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The Science of AGILE: Part II

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In this paper (Part II) we discuss the expected scientific performance of the AGILE mission, focusing on the large FOV, the spatial resolution and PSF of the γ-ray imager, and the crucial capability of simultaneous hard-X and γ-ray imaging with $\sim 1 - 3$ arcmin resolution.

1. AGILE AND GAMMA-RAY ASTROPHYSICS

High energy gamma-ray astrophysics is considered one of the most challenging fields of study in the foreseeable future. Nearly 300 gamma-ray sources above 30 MeV were detected by EGRET, of which only a small fraction, $\sim 30\%$, currently identified. Despite its simplicity and moderate cost, the AGILE scientific performance will provide a unique set of data, suitable to fulfil the mission scientific objectives. 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 (MCAL) and a segmented Anticoincidence System. The AGILE instrument is described in more detail in paper Part I, these Proceedings [1].

The 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 $\sim 1/5$ of the entire sky per each pointing;
- **excellent timing capability**, with absolute time tagging of uncertainty near 1 μs and very small deadtimes;
- **a good sensitivity for point sources**, comparable to that of EGRET for *on-axis* sources, and substantially better for *off-axis* sources;

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- **excellent sensitivity to photons in the energy range ~30-100 MeV**, with an effective area above 200 cm^2 at 30 MeV [1];
- **a very rapid response to gamma-ray transients and gamma-ray bursts (GRB)**, obtained by a special Quicklook Analysis program and coordinated ground-based and space observations.

AGILE will also have detection and imaging capabilities in the hard X-ray range provided by the **Super-AGILE** detector. It consists of an additional plane of four Silicon square detectors positioned on top of the GRID Tracker. 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 burst alert and on-board trigger capability.

2. SCIENTIFIC PERFORMANCE OF THE AGILE INSTRUMENT

2.1. Field of view

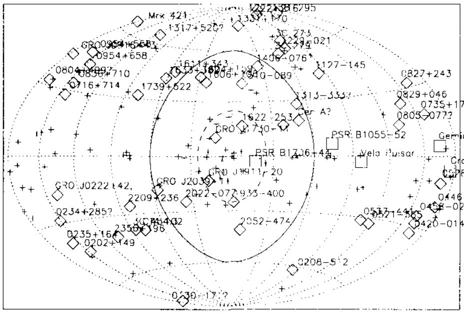

Figure 1. Comparison between the AGILE GRID (solid line circle of radius equal to 60°) and EGRET (dashed line of radius equal to 25°) fields of view for a typical pointing of the Galactic center region.

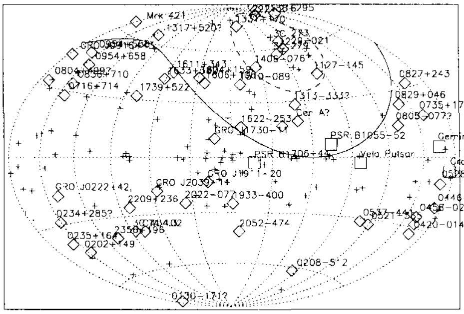

Figure 2. Comparison between the AGILE GRID (solid) and EGRET (dashed) fields of view for a pointing centered at the blazar 3C 279

AGILE will have, among other features, an unprecedently large field of view: FOV ~ 3 sr, larger than previous gamma-ray experiments such as EGRET by a factor ~ 5. Figs. 1 and 2 show typical AGILE pointings. Relatively bright AGNs and Galactic sources flaring in the gamma-ray energy range above a flux of 10^{-6} 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 ~ 2 − 3 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 ~1 GRB/month can be detected and imaged in the gamma-ray range by the GRID.

2.2. Spatial resolution

The AGILE Tracker makes a crucial use of the analog signal from the Si-microstrips. The AGILE Tracker layout consists of Si-microstrip pitch of 121μm, for a floating strip readout system of 242μm pitch. The "floating strip" configuration was chosen to achieve an excellent spatial resolution while minimizing the number of readout channels and the detector power consumption. By using the analog information of charge deposit in Si-microstrips, the spatial resolution achieved by this readout configuration is excellent: below $40\mu m$ for a wide range of photon incidence angles [2].

