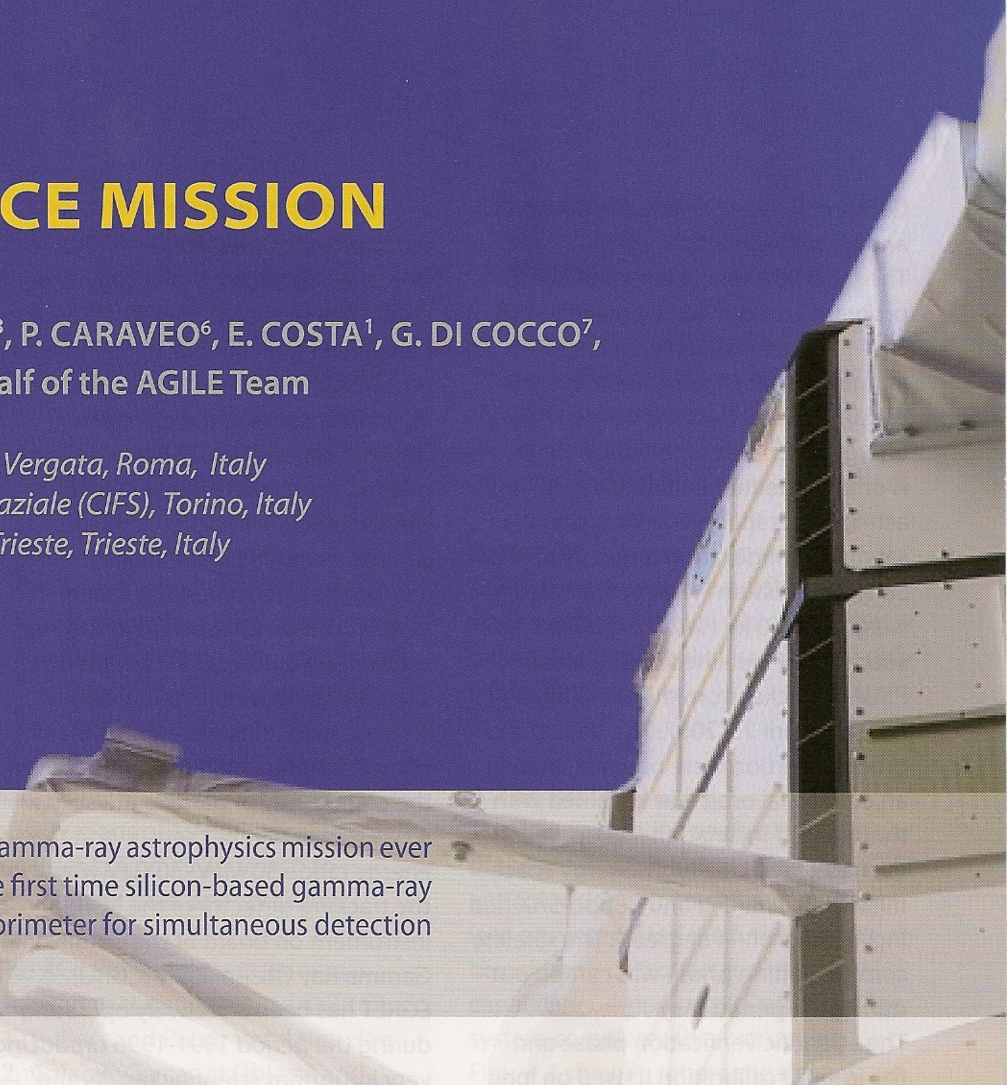

THE AGILE SPACE MISSION

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AGILE is the most compact and lightest gamma-ray astrophysics mission ever operating in space, and combines for the first time silicon-based gamma-ray and X-ray images and cesium iodide calorimeter for simultaneous detection of cosmic sources and transients.

