The space gamma-ray observatory AGILE

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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. The mission AGILE (*Astro-rivelatore Gamma a Immagini LEggero*) is an innovative, cost effective gamma ray mission selected by the Italian Space Agency (ASI) as first payload of the Program for Small Scientific Missions. It is designed to detect and image gamma-ray sources in the energy range 30 MeV–50 GeV and operate as an Observatory open to the international community. Primary scientific goals include the study of AGN's, gamma ray bursts, Galactic sources, unidentified gamma ray sources, solar flares and diffuse gamma ray emission. AGILE is planned to be operational during the years 2002-2005. It will an ideal 'bridge' between EGRET and GLAST, and support space observations and ground based multiwavelength studies of high energy sources

1. Introduction

Gamma-rays can reach the Earth from remote regions of the Universe, providing crucial information on the cosmological evolution of energetic sources. Many gamma-ray sources are transient, often on timescale of 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 CGRO-EGRET discoveries [1] of gamma-ray blazars, pulsars, high-energy gamma-ray bursts and a large class of unidentified high-energy sources have given us a new view of the high-energy sky , while raising fundamental new questions about the origin, evolution and destiny of high-energy sources. It is now clear that to address these questions it is necessary to study the gamma-ray emission and correlate these observations with those at other wavelengths; increase the sample of high-energy sources detected, including objects at large distance; measure high-energy spectral turnovers in a large sample of sources distributed over a large range of redshifts; determine if the average spectrum is consistent with that of the isotropic component of the high-energy gamma-ray background. To fulfill these task some next generation experiments has been proposed. For the low energy part of the spectrum (20 MeV-50 GeV) the use of the satellite experiments is unavoidable and at higher energies is highly desirable to have an overlap with the ground experiments and to have a monitoring and an alert system with a large field of view for all the transient phenomena.

2. the AGILE detector

The AGILE design was derived from a refined study of the GILDA project [2, 3] that was

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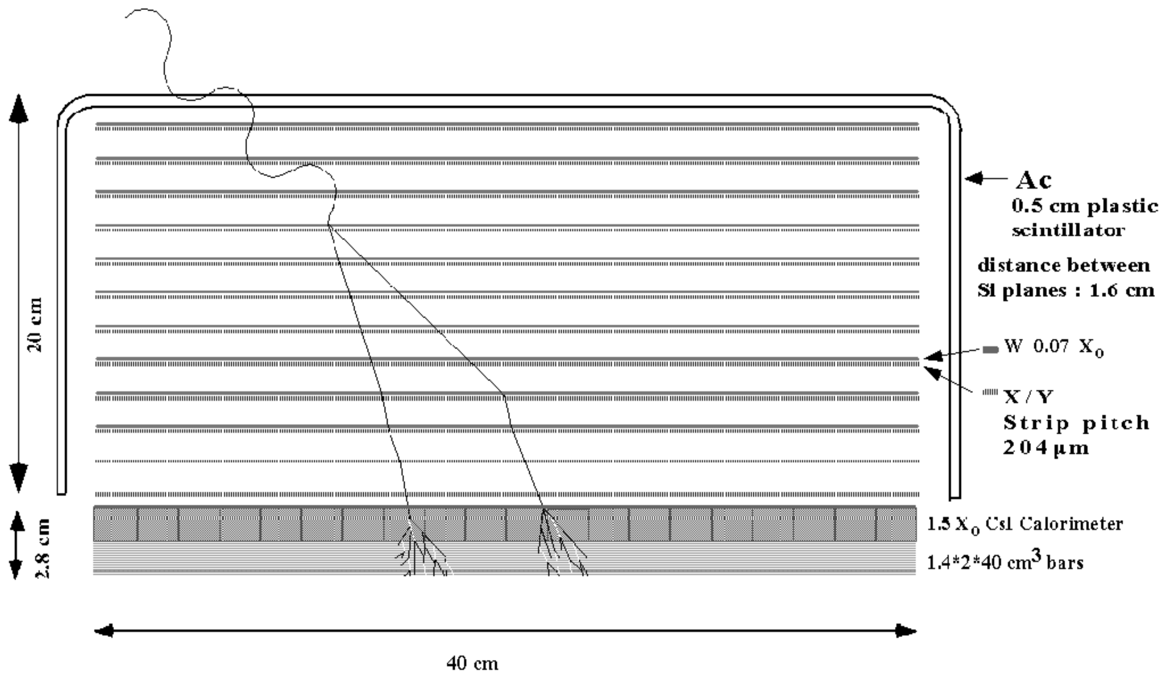