2.3. Angular resolution

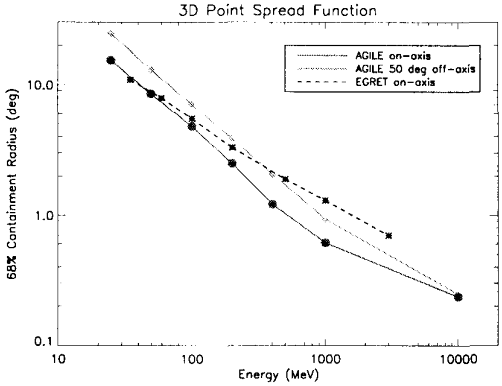

Figure 3. Three dimensional PSF (68% containment radius) as a function of photon energy for AGILE-GRID (on-axis and 50° off-axis) and EGRET (on-axis).

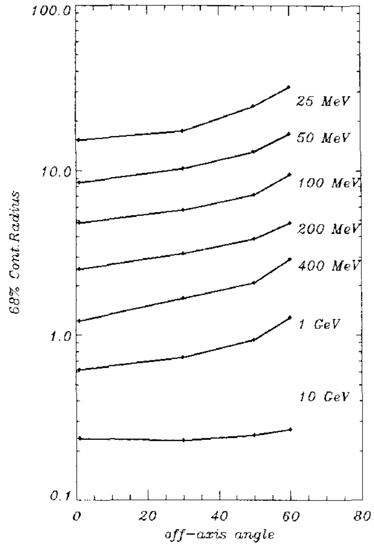

Figure 4. Three dimensional AGILE-GRID PSF (68% containment radius) as a function of off-axis angle at fixed energy values.

The γ-ray direction reconstruction is based on the physical process of pair production, and is obtained from the identification and the detailed analysis of the electron/positron tracks stemming from a common vertex. The direction reconstruction should take into account the effect of multiple Coulomb scattering and the distribution of the total energy of the incident photon between the e^+/e^- particles. Before AGILE this was done by applying a "2-D projection method", that is by analyzing separately the two tracks projections in the ZX and ZY views. Contrary to previous γ-ray experiments, this simplified 2-D projection method would not be a good approximation for AGILE because of its large field of view and very good intrinsic spatial resolution. The Agile REconstruction Method (AREM) is a general method for γ-ray direction reconstruction applicable to high-resolution Silicon Tracker detectors in space [3,4]. AREM correctly addresses three points of the analysis which become relevant for off-axis incidence angles:

- intrinsic ambiguity in the identification of the 3-dimensional e^+/e^- tracks;
- proper identification of the 3-dimensional pair production plane and reconstructed direction;
- careful choice of an energy weighting scheme for the 3-dimensional tracks.

As shown in Fig. 3, by integrating the AREM method with a dedicated track reconstruction method based on the Kalman filter technique [5], the AGILE 3-D Point Spread Function (PSF) on-axis is found to be better than that of EGRET by a factor of ~ 2 above 400 MeV. The PSF relatively smooth behaviour as a function of the off-axis angle at fixed energy values is shown in Fig.4.

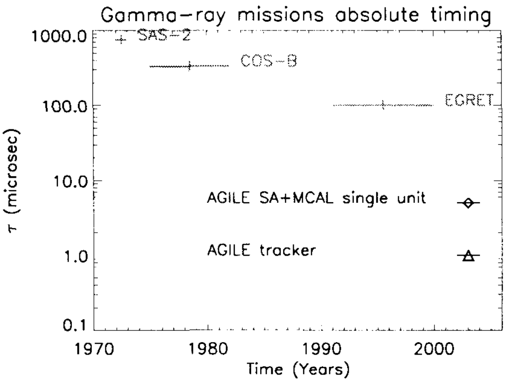

Figure 5. Single photon time-tagging uncertainty (τ) of AGILE and previous gamma-ray detectors.

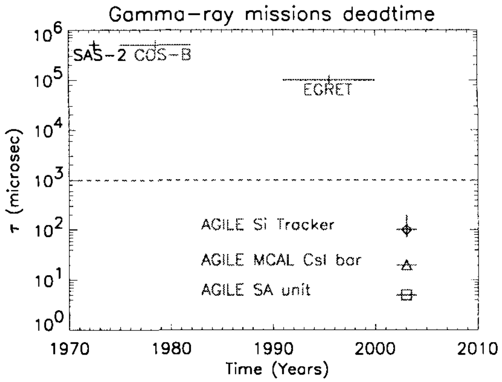

Figure 6. Instumental deadtimes (τ) for the AGILE detectors and previous gamma-ray instruments.

The GRID configuration will achieve a PSF with 68% containment radius better than ∼ 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 GRBs at the Crab flux level and for longer transients at the few tens of mCrab flux level).

2.4. 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 in the Mini-Calorimeter. Because of the AGILE high spatial resolution, 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.