AGILE is an Italian Space Agency mission dedicated to the observation of the gamma-ray Universe. The AGILE very innovative and most compact instrumentation combines for the first time a gamma-ray imager (sensitive in the energy range 30 MeV–50 GeV) and a hard–X-ray imager (sensitive in the range 18–60 keV) together with a calorimeter (sensitive in the range 300 keV–100 MeV) and an anticoincidence system. AGILE was launched on April 23, 2007 from the Indian base of Sriharikota and was inserted in an equatorial orbit with a very low particle background. AGILE will provide crucial data for the study of Active Galactic Nuclei, Gamma-Ray Bursts, pulsars, unidentified Gamma-ray sources, Galactic compact objects, supernova remnants, TeV sources, and fundamental physics by microsecond timing. An optimal angular resolution (reaching 0.1–0.2 degrees in gamma-rays and 1–2 arcminutes in hard X-rays) and very large fields of view (2.5 sr and 1 sr, respectively) are obtained by the use of silicon detectors integrated in a very compact instrument. During the first year of operations AGILE surveyed the gamma-ray sky and detected many galactic and extragalactic sources producing a wealth of interesting results. The main scientific results will be presented in this journal in a forthcoming paper.

1 Introduction

The space program AGILE (Astro-rivelatore Gamma a Immagini LEggero) is an Italian high-energy astrophysics mission supported by the Italian Space Agency (ASI) with scientific and programmatic participation of INAF, INFN, CNR, ENEA and several Italian universities [1–3]. The main industrial contractors include Carlo Gavazzi Space, Thales-Alenia-Space (formerly Laben), Rheinmetall Italia (formerly Oerlikon-

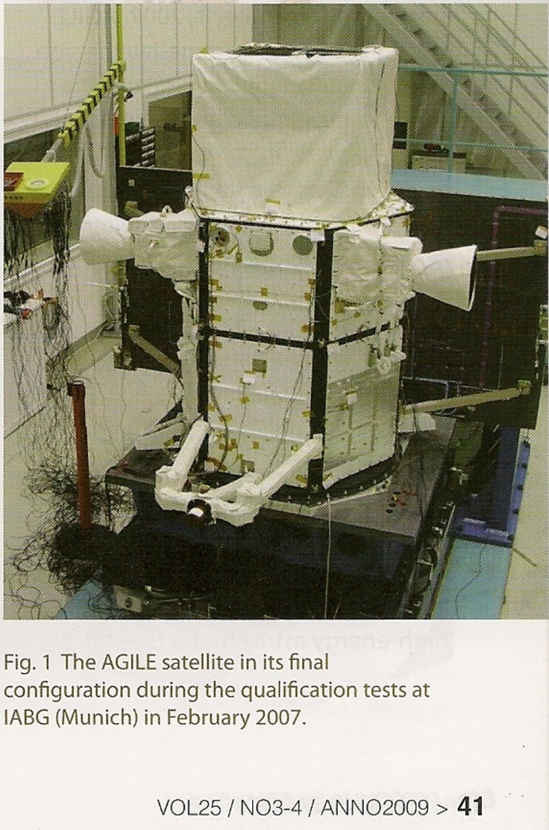

Fig. 1 The AGILE satellite in its final configuration during the qualification tests at IABG (Munich) in February 2007.

The Gamma-Ray Imaging Detector (GRID) is sensitive in the energy range 30 MeV–50 GeV, and consists of a silicon-tungsten tracker, a cesium iodide calorimeter, and an anticoincidence system. The GRID trigger logic and data acquisition system (based on anticoincidence, tracker and mini-calorimeter information) allows for an efficient background discrimination and inclined photon acceptance. The GRID is designed to achieve an optimal angular resolution (source location accuracy ~ 6′–12′ for intense sources), a very large FOV (~ 2.5 sr), and an average exposure per day at 100 MeV comparable with that of FERMI for sources within 30–40 degrees from the main axis direction.

The silicon tracker (ST) is made of a sequence of tungsten converters of 250 μm thickness and silicon detector tiles assembled in 40 x 40 cm^2 planes. The silicon strip pitch is 121 μm.

The silicon-tungsten tracker is based on the gamma-ray conversion into electron/positron pairs. The photon energy and direction are reconstructed by adding the energy momentum vectors of the two charged particles. The neutral incoming photon is converted in a thin foil of high-Z material (tungsten) and the positions of the scattering charged particles are given by electric signals obtained by charge-sensitive channels made of silicon microstrips.