Figure 1. Schematic lateral view of the AGILE baseline instrument.

based on the techniques developed for the Wizard silicon calorimeter [4], already successful flown in balloon experiments [5] and in space experiments such as *Nina* [6] and Sileye and in the the proposed experiment *Pamela* [7].

Fig.1 shows schematically the baseline AGILE configuration. The instrument has a height of $\sim$ 35 cm, a Si–plane geometric area of 40·40 cm^2, a weight of $\sim$ 60 kg and is made of the following elements:

• **Silicon-tracker**: the gamma-ray photon pair converter, is made of 14 Si-planes with microstrip pitch equal to 121 μm. The fundamental unit is a module of area 9.5*9.5 cm^2, thickness 380 μm with 768 microstrips and 384 electronic channels; half of the strips are left floating in order to minimize the number of electronic channel. The first 10 planes are made of three layers: a first layer of tungsten (0.07 X_0) for gamma-ray conversion and two Si-layers with microstrips orthogonally placed to obtain the plane coordinates of charged particles produced by gamma-rays pair creation interactions. For each Si-layer there are then 1536 electronic channels. Since the readout trigger requires at least three Si-planes out of four to be activated, two more Si-planes are inserted at the bottom of the tracker without tungsten layer. The total readable channel number for the baseline tracker is then 43008. The distance between planes equals 1.6 cm as obtained by Montecarlo simulation optimization. The AGILE photon tracking system has an on-axis total radiation length larger than 0.84 X_0 for an interaction probability above 1 GeV near 48%. Special algorithms applied off-line to telemetered data will allow an optimal reconstruction of the photon incidence angle.

• **light calorimeter**: made of two orthogonal planes of CsI bars, for a total radiation length of 1.5 X_0 on-axis. The signal from each CsI bar is collected by photodiodes for each exposed face. The aims of the calorimeter are: *(i)* obtaining additional information on the energy deposited in the CsI bars by particles produced in the tracker, and therefore contributing to the determination of the total photon energy; *(ii)* discriminating between hadronic and electromagnetic showers; *(iii)* obtaining spectral and intensity information in the energy band $\sim$ $0.2 - 20$ MeV for impulsive energy releases caused by GRBs and solar flares. We note that the problem of particle backscattering for this configuration is much less severe than in the case of EGRET and this, together with the segmented anticoincidence described below and with first and second level triggers, will allows an efficient detection of photons above 10 GeV for AGILE.

• **anticoincidence system**: aimed at both charged particle background rejection and preliminary direction reconstruction for triggered photon events. The AC system hermetically surrounds the tracker and mini-calorimeter, and is segmented with three overlapping plastic scintillator layers (0.5 cm thick) for each lateral face. The signal from each scintillator layer is collected laterally by optical fibers attached to photomultipliers at the bottom. A single plastic scintillator layer (0.5 cm thick) constitutes the top-AC that is read by four light photomultipliers placed inside the AC structure and supported by the four corners of the structure frame. A more complete description and references can be found at *http://www.roma2.infn.it/infn/agile/* and related sites therein.

We are also studying the possibility of adding an ultra-light coded mask imaging system sensitive in the energy band ~ 10-40 keV on top of AGILE. Super-AGILE is an innovative concept, exploiting silicon technology to simultaneously detect gamma-rays and hard X-rays coded mask imaging.

The expected performances of AGILE in angular and energy resolution, as derived from Montecarlo simulations, are shown in Fig.2 and 3 . The energy resolution is obtained by combining the information on the particle energy deposited in the tracker and mini-calorimeter. However, the scattering multiple particularly relevant for particle energies near and below 500 MeV can provide additional information on the individual particle energies and therefore a further improvement of the photon energy resolution.

Fig.4 show an example of pointings and accessible sky area for both EGRET and AGILE.

