Chin. J. Astron. Astrophys. Vol. 3 (2003), **Suppl.**, 517–522
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

The Gamma-Ray Imaging Detector AGILE: Scientific Goals and Instrument Performance

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Abstract AGILE is an ASI Small Scientific Mission dedicated to gamma-ray astrophysics, which will detect and image photons in the 30 MeV –50 GeV and in the 10–40 keV energy ranges. It is planned to be operational during the second half of 2005 and it will be the only mission entirely dedicated to high energy astrophysics above 30 MeV during the period 2005–2007. We discuss the expected performance of the AGILE space detector, which scientific program emphasizes a quick response to gamma-ray transients and multiwavelength studies of gamma-ray sources.

Key words: gamma rays: observations – gamma rays: theory – instrumentation: detectors

1 INTRODUCTION

High energy gamma-ray astrophysics is entering a new challenging phase of discovery. Our present knowledge of cosmic gamma-ray emission and phenomena above 30 MeV is based mainly on the remarkable results obtained by EGRET (Hartman et al. 1999). Nearly 300 gamma-ray sources above 30 MeV were detected by EGRET, however only a small fraction, $\sim 30\%$, is currently identified. Many sources are variable or transient on short timescales and our understanding of many high energy phenomena is still preliminary. To make progress a new generation of gamma-ray experiments is needed, aimed at reaching:

– excellent gamma-ray imaging with a large Field-of-View (FOV);
– simultaneous broad-band spectral information;
– microsecond timing;
– efficient transient detection and alerts.

AGILE (*Astro-rivelatore Gamma a Immagini LEggero*) is the next Small Scientific Mission dedicated to high-energy gamma-ray astrophysics supported by the Italian Space Agency (ASI). It is planned to be operational during the second half of 2005 and it will be the only mission entirely dedicated to source detection above 30 MeV during the period 2005–2007. The AGILE

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instrument is highly innovative and allows simultaneous observations in the hard X-ray and in the γ-ray bands, being designed to detect and image photons in the 10–40 keV and 30 MeV – 50 GeV energy ranges (Tavani et al. 2003). Despite its simplicity and moderate cost, the AGILE scientific performance will provide a unique set of data, suitable to fulfil the mission scientific objectives. AGILE data will be very important for joint multiwavelength studies of high-energy sources.

2 THE AGILE MISSION

The AGILE scientific instrument is based on the state-of-the-art technology of solid state Silicon developed by the Italian INFN laboratories (Barbiellini et al. 2001), and consists of three detectors with broad band detection capabilities, see Fig. 1. The AGILE Gamma-Ray Imaging Detector (**GRID**), sensitive in the 30 MeV –50 GeV energy range, consists of a Silicon Tracker, a Cesium Iodide Mini-Calorimeter and a segmented Anticoincidence System. The additional hard X-ray detection capability is provided by the Super-AGILE detector (**SA**) (Lapshov et al. 2001) which consists of four additional Silicon detectors and an ultra-light coded mask system positioned on top of the first GRID tray. The CsI Mini-Calorimeter (**MCAL**) will also detect events independently of the GRID. The energy range for this non-imaging detector is 0.3–200 MeV and will provide spectral and accurate timing information on transient events (Auricchio et al. 2001). The AGILE instrument is described in detail in Tavani et al. (2003). AGILE is characterized by excellent spatial resolution ($\sim 40\ \mu$m) and timing capabilities (absolute timing of $\sim 2\ \mu$s and deadtimes of $\sim 100\ \mu$s for the GRID and of $\sim 5\ \mu$s for Super-AGILE and the Mini-Calorimeter), and by an unprecedently large field of view covering $\sim 1/5$ of the entire sky at energies above 30 MeV. The AGILE Science Program will be focused on prompt response to gamma-ray transients and alert for follow up multiwavelenth observations.

