Gamma-ray Astrophysics with AGILE

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Abstract.
AGILE will explore the gamma-ray Universe with a very innovative instrument combining for the first time a gamma-ray imager and a hard X-ray imager. AGILE will be operational in spring 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. The AGILE instrument is designed to simultaneously detect and image photons in the 30 MeV - 50 GeV and 15 - 45 keV energy bands with excellent imaging and timing capabilities, and a large field of view covering $\sim 1/5$ of the entire sky at energies above 30 MeV. A CsI calorimeter is capable of GRB triggering in the energy band 0.3-50 MeV. AGILE is now (March 2007) undergoing launcher integration and testing. The PLSV launch is planned in spring 2007. AGILE is then foreseen to be fully operational during the summer of 2007.

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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 scientifi c and programmatic participation by INAF, INFN and several Italian universities[1]. The industrial team includes Carlo Gavazzi Space, Alcatel-Alenia-Space-Laben, Oerlikon-Contraves, and Telespazio.

Despite its small dimensions ($\sim$0.3 m^3) and weight ($\sim$100 kg) compared to other future instruments such as GLAST, the AGILE performance will be as good as, or better than, that of bigger past instruments such as EGRET, thanks to the new silicon detector technology employed for the AGILE instruments[2].

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 unidentifi ed 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 fi rst 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 [3] .

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.

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This paper is essentially based on the last review written by the AGILE collaboration on the AGILE instrument and its science objectives[4].

THE AGILE INSTRUMENT

The AGILE scientific instrument is based on an innovative design based on three detecting systems: (1) a Silicon Tracker, (2) a Mini-Calorimeter (MC), and (3) an ultralight coded mask system with Si-detectors (Super-AGILE). AGILE is designed to provide: (1) excellent imaging in the energy bands 30 MeV–50 GeV (5–10 arcmin for intense sources) and 15-45 keV (1–3 arcmin for intense sources); (2) optimal timing capabilities, with independent readout systems and minimal deadtimes for the Silicon tracker, Super-AGILE and Mini-Calorimeter; (3) large fields of view for the gamma-ray imaging detector (GRID) ($\sim$3 sr) and Super-AGILE ($\sim$1 sr)[2].. The innovative technology will allow AGILE to achieve the smallest deadtime in high-energy astrophysics. More detailed information will be presented elsewhere[5, 6].

The AGILE scientific payload is made of three detectors combined into one integrated instrument with broad-band detection and imaging capabilities[7, 8]. The Anticoincidence and Data Handling systems complete the instrument.

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 (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 angle for the same exposure).

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 is also capable of independently detecting GRBs and other transients in the 400 keV - 100 MeV energy range with optimal timing capabilities.

- The **Silicon-Tracker**, is a gamma-ray pair-converter and imager 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. Each Si-Tracker layer is made of 4 ladders (each composed of 4 Si tiles), for a total geometric area of 38×38 cm^2 and 1,536 readout channels. 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 (views) with microstrips orthogonally positioned. Both digital and analog information (charge deposition in Si-microstrip) is read by front-end electronics (FEE). The GRID has an *on-axis* total radiation length $\sim 0.8 X_0$. 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.
- **Super-AGILE** is the hard x-ray imager of the mission. It is composed of four independent unidimensional coded mask units, two with the same coding direction, the other two with the orthogonal. The detection plane of each unit is made of four square Silicon detectors (9.5×9.5 cm^2 each). Detection plane and associated FEE is placed on the first GRID tray. The Tungsten coded mask is 14 cm above the detection plane. Super-AGILE characteristics are: *(i)* photon-by-photon detection and imaging of sources in the 15-45 keV energy range; *(ii)* a field of view of 1 sr and a PSF of 6 arcmin; *(iii)* excellent timing (4 μs); *(iv)* quick on-board burst alert and localization; *(v)*GRB trigger for the GRID and MCAL.
- The **Mini-Calorimeter** (MCAL) is made of two planes of Cesium Iodide (CsI) bars, for a total (on-axis) radiation length of $1.5 X_0$. The signal from each CsI bar is collected by two photodiodes placed at both ends. The MCAL tasks are: *(i)* obtaining additional information on the energy of particles produced in the Si-Tracker; *(ii)* detecting GRBs and other impulsive events with spectral and intensity information in the energy band $\sim 0.3 - 50$ MeV. We note that the problem of "particle backsplash" for AGILE is much less severe than in the case of EGRET. AGILE allows a relatively efficient detection of (inclined) photons near 10 GeV and above also because the AC-veto can be disabled for events with more than $\sim$ 100 MeV total energy collected in the MCAL.

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.

- **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. 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.

SCIENCE WITH AGILE

The AGILE instrument has been designed and developed to obtain an excellent imaging capability in the energy range 100 MeV-50 GeV, improving the EGRET angular resolution by a factor of 2. AGILE will have 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); The excellent timing capabilities of AGILE, with overall photon absolute time tagging of uncertainty below $2\ \mu s$ and very small deadtimes ($200\ \mu s$ 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) allows fundamental physics studies; AGILE will achieve 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 $(10-20) \times 10^{-8}\ \mathrm{ph\,cm^{-2}\,s^{-1}}$ 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; furthermore AGILE will have a good sensitivity to photons in the energy range $\sim$30-100 MeV, with an effective area above 200 cm^2 at 30 MeV; and a very rapid response to gamma-ray transients and gamma-ray bursts, obtained by a special quicklook analysis program and coordinated ground-based and space observations. AGILE will provide accurate localization ($\sim$2-3 arcmins) of GRBs and other transient events obtained by the GRID-SA combination (for typical hard X-ray transient fluxes above $\sim$1 Crab); the expected GRB detection rate is $\sim 1-2$ per month; and long-timescale continuous monitoring ($\sim$2-3 weeks) of gamma-ray and hard X-ray sources; Finally the AGILE satellite can be repointed after special alerts ($\sim$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. 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.

A crucial feature of AGILE is its large field of view for both the gamma-ray and hard X-ray detectors. 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 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 [9]; about 10 hard X-ray sources per day are expected to be detected by SA for typical pointings of the Galactic plane.

The existence of a large number of variable gamma-ray sources (extragalactic and near the Galactic plane[10]) 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 $10^{-6} \mathrm{ph\,cm^{-2}\,s^{-1}}$) 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.

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. 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.

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.

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.

CONCLUSIONS

The AGILE scientific instrument is innovative in many ways, and is designed to obtain an optimal gamma-ray detection performance despite its relatively small mass and absorbed power. The combination of hard X-ray and gamma-ray imaging capabilities in a single integrated instrument is unique to AGILE. We anticipate a crucial role of AGILE for studies of the high energy sky in X and gamma ray energy ranges. Updated documentation on the AGILE Mission can be found at the web site http://agile.iasf-roma.inaf.it.

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