparison between a typical GRID pointing of the Galactic center region (area within the solid line circle of radius equal to 60°) and by EGRET (area within the dashed line of radius equal to 25°).

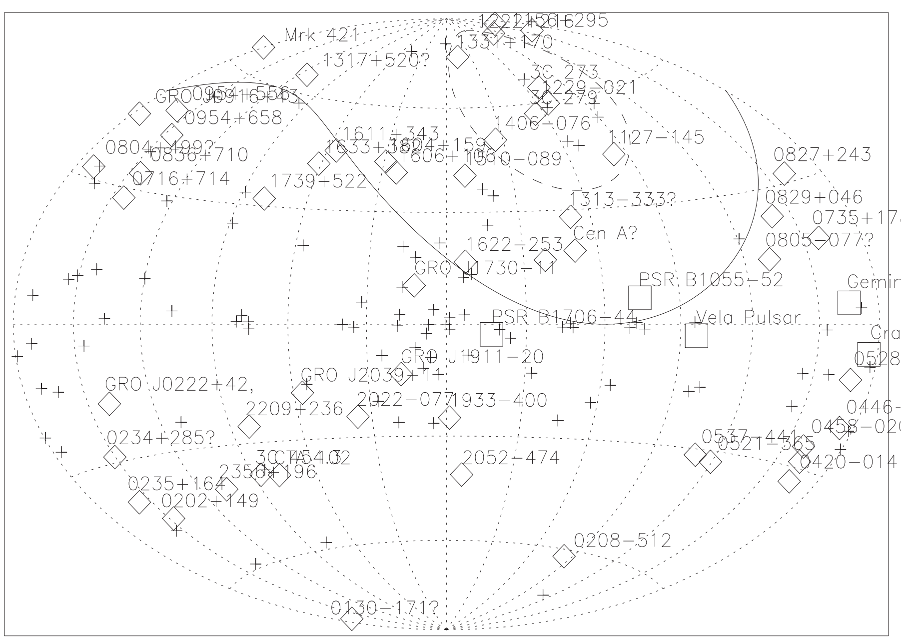
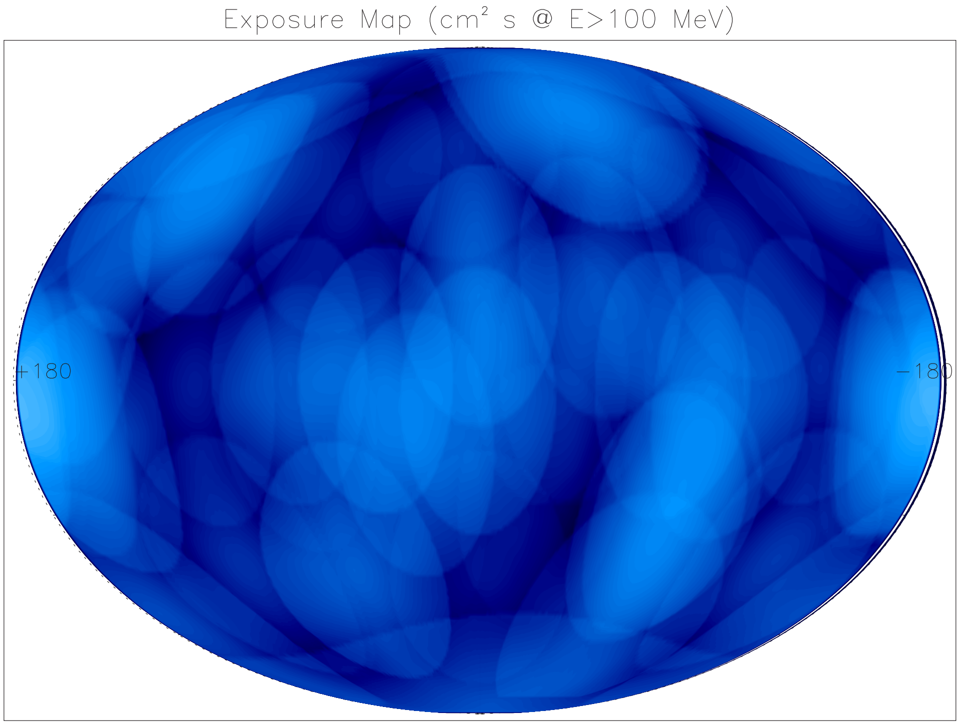


Figure 18: Comparison between the GRID (solid) and EGRET (dashed) fields of view for a pointing centered at the blazar 3C 279 (see Fig. 17).