MCAL 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 ∼ 100 MeV band with ∼1 MeV energy resolution (for 2-diode detections) [6].

2.5. 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 MCAL 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 almost 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 MCAL elements and 16 Super-AGILE elements) the effective dead-

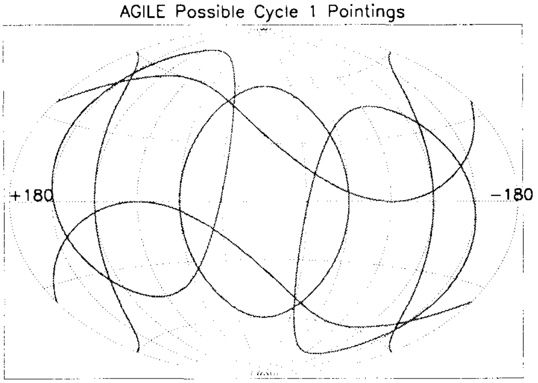

Figure 7. Possible set of AGILE pointings, lasting 2 months each, covering all sky with only 6 pointings in approximately one year.

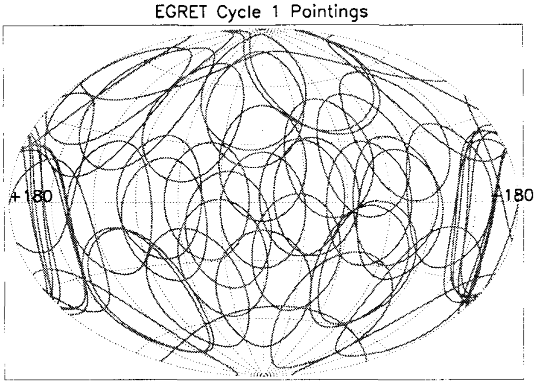

Figure 8. EGRET Cycle 1 pointings during the first 18 months of life of the instrument.

times will be much less than those for individual units. Furthermore, the 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 is crucial for AGILE high-precision timing investigations.

Figs. 5 and 6 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.

2.6. Sky exposure and sensitivity maps

Fig. 7 shows a possible set of AGILE pointings (lasting 2 months each) covering all sky with only 6 pointings. For comparison, in Fig. 8 we show the EGRET Cycle 1 pointings during 18 months and the two corresponding exposure distributions are shown in Fig. 9.

The sensitivity map corresponding to the 1-year AGILE all-sky survey of Fig. 7 is shown in Fig. 10 [7]. The distribution of the flux limits is presented in Fig. 11 showing that the typical sensitivity of the survey is $\sim 2 \times 10^{-7}$ph cm^{-2} s^{-1}. Due to the larger AGILE FOV, after a 1-year all-sky pointing program, we expect the average exposure for a generic source to be larger by a factor of $\sim 3 - 4$ compared to what obtained by EGRET during the same time period. Therefore, AGILE average sensitivity for a generic gamma-ray source above the Galactic plane is expected to be better than EGRET by a factor ~ 2 with a greatly enhanced probability of detecting transient sources. 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 $\sim 5 \times 10^{-8}$ph cm^{-2} s^{-1}.

AGILE simulated intensity map (above 100 MeV) for the same 6-pointings set, assuming the gamma-ray background and the sources of the 3rd EGRET catalogue, is presented in Fig. 12 [8]. Finally in Fig. 13 we show a comparison of simulated 95% contour levels of GRID (solid curve) and Super-AGILE (square) positioning of a relatively weak off-axis AGN, with data obtained by EGRET VP227.0 (dotted curve). We assumed a 1-week effective exposure time for a gamma-ray source of flux above 100 MeV equal to 30×10^{-8} ph cm^{-2} s^{-1} positioned at $\sim$ 28 degrees off-axis for AGILE and at $\sim$ 17 degrees off-axis

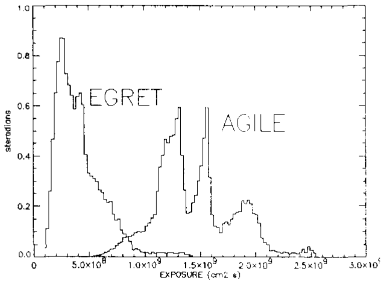

Figure 9. AGILE and EGRET exposure distributions corresponding to the two all-sky surveys discussed in the text.

for EGRET [8].

3. SIMULTANEOUS HARD X/γ RAY INFORMATION

The Super-AGILE imaging coded mask detector 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 $\sim$ 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 (5σ) for a 50 ksec integration time);
- **accurate localization (~1-2 arcmins) of GRBs and other transient events**; the expected GRB detection rate is $\sim 1-2$ per month;
- **excellent timing**, with absolute time tagging uncertainty and deadtime near $5\,\mu$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.