A gamma-ray "telescope" is obtained by adding in sequence many converter-detector planes (see figs. 2 and fig. 3). The optimization of the AGILE tracker required a compromise among different requirements: 1) a small radiation length per single converter plane (to keep the electron/positron scattering as small as possible), 2) a radiation length for the complete tracker of order unity to provide a gamma-ray conversion probability near 0.7. These two requirements and a sustainable number of electronics channels (limited by power consumption) finally lead to the AGILE optimized configuration of 12 total planes. The total readout channel number for the GRID tracker is 36 864. Both digital and analog information (charge deposited in the Si-microstrips) is read by dedicated front-end electronics. Special trigger logic algorithms implemented on-board (Level-1 and Level-2) are necessary for 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. The positional resolution obtained by the AGILE ST is excellent, being below 40 μm for a large range of particle incidence angles. This spatial resolution is unprecedented in space gamma-ray astrophysics and is the basis for obtaining an optimal Point Spread Function (PSF) at gamma-ray energies. The AGILE tracker is the smallest and most compact gamma-ray imaging detector ever developed and operational in the energy range 30 MeV–50 GeV.

The AGILE GRID was calibrated during an intensive campaign at the Beam Test Facility of the INFN Laboratories of Frascati during November 2005. A gamma-ray photon beam has been produced by Bremsstrahlung in the energy range 1–600 MeV and the GRID has been tested and calibrated for different geometries and energy selections [8,9].

The hard–X-ray imager (super-AGILE, SA) is also a unique feature of the AGILE instrument (for a complete description, see ref. [10]). This ultra-light imager (a few kg) is placed on top of the gamma-ray tracker and is sensitive in the 18–60 keV band. It has an optimal angular resolution (6 arcmin) and a good sensitivity over a ~1 sr field of view (10–20 mCrab on-axis for a 1-day integration). It is a coded-mask system made of a silicon detector plane and a thin tungsten mask positioned 14 cm above it (fig. 4). The detector plane is organized in four independent square silicon detectors plus dedicated front-end electronics. 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 18–60 keV, with a large field of view (FOV ~1 sr); 2) a good sensitivity (10–15 mCrab between 18–60 keV for 50 ks integration, and ~1 Crab for a few seconds integration). SA is aimed at the hard–X-ray detection simultaneously with gamma-ray detection of high-energy sources with excellent timing capabilities (a few microseconds). The SA on-board acquisition logic provides essential GRB parameters such as time, position and preliminary flux estimates.

The mini-calorimeter (MCAL) is the third AGILE detector [11]. It is an array of cesium iodide bars which can be operated as part of the GRID, but also work independently to detect GRBs and other transients in the 300 keV–100 MeV energy range with excellent timing capability. MCAL is composed of 30 CsI(Tl) scintillator bars, each one 15 x 23 x 375 mm^3 in size, arranged in two orthogonal layers, for a total thickness of 1.5 radiation lengths. The bar readout of the scintillation light is accomplished by two custom PIN photodiodes (PD) positioned at the bar ends. The readout circuits have been optimized for best noise performance, fast response, low power consumption and wide dynamic range. For each bar, the energy and position of an interacting gamma-ray or ionizing particle can be determined combining the signals of the two PDs. Figure 5 shows the integrated MCAL during laboratory testing.

MCAL can operate: 1) in a GRID mode, following an ST trigger; 2) in a BURST mode, for which each bar behaves as an independent self-triggering gamma-ray detector in the energy range 300 keV–100 MeV. These data

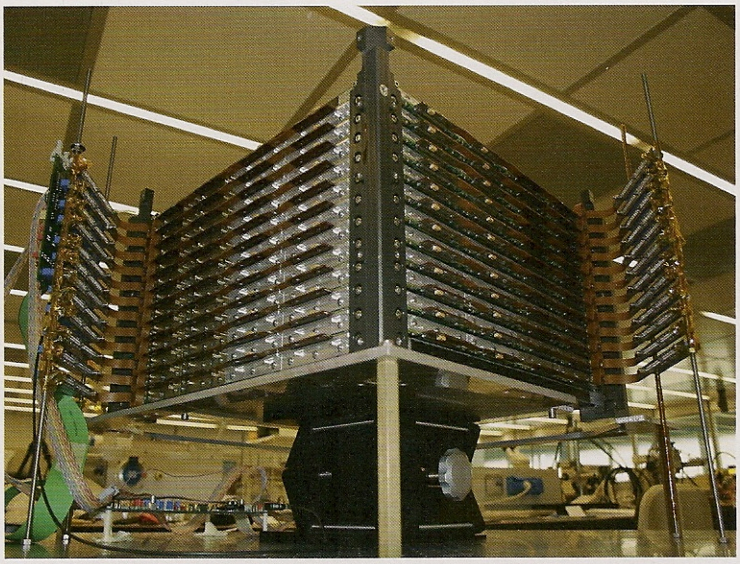

Fig. 3 The AGILE silicon-tungsten tracker during the final assembly and test phase in the INFN laboratories of Trieste and MIPOT facility (June 2005).