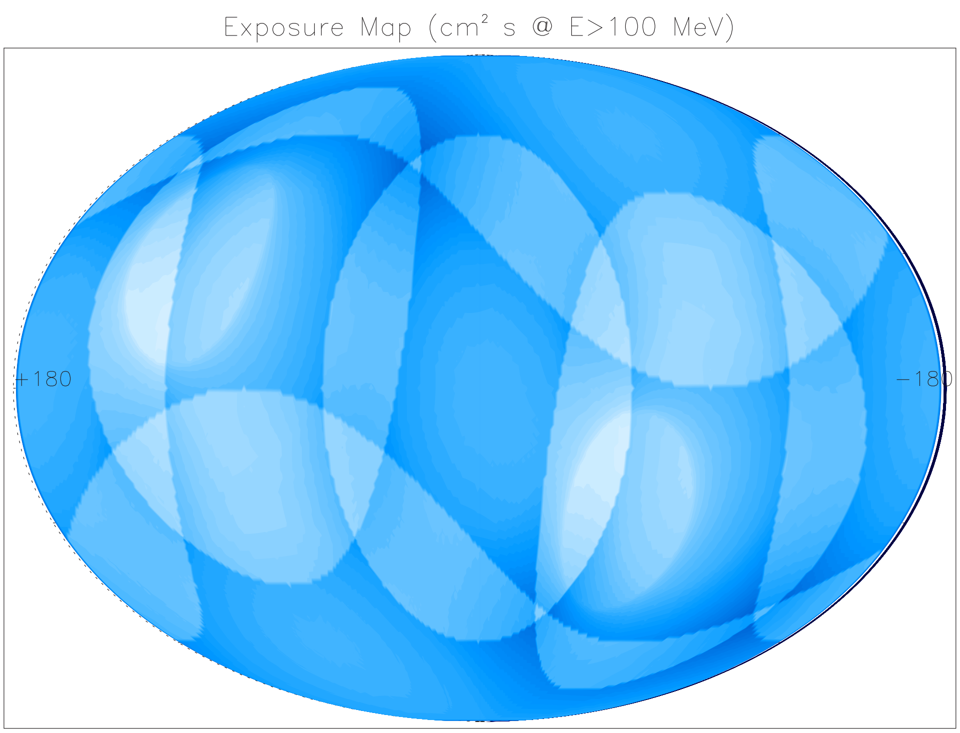


Figure 19: Exposure sky maps (Galactic coordinates) obtained after the pointing program of the EGRET Cycle-1 (1.5 years, *top panel*) and simulated from a possible AGILE Cycle-1 program (1 year, *bottom panel*). The color code of the two figures is logarithmic, with exposure values varying between the minimum obtained by EGRET and the maximum exposure obtained by AGILE (according to the histogram of Fig. 20).

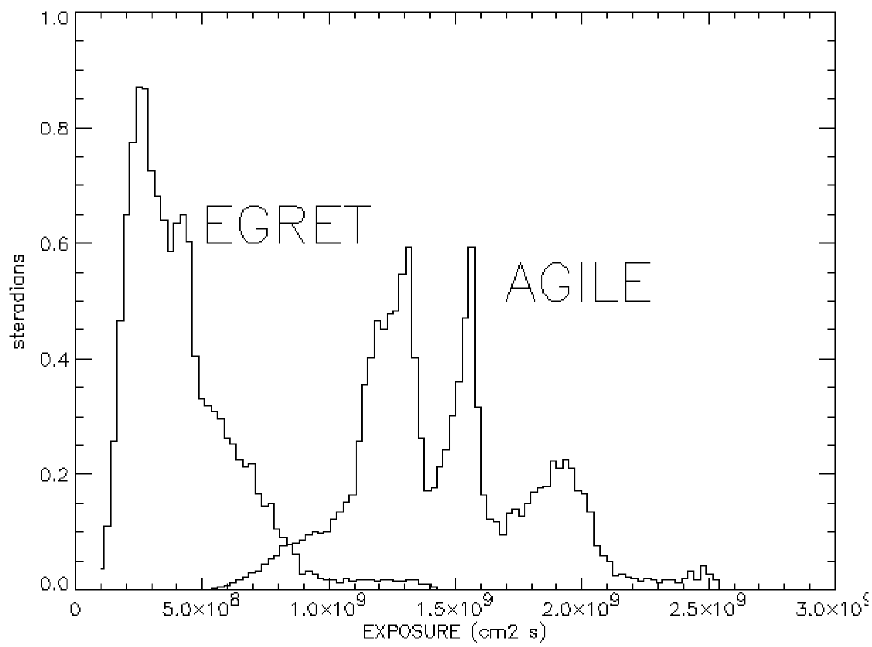


Figure 20: Distribution of exposures obtained by the EGRET and AGILE Cycle-1 pointing programs shown in Fig. 19. Note that the EGRET Cycle-1 period lasted ~ 1.5 years, and the AGILE Cycle-1 period is assumed to last 1 year. The bimodal AGILE distribution with two prominent peaks is a consequence of the accumulated exposure at the celestial poles.

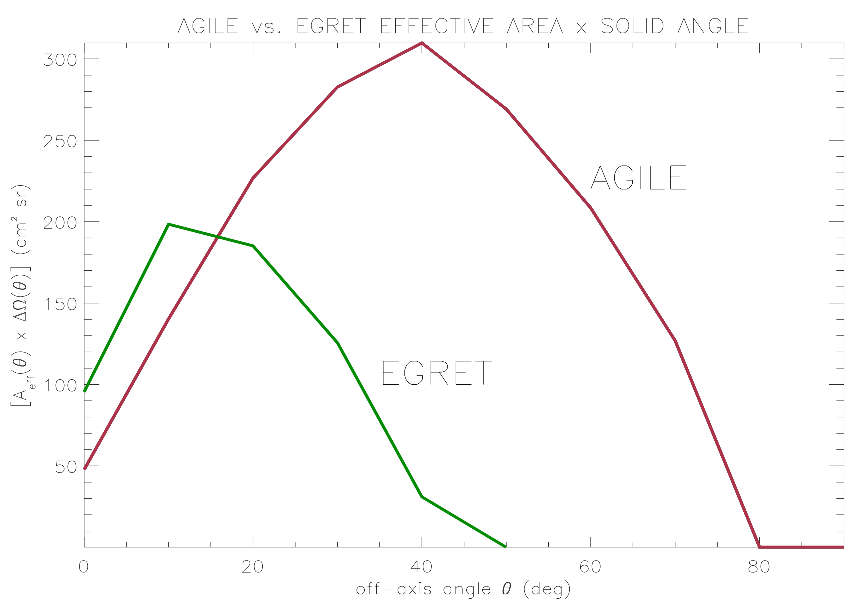


Figure 21: The quantity $A_{eff}(\theta) \times \Delta\,\Omega(\theta)$ is shown as a function of the off-axis angle θ for EGRET *(green curve)* and AGILE *(red curve)* with $\Delta\,\Omega(\theta)$ the bin-integrated solid angle centered at θ. The comparison shows that despite a smaller on-axis effective area, the combination of the shallow AGILE A_{eff} and its large field-of-view is expected to produce a coverage of a wide portion of the sky by AGILE with very good sensitivity.