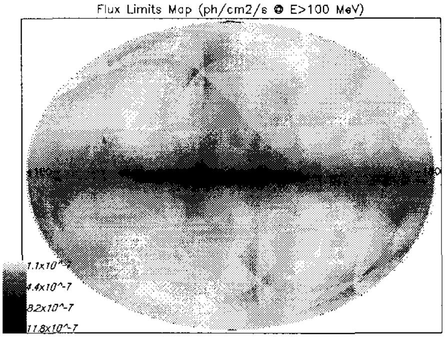

Figure 10. Sensitivity map corresponding to the 6-pointings AGILE all-sky survey of Fig. 7.

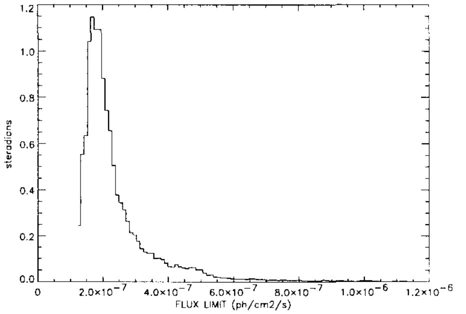

Figure 11. The distribution of flux limits for AGILE.

Given the sensitivities of the GRID and Super-AGILE, simultaneous hard X-ray/gamma-ray information is anticipated to be obtainable for GRBs, blazars with strong X-ray continuum such as 3C 273 and Mk 501, Galactic jet-sources with favorable geometries, unidentified variable gamma-ray sources. Fig. 14 shows the expected scientific performance of Super-AGILE for GRB detection capability [9]. Super-AGILE is able to obtain on-board sky images and GRB positions within a few arcminutes in $\sim 10-15$ sec. It would be extremely important for the astrophysics community to have a transceiver on board of AGILE, not yet in the baseline, allowing fast communication of GRB coordinates within $\sim 10-20$ sec.

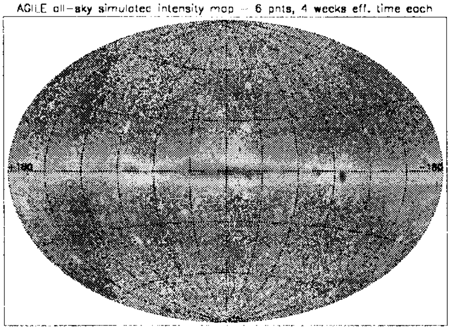

Figure 12. AGILE simulated intensity map (above 100 MeV) corresponding to the 6-pointings AGILE all-sky survey.

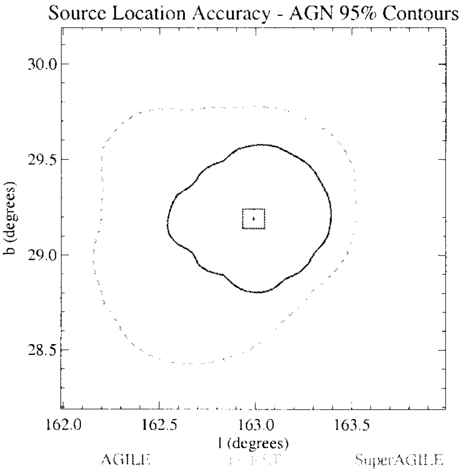

Figure 13. Comparison of simulated 95% contour levels of AGILE GRID (solid curve) and Super-AGILE (square) positioning of a relatively weak off-axis AGN, with data obtained by EGRET (dotted curve).