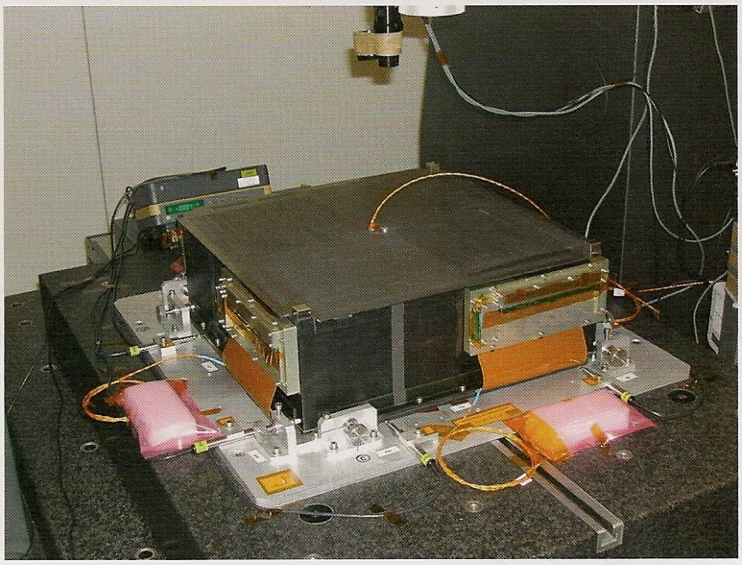

Fig. 4 The AGILE hard–X-ray imager (Super-AGILE) during the final assembly and test phase in the INAF-IASF Rome laboratories (June 2005). The tungsten mask is clearly visible on top of the detector.

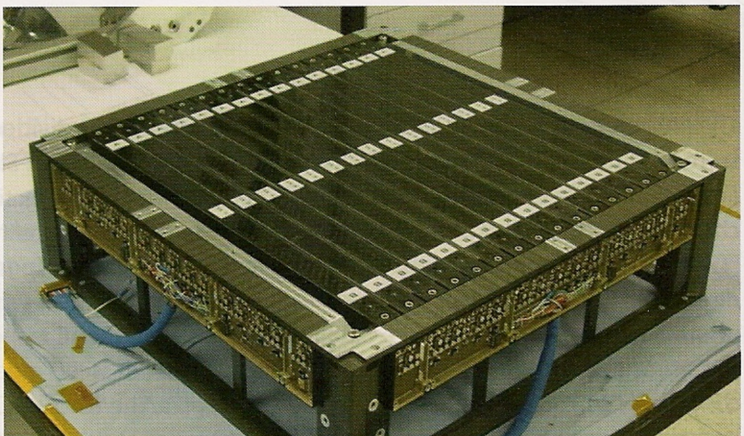

Fig. 5 The Integrated MCAL during the assembly and test phase (carried out with the INAF-IASF Bologna supervision) at the Thales-Alenia-Space (former LABEN) laboratories (March 2005). The upper layer of the detection plane and two preamplifiers boards are clearly visible.

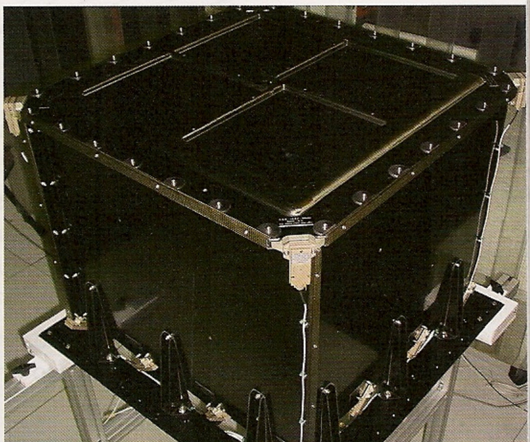

Fig. 6 The integrated anticoincidence system during the assembly and test phase at the INAF-IASF-Milan laboratories (March 2005).