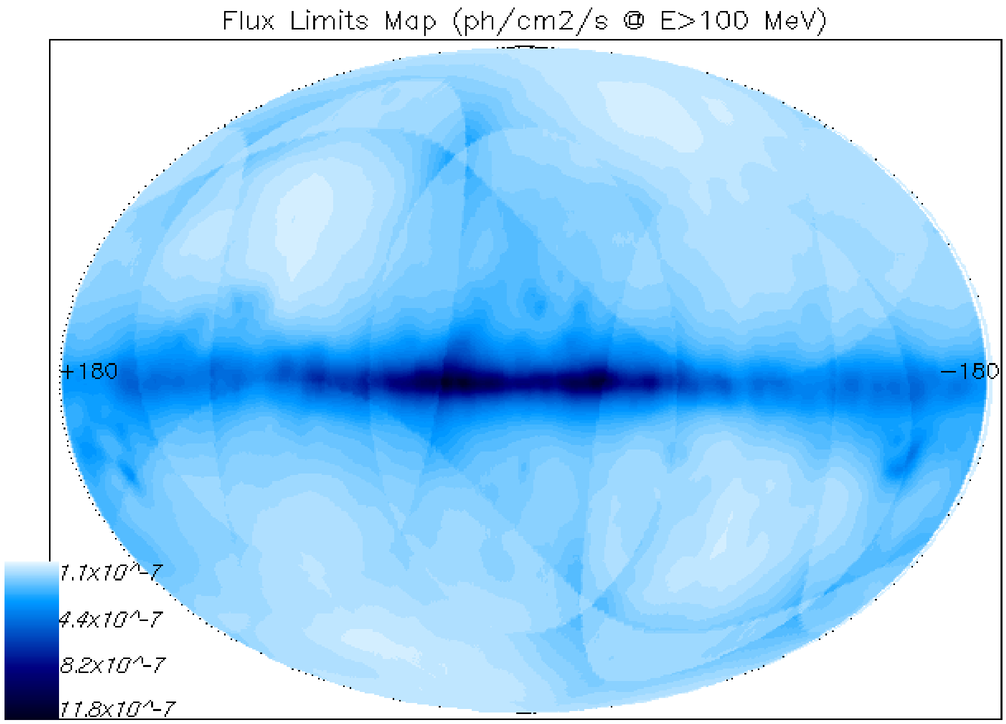


Figure 22: AGILE simulated γ-ray sensitivity map (in units of 10^{-7} photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) above 100 MeV. The map is obtained from the exposure map of Fig. 19 (bottom panel) taking into account Earth occultations and the diffuse gamma-ray radiation mostly concentrated in the Galactic plane.

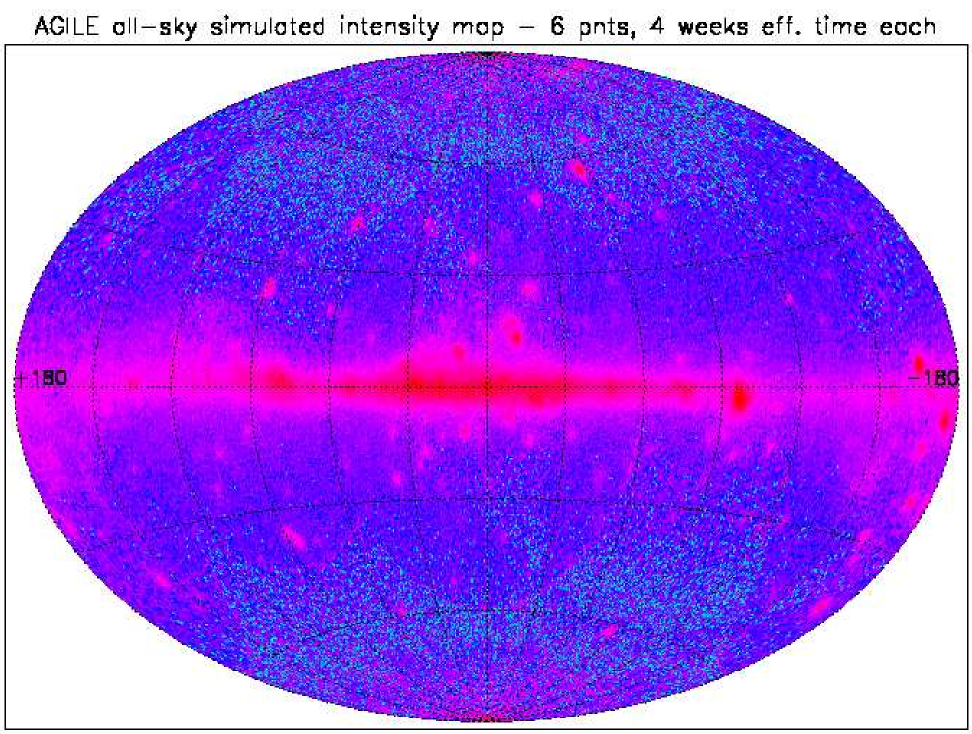


Figure 23: AGILE simulated *all-sky* intensity map (in units of photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$) above 100 MeV assuming the complete sky coverage with 6 pointings lasting 4 weeks (effective time) each (from Figs. 19 and 22).