3 SCIENTIFIC PERFORMANCE OF THE AGILE INSTRUMENT

Field of View. AGILE will have, among other features, an unprecedently large field of view: ~ 3 sr, larger than EGRET by a factor $\sim 4-5$. Fig. 2 shows on the right a possible set of AGILE pointings (lasting 2 months each) which would cover the whole sky with only 6 pointings due to the large AGILE FOV. For comparison on the left we show the EGRET Cycle 1 pointings, lasting 18 months.

Angular Resolution and Effective Area. The AGILE Point Spread Function (PSF) is obtained by applying the AGILE REconstruction Method (AREM), integrated with Kalman filter algorithms for track identification (Pittori & Tavani 2002). AREM is a 3-Dimensional gamma-ray direction reconstruction method applicable to high resolution Si-Tracker detectors. As shown in Fig. 3 left panel, the AGILE 3-D PSF on-axis is better than that of EGRET by a factor of ~ 2 above 400 MeV. AGILE effective area is characterized by an excellent performance off-axis, Fig. 3 right panel, being smaller by only a factor of 2 than EGRET for on-axis events, despite the much smaller geometric area. The comparison between AGILE and EGRET effective areas, for fixed directions as a function of photon energy is shown in Fig. 4.

Temporal Resolution. AGILE detectors will have optimal timing capabilities, see Fig. 5. The on-board GPS system allows to reach an absolute time tagging precision for individual photons near 1 μs. Instrumental deadtimes will be unprecedently small for gamma-ray detection. The GRID deadtime will be lower than 200 μs improving by about three orders of magnitude the performance of EGRET.

Sensitivity. AGILE average sensitivity above the Galactic plane expected to be better than EGRET by a factor ~ 2, with a greatly enhanced probability of detecting transient sources. The typical sensitivity of the possible 1-year AGILE all-sky survey of Fig. 2 is 2×10^{-7} ph cm^{-2} s^{-1}.

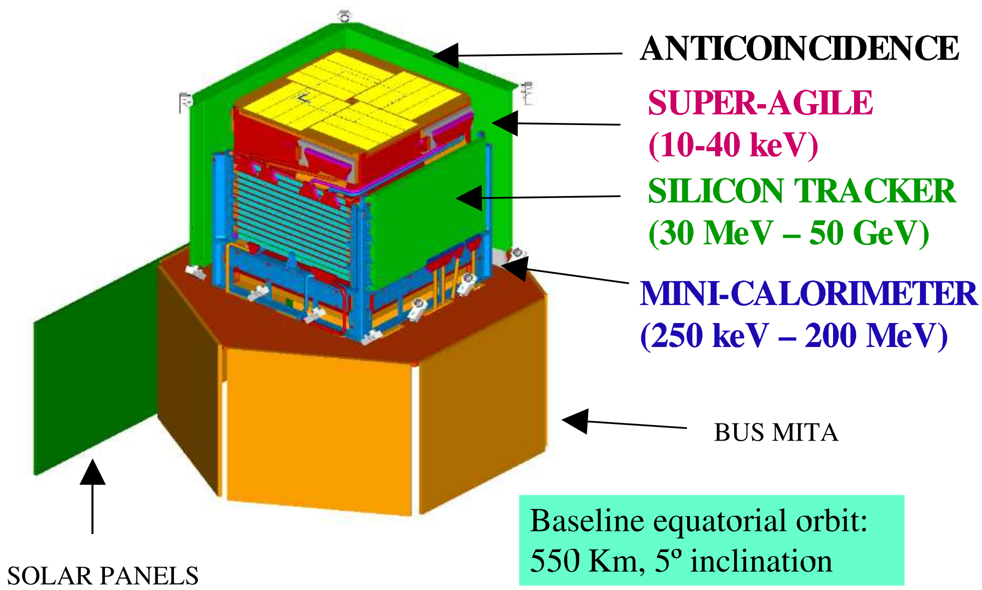

Fig. 1 The AGILE instrument size is $\sim 63 \times 63 \times 58.5$ cm^3 for a total payload weight of ~ 130 kg.