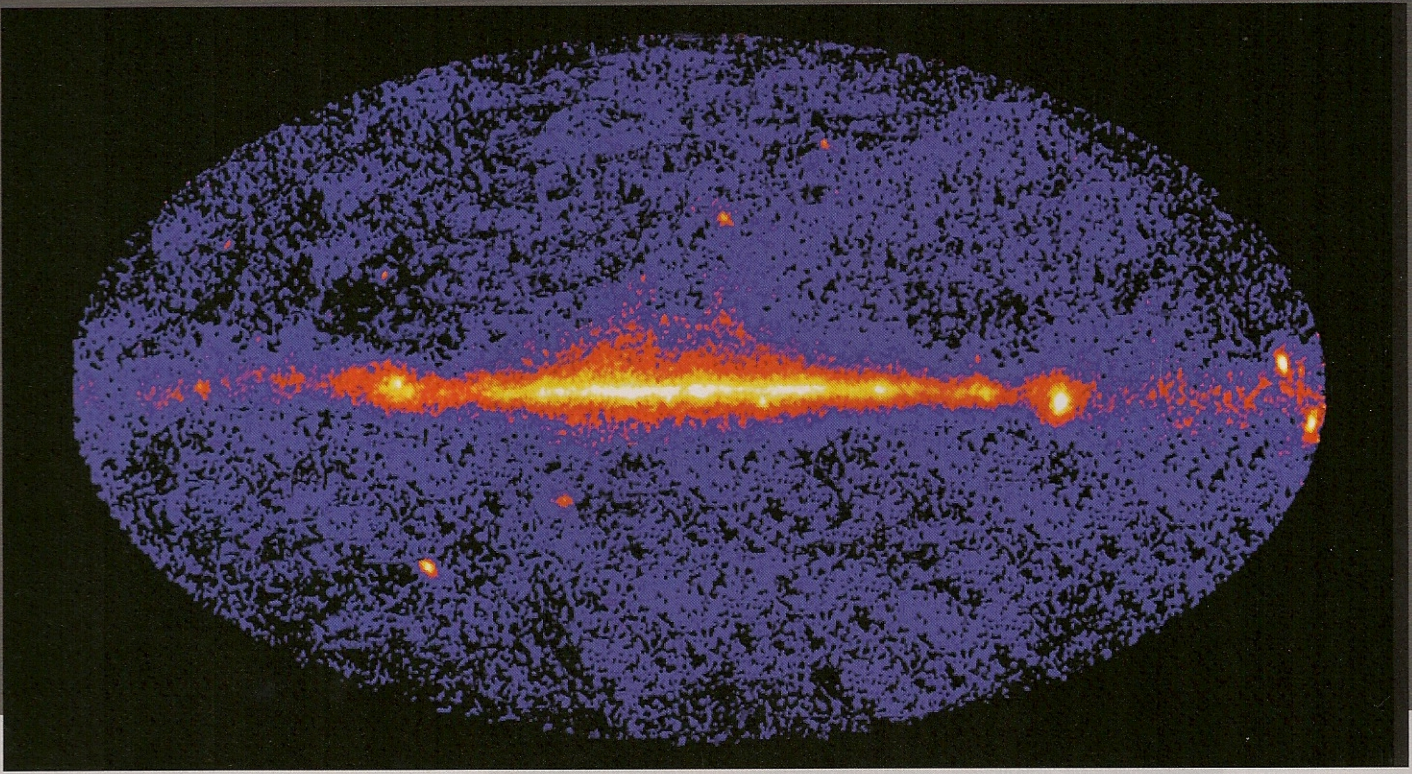

Fig. 7 The gamma-ray sky in galactic coordinates above 100 MeV imaged by AGILE during its first 9 months of operations (July 2007-March 2008).

are processed by a dedicated trigger logic to detect impulsive variations in count rates. During nominal operations, both operating modes are active at the same time. Operating in BURST mode, the main goal of MCAL is the detection of fast transients and GRBs at MeV energies with microsecond time resolution. MCAL is not an imaging system and it can provide only limited information on burst direction. However, it currently operates as an all-sky detector. For transients outside of the Super-AGILE or GRID fields of view, a localization from other satellites is usually required to perform the spectral analysis (since the detector's response is direction dependent).