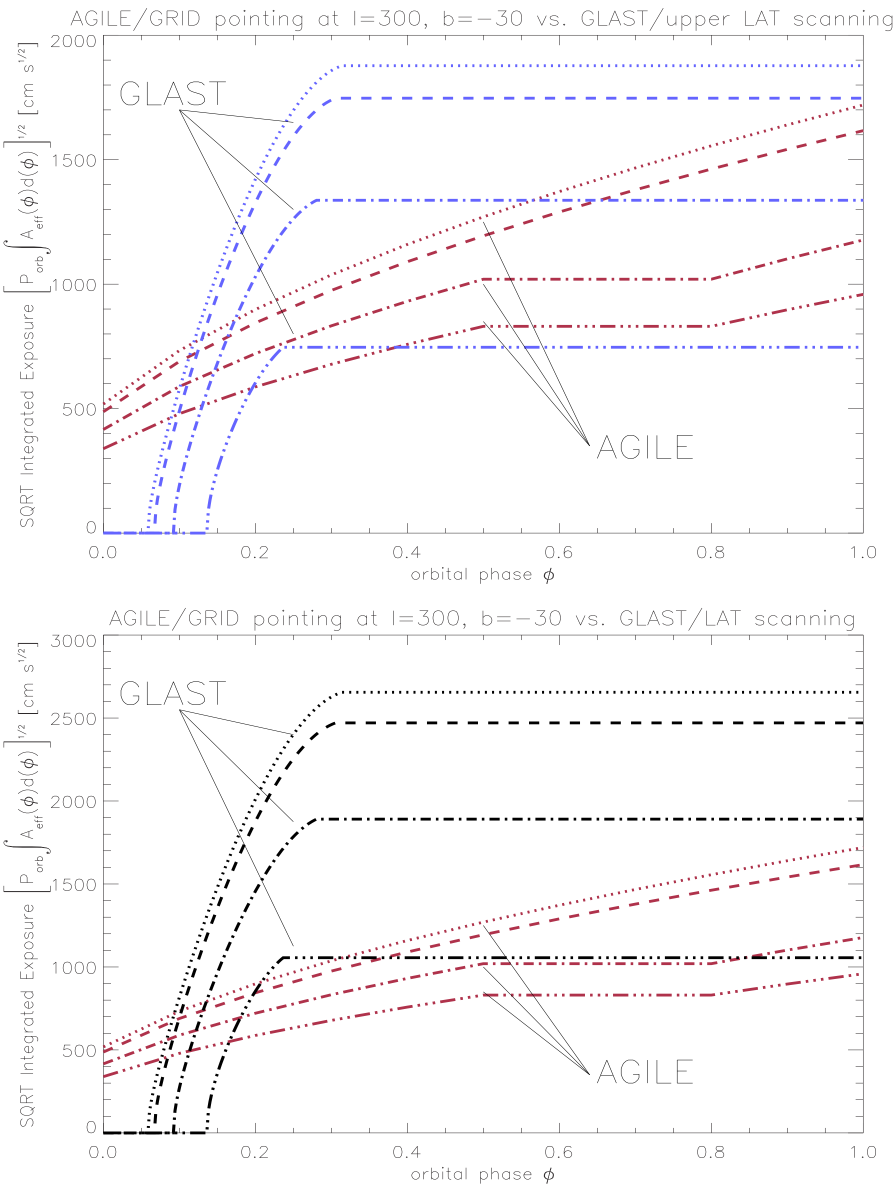


Figure 24: Comparison of the simulated performance of AGILE and GLAST in detecting gamma-ray transients above 100 MeV lasting a few days (typical of AGN γ-ray flaring) during the first year of the GLAST sky scanning mode and for an AGILE pointing centered at a celestial pole (minimizing Earth occultations). We distinguish the performance of the GLAST γ-ray imager "Upper-LAT" (first 12 planes with a light Tungsten converter [12]) from those of the whole LAT. The Figure shows the relevant quantity, i.e., the square-root of the on-source integrated exposure (at 100 MeV) as a function of the orbital phase for the AGILE/GRID *(red curves)*, the Upper-LAT/GLAST *(blue curves, top panel)*, and the whole LAT/GLAST *(black curves, lower panel)*. We assumed an AGILE fixed pointing centered in an unocculted sky region (celestial South pole), and the exposure of the same region obtained during the GLAST sky-scanning mode. Only one (first) orbit is shown. The exposures are obtained for sources on-axis *(dotted lines)*, at 20° off-axis *(dashed lines)*, at 40° off-axis *(dotted-dashed lines)*, and at 60° off-axis *(dot-dotted-dashed lines)* for both instruments. The ratios of curves representing the AGILE and GLAST (Upper and whole LAT) capabilities at the end of the first orbit are indicative of the asymptotic values reached after several orbits. The conclusion is that during the first year of the GLAST scanning mode the γ-ray imaging capabilities of the GRID and Upper-LAT are comparable for gamma-ray transients lasting hours-days, and AGILE can reach a flux sensitivity a factor of $\sim 1/2$ that of the whole LAT/GLAST.