In figure 5 is shown the AGILE sensitivity compared with present and future detectors

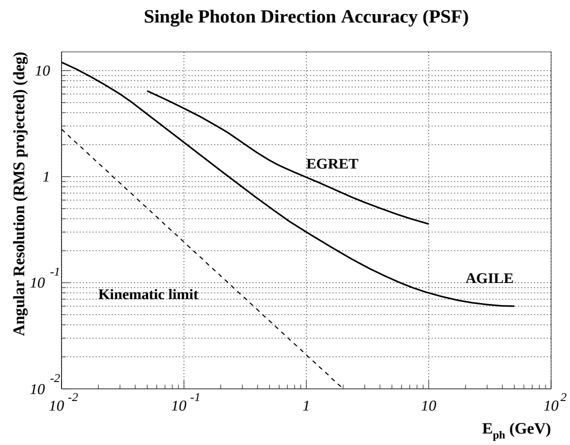

Figure 2. Single photon angular resolution (67% containment angular distance) as a function of photon energy for AGILE and EGRET.

in the gamma-ray astrophysics range. The predicted sensitivity of a number of operational and proposed Ground based Cerenkov telescopes, is given for a 50 hour exposure on a single source. EGRET, GLAST, MILAGRO and AGILE sensitivity is shown for one year of all sky survey. Because of a better angular resolution despite a smaller effective area, AGILE will reach a sensitivity comparable to that of EGRET for the same on-source integration time (typically 2-3 weeks). After one year of large FOV pointings by AGILE, the average accumulated exposure (in $cm^2\ s$) per typical source will be four times larger than that of EGRET. This implies a typical integrated gamma-ray flux threshold lower by a factor of 2 than EGRET. Note that on ground only MILAGRO and ARGO will observe more than one source simultaneously. In figure 6 is shown the Energy range covered by the different experiments versus the activity period. AGILE will covered an interval were no other experiments will be present.

Table 1: Comparison between AGILE and EGRET

	EGRET	AGILE
Mass	1830 Kg	55 kg
Energy band	20 MeV – 30 GeV	30 MeV – 50 GeV
Field of view	0.15 π sr	0.8 π sr
Angular resolution*	$\lesssim 1°$	$\lesssim 0.5°$
Sensitivity for pointlike sources† (ph $cm^{-2}s^{-1}$)	6×10^{-8} 1×10^{-8} 1×10^{-9}	5×10^{-8} (0.1 GeV) 5×10^{-9} (1 GeV) 1×10^{-9} (10 GeV)
Required pointing reconstruction	~10 arcmin	~1-2 arcmin

(*) FWHM of the PSF calculated for a photon flux above 100 MeV $5 \times 10^{-7}\ ph\, cm^{-2}\ s^{-1}$ (typical of a high-galactic latitude source), incidence angle less than 20° and average spectral energy 460 MeV (for a photonic spectrum $\sim E^{-2}$).

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

3. Scientific Objectives

Because of the large field of view AGILE will discover a large number of gamma-ray transients, monitor known sources, and allow rapid multiwavelength follow-up observations because of a dedicated data analysis and alert program. Table 1 summarizes the expected performance of AGILE vs. those of EGRET.

• *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. 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.

•*Diffuse Galactic and extragalactic emission.* The AGILE good angular resolution and large field of view 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 in several ways: (1) improving photon statistics for gamma-ray period searches (2) detecting possible secular fluctuations of the gamma-ray emission from neutron star magnetospheres; (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.

• *Galactic sources, new transients.* A large number of gamma-ray sources near the Galactic plane are unidentified. Recently, evidence for the existence of a new class of gamma-ray sources in addition to isolated pulsars and blazars has been obtained [8]. These enigmatic sources are concentrated in the Galactic plane, are strongly time variable and not associated with blazars (such as GRO J1838-04). Time variability cannot be due to isolated pulsars [10] and known radio-quiet AGNs cannot be the counterparts of these inidentified sources (otherwise a large number of these radio-quiet sources would have been discovered at large Galactic latitudes).