The anticoincidence (AC) system surrounds the GRID and Super-AGILE and is aimed at a very efficient charged-particle background rejection [12]; it also allows a preliminary direction reconstruction for triggered photon events through a special data acquisition system. The AC system completely surrounds all AGILE detectors (Super-AGILE, Si-tracker and MCAL). Each lateral face is segmented in three plastic scintillator layers connected to photomultipliers placed at the bottom of the panels.
The AC achieves an optimal charged-particle background rejection with a particle detection inefficiency lower than 10^{-4}. The AC detector, shown in fig. 6, is divided into two main elements, named Top-Side AC and Lateral-Side AC, respectively. With the aim of providing a preliminary direction reconstruction for triggered photon events, each of the 4 sides forming the Lateral-Side AC is segmented and encompasses 3 independent detectors. The whole AC then consists of 13 independent charged-particles detectors. The flight-unit of the AC detector has been extensively calibrated at the CERN PS T9 beam line in August 2004, in the course of a dedicated run, by using particles (mainly pions) having a momentum set at 8 GeV/c.

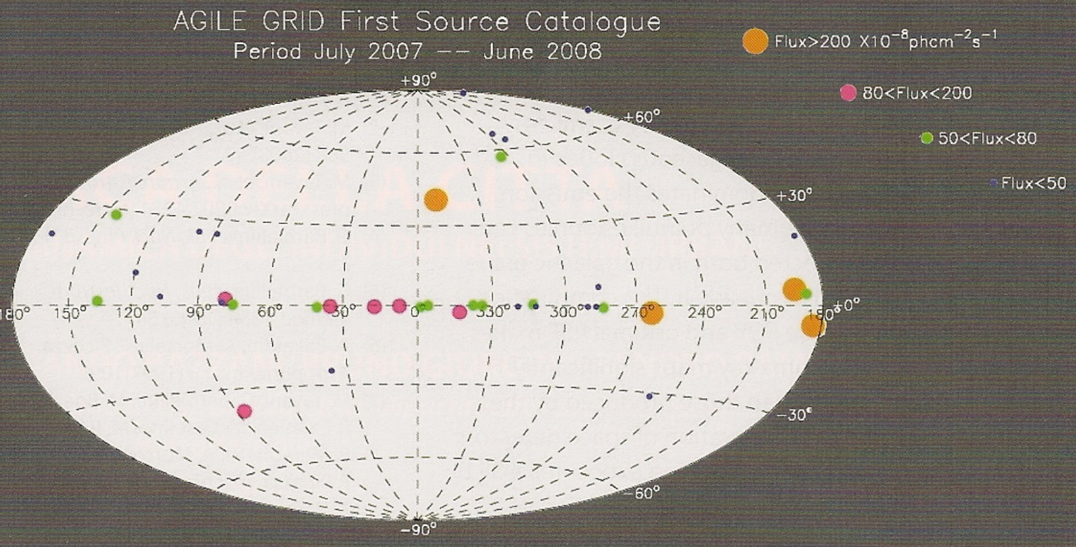

Fig. 8 First AGILE-GRID Catalog of high-confidence gamma-ray sources detected during the first 12 months of operations [15]. All data collected during the period July 2007 – June 2008 were used to optimize source positions and fluxes. The color code refers to the average gamma-ray intensity.