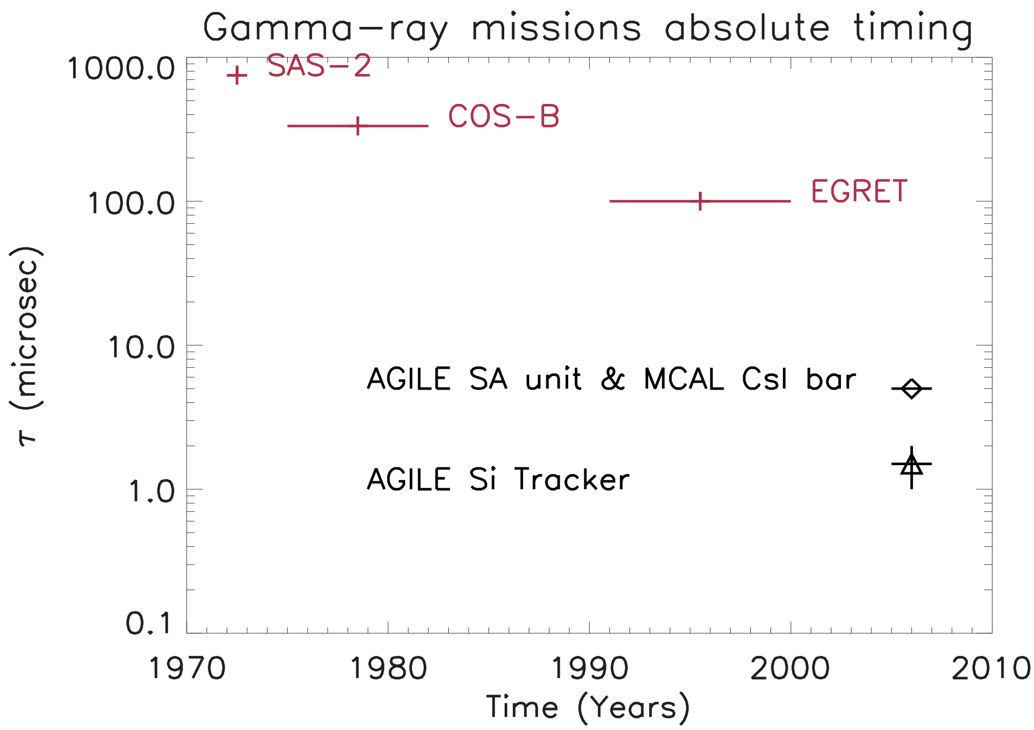


Figure 25: Single photon time-tagging uncertainty (τ) of AGILE and previous gamma-ray detectors.

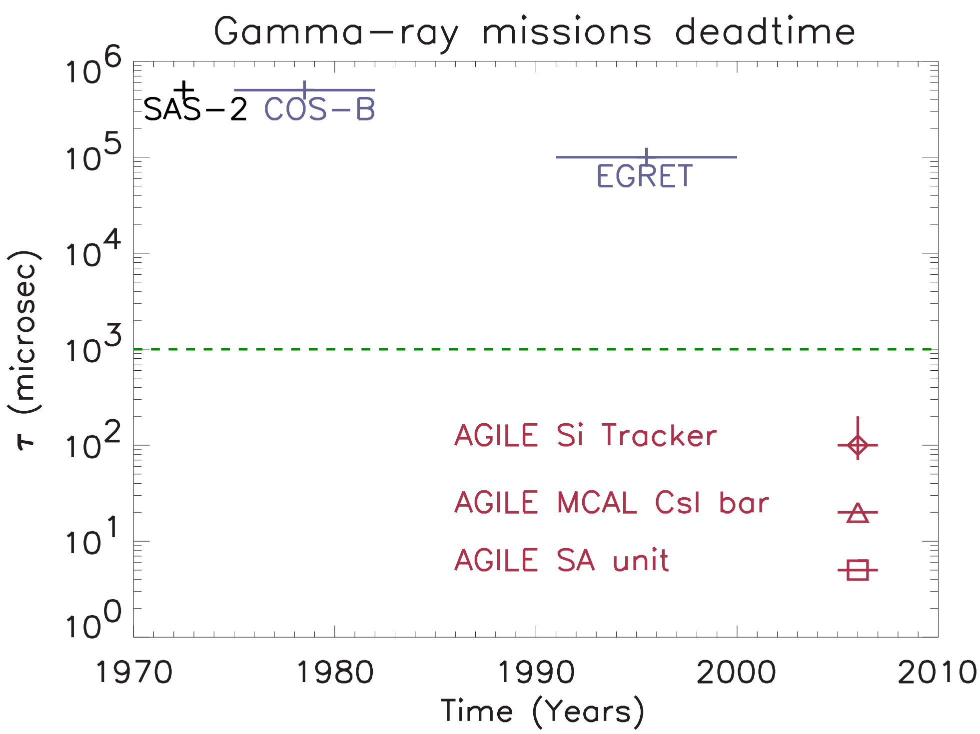


Figure 26: Instumental deadtimes (τ) for the AGILE detectors and previous gamma-ray instruments.