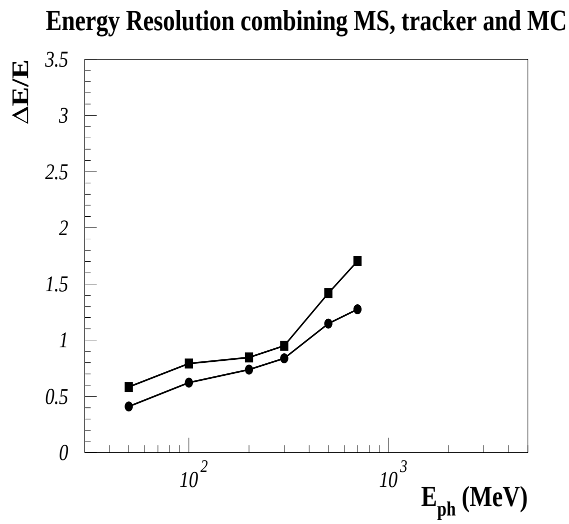

Figure 3. Energy resolution for photons that convert in the first (bullets) and in the last (squares) plane of the tracker as a function of photon energy for AGILE.

These sources, can be monitored on timescales of months/years by AGILE.

• *Gamma-ray bursts.* About ten GRBs have been detected by EGRET's spark chamber during ~ 7 years of operations [9]. This number appears to be limited by the EGRET FOV and sensitivity and not by the GRB emission mechanism. GRB detection rate by AGILE is expected to be a factor of ~ 5 larger than that of EGRET, i.e., $\geq$ 5-10 events/year). The small AGILE deadtime (≥ 100 times smaller than that of EGRET) allows a better study of the initial phase of GRB pulses. The remarkable discovery by EGRET of 'delayed' gamma-ray emission up to ~ 20 GeV from GRB 940217 [11] 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 backscattering. 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.

• *Solar flares.* During the last solar maximum, solar flares were discovered to produce prolonged

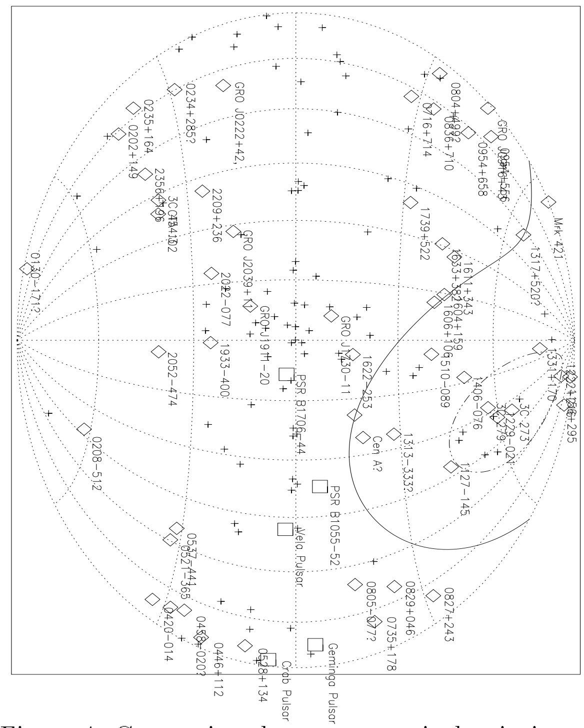

Figure 4. Comparison between a typical pointing of the field near 3C 279 by AGILE (area within the solid line circle of radius equal to 60°) and EGRET (area within the dashed line of radius equal to 25°)

high-intensity gamma-ray outbursts. AGILE will be operational during part of the next solar maximum and several solar flares may be detected.

4. Conclusion

AGILE ideally conforms to the faster, cheaper, better philosophy adopted by space agencies for scientific missions. The AGILE mission is being planned as an *Observatory* with a scientific program of managementof data to be made available to the Italian and international community on a competitive basis. Detection and monitoring of extragalactic and galactic gamma-ray sources with prompt data analysis of transient alert are the primary goals of the baseline AGILE detector. AGILE's data will provide crucial