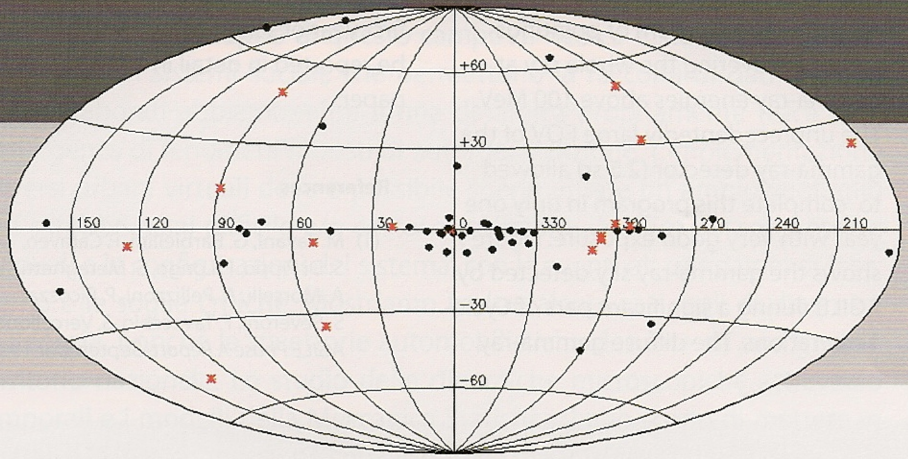

Fig. 9 Sources detected by the Super-AGILE hard–X-ray imager in the energy range 18–60 keV during the first year of operations (July 2007 – July 2008). The majority of these sources is variable on short timescales. GRBs and SGRs are marked in red.

5 The Data Handling system

A sofisticated Data Handling (DH) system based on a single DSP processor is required for the on-board management of the readable channels in the ST and Super-AGILE (~ 40 000) and for the multi-task instrument sub-systems [3, 13, 14]. 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 (~ 5 μs) and requires a signal in at least three out of four contiguous tracker planes, and a proper combination of fired Si-microstrip and AC signals. Level-2 data processing includes a GRID readout and pre-processing, "cluster data acquisition" (analog and digital information). The GRID deadtime turns out to be ~ 200 μs and is dominated by the tracker readout. The charged particle and albedo-photon background passing the Level-1 trigger level is measured in orbit to be ~ 100 Hz. The on-board Level-2 processing has the task of further reducing this background by a factor of 10. Off-line ground processing and filtering of GRID data reduce the particle and albedo-photon background rate above 100 MeV to the expected rate of ~ 0.02 events/s.

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 timing of all these detectors is excellent and can achieve sub-millisecond time tagging and burst trigger. Operating with a dynamic range of GRB triggers from sub-milliseconds to seconds is a crucial feature of the AGILE on-board DH system.

6 First year of operation

AGILE started scientific observations after the completion of the satellite in-orbit test and commissioning phase (early July 2007). AGILE carried out a Science Verification and Calibration phase during the months of July-November 2007. On December 1, 2007 the AGILE Cycle-1 started and continued until November 30, 2008. On December 1, 2008 the Cycle-2 started and is ongoing at the time of this writing, with the satellite performing nominally. Satellite data are transmitted first to the ASI ground station in Malindi (Kenya), and then transferred to the Satellite Operations Center in Fucino. The scientific data are transferred, preprocessed [16], and stored at the AGILE Data Center (ADC) located at the ASI Science Data Center in Frascati. The ADC is in charge of all scientific activities related to the analysis, archiving, distribution of AGILE data, and management of the AGILE Guest Observer Program.

During Cycle-1 AGILE carried out an ambitious program of pointings aimed at covering the whole sky at gamma-ray energies above 100 MeV. The unprecedentedly large FOV of the gamma-ray detector (2.5 sr) allowed to complete this program in only one year with very good exposure. Figure 7 shows the gamma-ray sky detected by AGILE during a significant part of Cycle-1 operations. The diffuse gamma-ray emission originating by cosmic-ray interactions in gaseous clouds in the Galaxy dominates the emission. However, many pointlike sources can be detected both in the galactic plane as well as outside it. The combination of a large FOV and optimal PSF makes the gamma-ray maps significantly sharper than those produced by the previous generation of space detectors (*e.g.*, EGRET). For long exposures AGILE can reach an angular resolution of 0.1 degrees at 100 MeV.

Figures 8 and 9 show the positions of high-confidence sources detected by AGILE during the first 12 months of operations in the gamma-ray and hard–X-ray ranges, respectively.

The main results obtained during the first year of scientific operations will be reported in detail in a forthcoming paper.

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Marco Tavani obtained his Laurea in Physics at the University of Rome (1983) and the Ph.D. in theoretical astrophysics at Columbia University in New York (1989). His research activity continued at UC Berkeley, Princeton University and Columbia University during the years 1990-1997. He then moved back to Italy at the CNR-IASF Institute in Milan in 1997 and was appointed Research Director in 1999. He is teaching Space Physics at the University of Rome Tor Vergata. His reasearch interests include the theory of high-energy relativistic sources, compact binaries and GRBs. He is the Principal Investigator of the ASI space mission AGILE dedicated to gamma-ray astrophysics.