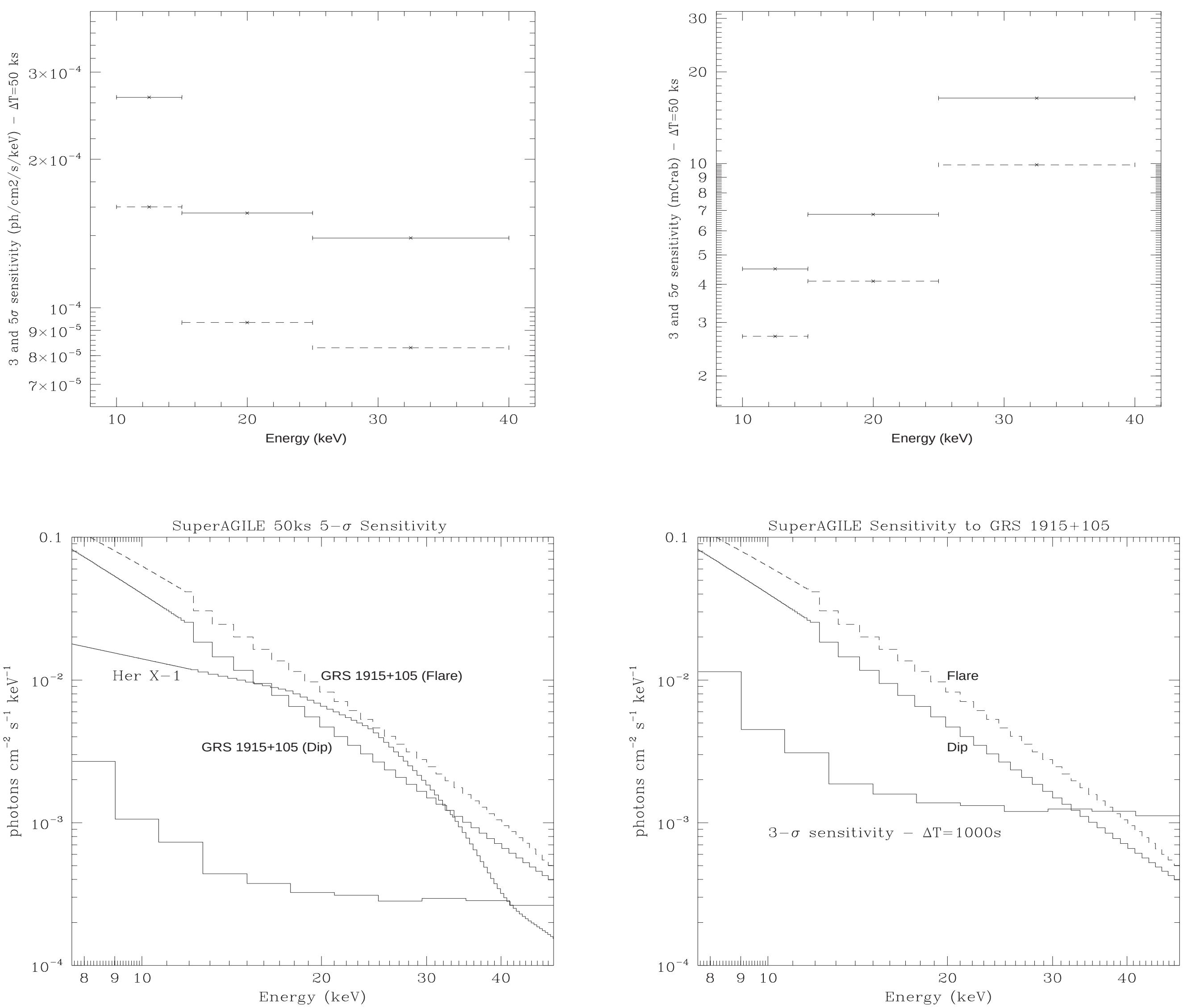


Figure 27: *Top Panel:* Super-AGILE simulated sensitivity (solid data points: 5σ, dashed data points: 3σ) for a 50 ksec integration and Crab-like spectrum for the combined four Si-detectors, in units of photons cm^{-2} s^{-1} keV^{-1} (left) and mCrab (right) *Bottom Panel:* On the left, hard X-ray spectral sensitivity reachable in one day (5σ) by Super-AGILE compared with hard X-ray spectra of known Galactic sources. On the right, hard X-ray spectral sensitivity reachable in 1 ksec (3σ) by Super-AGILE compared with the hard X-ray spectrum of GRS 1915+105 in two different states. Data from [9].