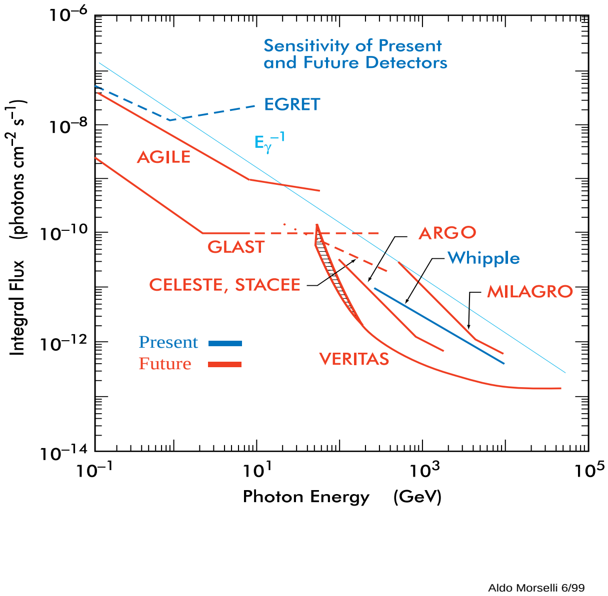

Figure 5. Sensitivity of present and future detectors in gamma-ray astrophysics

support for quicklook data analysis and fast communication of transient events for ground-based observations and several space missions including AXAF, INTEGRAL, XMM, ASTRO-E, SPECTRUM-X. No other gamma-ray mission in the band above ~ 30 MeV is planned before GLAST. AGILE will therefore 'fill the gap' during the next years.

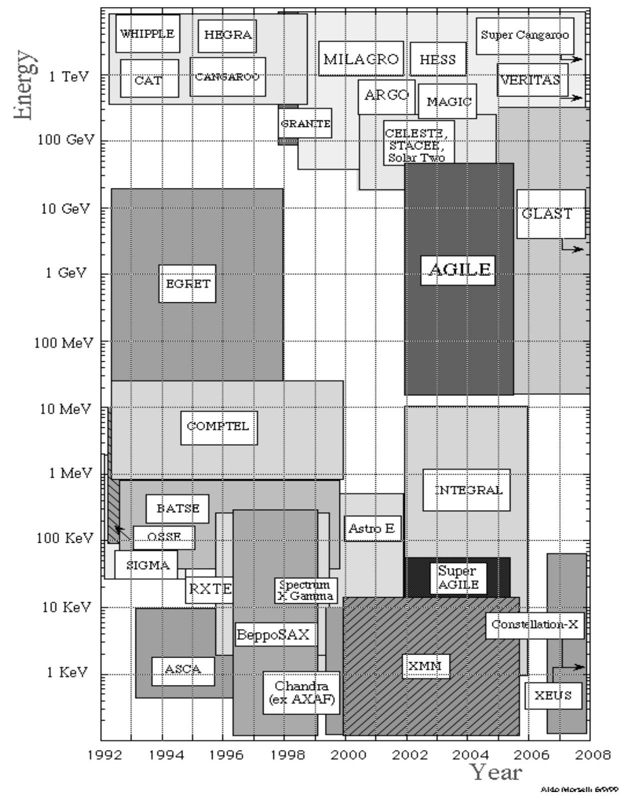

Figure 6. Timeline schedule versus the energy range covered by present and future detectors in X and gamma-ray astrophysics

REFERENCES

1 Thompson, D.J., *et al.*, ApJSS, 101, (1995), 259.
2 G.Barbiellini, et al, Nucl.Instrum. & Methods, 354, (1995), 547.
3 A. Morselli, et al, XXIV Int. Cosmic Ray Conf., 3, (1995), 669.
4 M.Bocciolini, et al., Nuclear Instruments & Methods, A333, (1993), 560.
5 M. Boezio, *et al.*, ApJ, 487, (1997), 415.
6 Bakaldin A., *et al.*, Astroparticle Physics 8, (1997), 109.
7 Barbiellini G., *et al.*, XXIV Int. Cosmic Ray Conf., OG 10.3.7, v.3, (1995), 591, Roma.
8 Tavani, M. *et al.*, ApJ, 479, (1997) , L109.
9 Schneid, E.J. *et al.*, AIP Conf. Proc. no. 384, (1996), 253
10 Ramanamurthy, P.V., *et al.*, ApJ, 450, (1995), 791.
11 Hurley, K., *et al.*, Nature, 372, (1994), 652.