Deep exposures for selected sky regions can be obtained by a program with repeated overlapping pointings. For selected regions, AGILE can then achieve a sensitivity larger than EGRET by a factor of $\sim 4-5$ at the completion of its program, reaching a minimum detectable flux near 5×10^{-8} ph cm^{-2} s^{-1} (Pellizzoni et al. 2001; Vercellone et al. 2001).

4 GAMMA-RAY ASTROPHYSICS WITH AGILE

We summarize here the main AGILE's scientific objectives.

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 transients and AGN 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 intense gamma-ray flares; (4) hard X-ray/gamma-ray correlations. A program for joint AGILE and ground-based monitoring observations is being planned. We conservatively estimate that for a 3-year program AGILE will detect a number of AGNs ~ 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 ~ 7 years of operations. This number was limited by the EGRET FOV and sensitivity and not by the GRB emission mechanism. The GRID detection rate of GRBs is expected to be

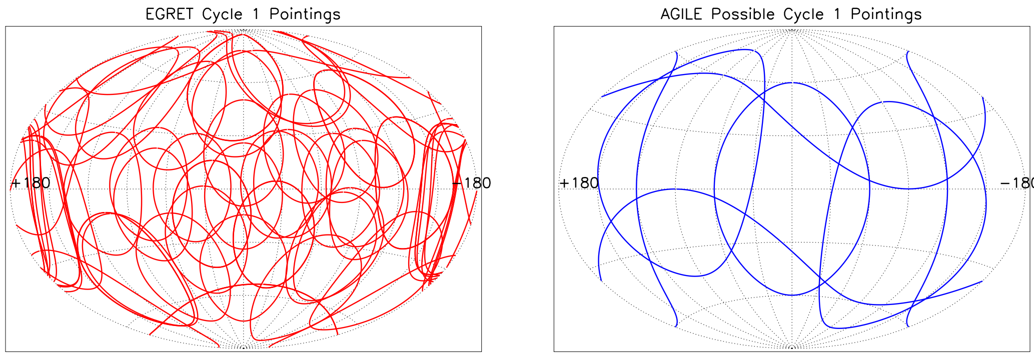

Fig. 2 EGRET Cycle 1 all-sky survey, ~ 56 pointings, compared to a corresponding possible AGILE Cycle 1, which would cover the whole sky with only 6 pointings.

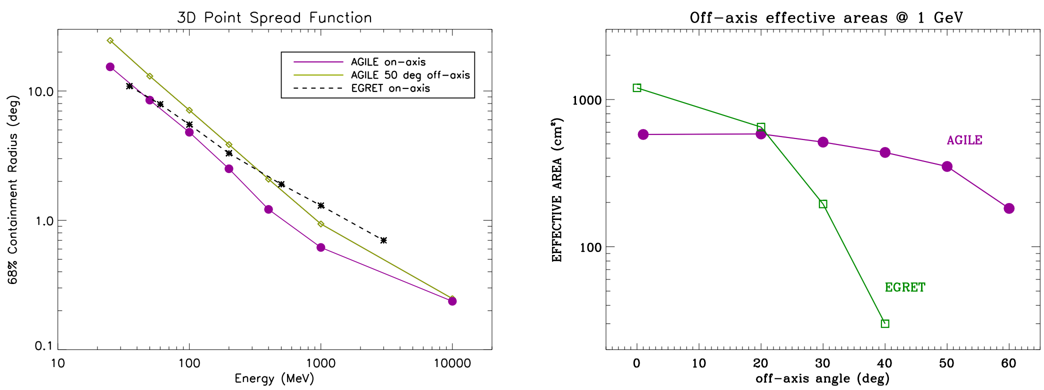

Fig. 3 Left panel: AGILE 3-D PSF. Right panel: AGILE effective area as a function of the off-axis angle.

a factor of ~ 5 larger than that of EGRET, i.e., more than 5–10 events/year. The small GRID deadtime allows a better study of the initial phase of GRB pulses.

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, MCAL and Super-AGILE.