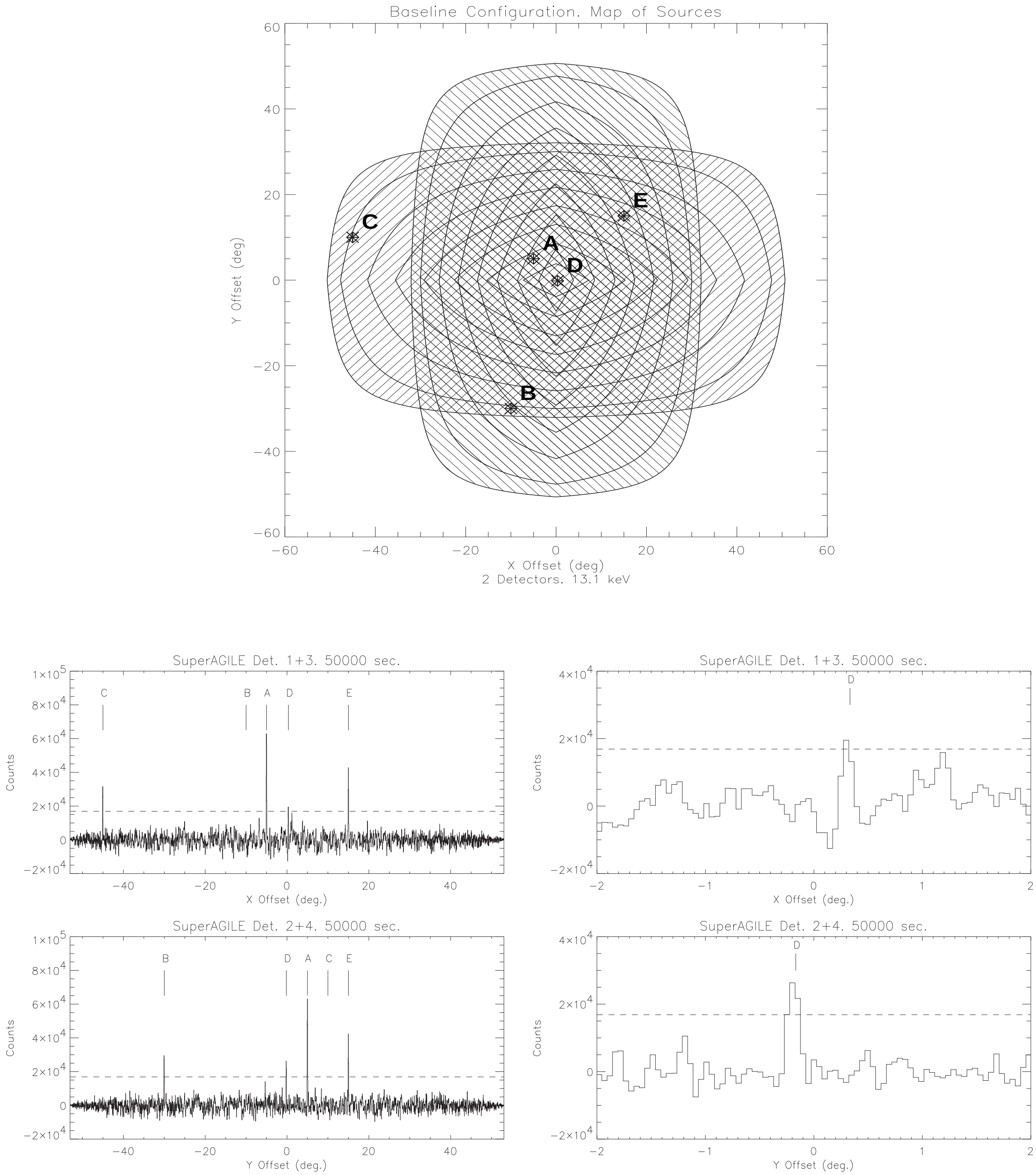


Figure 28: *Top Panel:* Super-AGILE FOV and simulated source locations for different intensities: (A) 50 mCrab, (B) 50 mCrab, (C) 150 mCrab, (D) 20 mCrab, (E) 50 mCrab. Integration time is 50 ks, and a Crab-like spectrum was assumed for the sources. Note that source C is only visible in one pair of detectors. *Left bottom Panel*: One-dimensional image of the above simulated field for the two pairs of Super-AGILE detectors. The horizontal dashed line is the 5σ detection threshold. *Right bottom Panel*: Zoom-in of the central one-dimensional image, showing the significance of the D source, compared to some image artifacts.

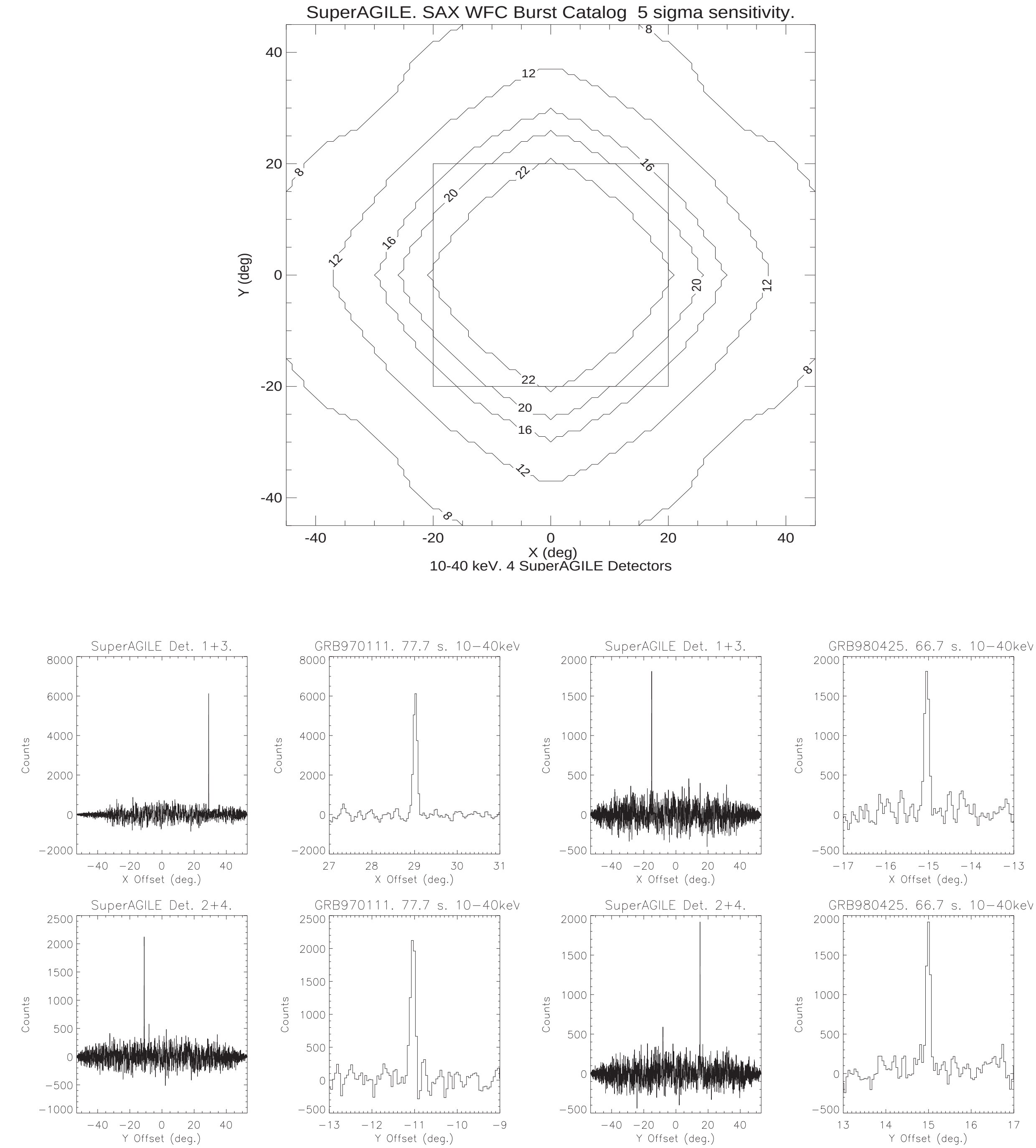


Figure 29: Simulation of the Super-AGILE (SA) GRB detection capability. The first 23 GRBs detected by the SAX/WFC (with an intrinsic spread in intensity and duration) were placed in the in different regions of the SA FOV. The contour levels indicate the number that are detectable by Super-AGILE as a function of off-axis angle. The central region of the SA FOV will detect practically all of the 23 GRBs. Detectable GRBs decrease as the sensitivity decrease for off-axis angles. The expected GRB detection rate in the SA FOV is $\sim 1-2$ per month. The square indicates the SAX/WFC (full width at zero response) FOV. *Left bottom two-Panels*: Simulated detection of GRB 970111. *Right bottom two-Panels*: Simulated detection of GRB 980425.

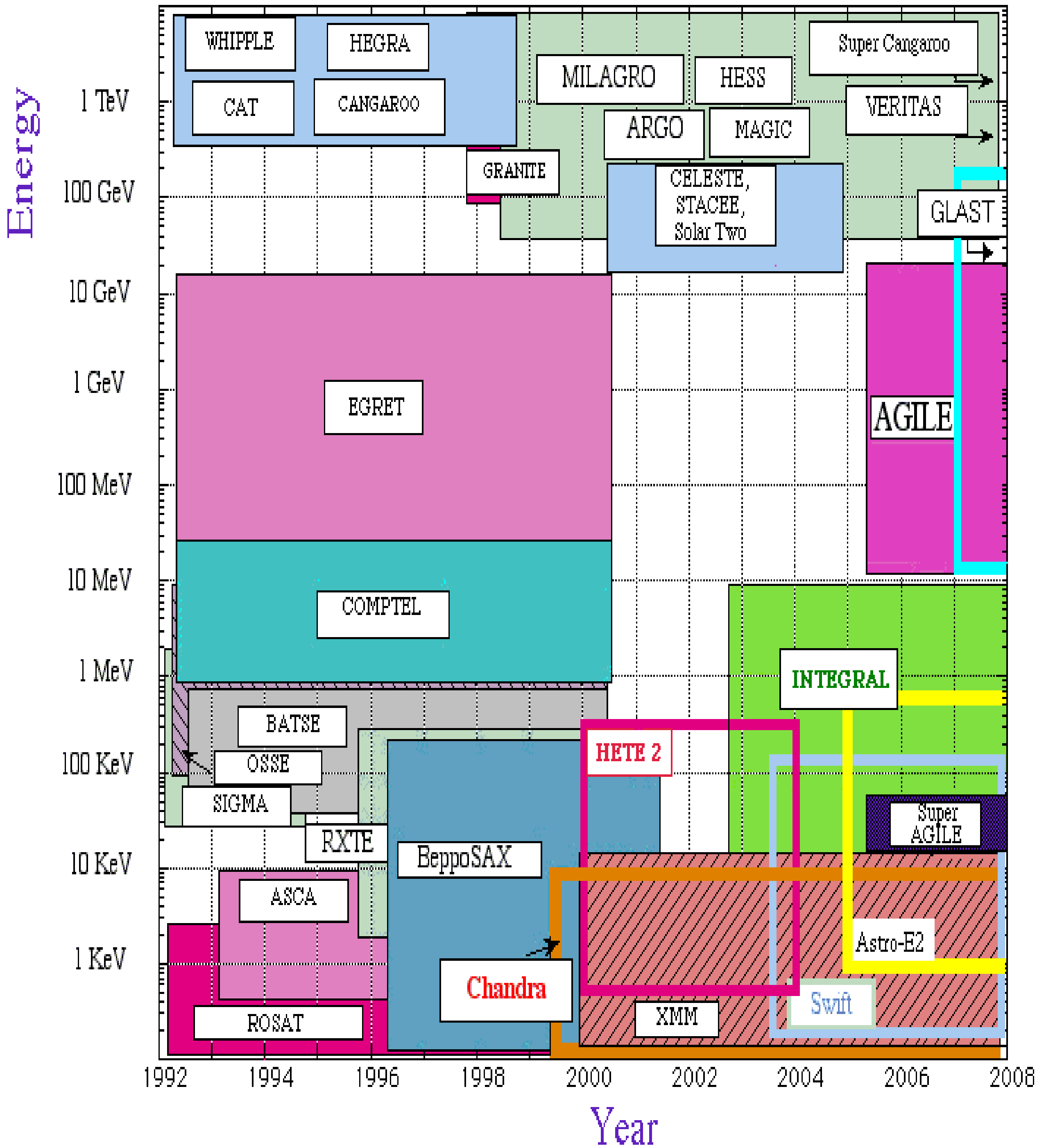


Figure 30: Timing and synergies of AGILE.