Diffuse Galactic 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 Galactic 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 in several ways: (1) searching for pulsed gamma-ray emission from the ~ 30 new young pulsars recently

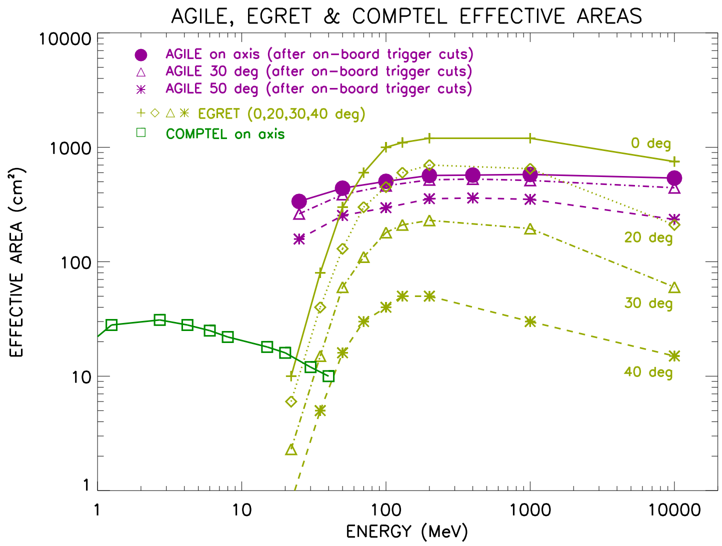

Fig. 4 AGILE effective area as a function of energy for several off-axis angles.

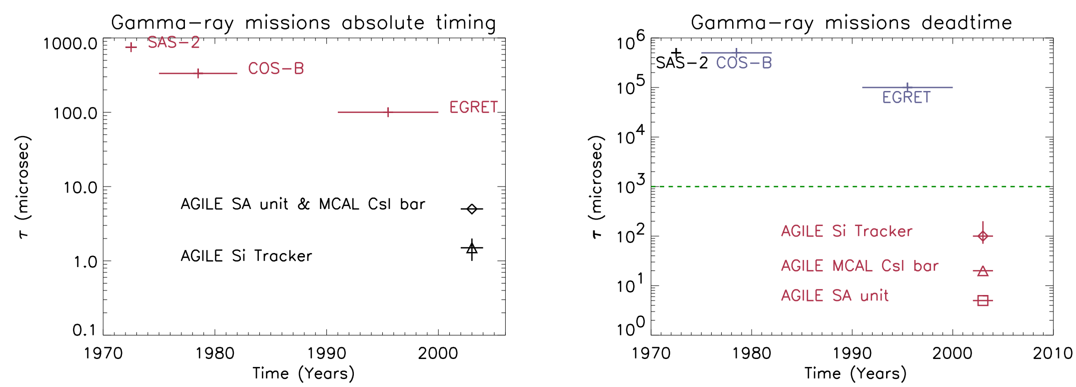

Fig. 5 AGILE excellent timing capability.

discovered in the Galactic plane; (2) improving photon statistics for gamma-ray period searches; (3) detecting possible secular fluctuations of the gamma-ray emission from neutron star magnetospheres; (4) 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.

Galactic sources, new transients. AGILE will contribute to the investigation of a new class of unidentified non-blazar gamma-ray variable sources in the Galactic plane, such as the mysterious GRO J1838-04 and the variable 2CG 135+1. A large number of gamma-ray sources near the Galactic plane are unidentified and can be monitored on timescales of months/years. Also Galactic X-ray sources can produce detectable gamma-ray emission for favorable source states and geometries, and a TOO program is planned to follow-up new discoveries of microquasars.

Fundamental Physics: Quantum Gravity. AGILE detectors are suited for Quantum Gravity studies. The existence of sub-millisecond GRB pulses lasting hundreds of microseconds opens the way to study QG delay propagation effects with the AGILE detectors. If these ultra-short GRB pulses originate at cosmological distances, sensitivity to the Planck's mass can be reached.

5 CONCLUSIONS

The gamma-ray Universe faces us with many challenges. The highly innovative ASI Mission AGILE, open to the international astrophysics community, will provide crucial data to successfully pursue these challenges, and substantially advance the understanding of the most energetic phenomena of our Universe.

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