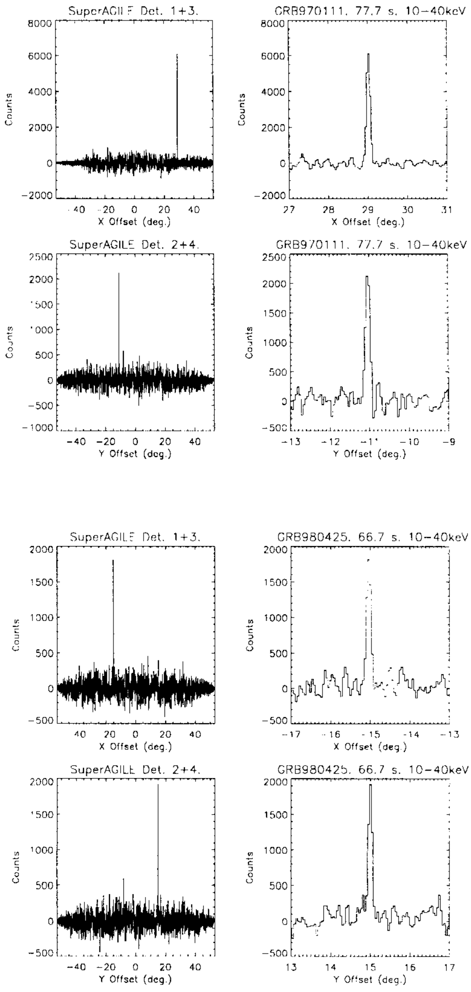

Figure 14. Simulation of the Super-AGILE (SA) GRB detection capability. *Upper four-panels*: Simulated detection of the intense GRB 970111 as detected by the SA x and y coordinate units and corresponding enlargement. *Lower four-panels*: Simulated detection of the relatively weak GRB 980425 (note the different counts scale).

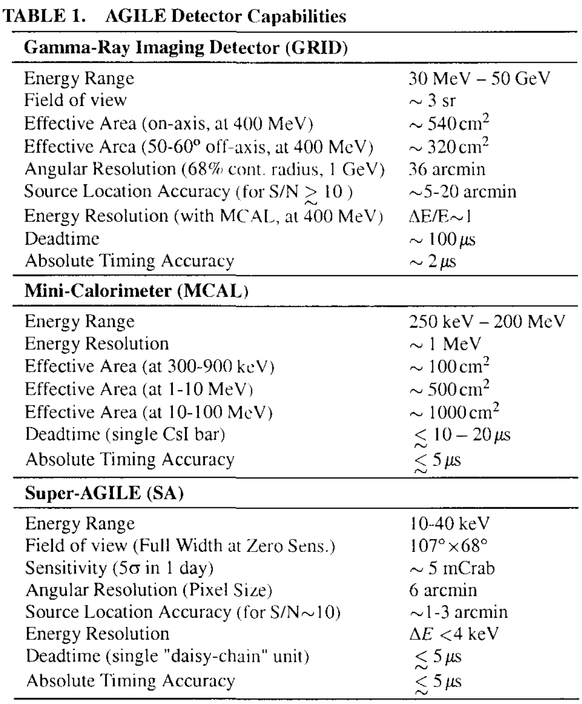

TABLE 1. AGILE Detector Capabilities

Gamma-Ray Imaging Detector (GRID)	
Energy Range	30 MeV – 50 GeV
Field of view	~ 3 sr
Effective Area (on-axis, at 400 MeV)	$\sim 540\,\mathrm{cm}^2$
Effective Area (50-60° off-axis, at 400 MeV)	$\sim 320\,\mathrm{cm}^2$
Angular Resolution (68% cont. radius, 1 GeV)	36 arcmin
Source Location Accuracy (for $S/N \gtrsim 10$)	$\sim$5-20 arcmin
Energy Resolution (with MCAL, at 400 MeV)	$\Delta E/E \sim 1$
Deadtime	$\sim 100\,\mu s$
Absolute Timing Accuracy	$\sim 2\,\mu s$
Mini-Calorimeter (MCAL)	
Energy Range	250 keV – 200 MeV
Energy Resolution	~ 1 MeV
Effective Area (at 300-900 keV)	$\sim 100\,\mathrm{cm}^2$
Effective Area (at 1-10 MeV)	$\sim 500\,\mathrm{cm}^2$
Effective Area (at 10-100 MeV)	$\sim 1000\,\mathrm{cm}^2$
Deadtime (single CsI bar)	$\lesssim 10 - 20\,\mu s$
Absolute Timing Accuracy	$\lesssim 5\,\mu s$
Super-AGILE (SA)	
Energy Range	10-40 keV
Field of view (Full Width at Zero Sens.)	$107° \times 68°$
Sensitivity (5σ in 1 day)	~ 5 mCrab
Angular Resolution (Pixel Size)	6 arcmin
Source Location Accuracy (for $S/N \sim 10$)	$\sim$1-3 arcmin
Energy Resolution	$\Delta E < 4$ keV
Deadtime (single "daisy-chain" unit)	$\lesssim 5\,\mu s$
Absolute Timing Accuracy	$\lesssim 5\,\mu s$

Figure 15. AGILE detector capabilities are summed up in this table.

4. CONCLUSIONS

The gamma-ray Universe faces us with many challenges. We believe that AGILE developed as an highly innovative Italian Mission, open to the international high-energy astrophysics community, will provide crucial data to successfully pursue these challenges, and substantially advance the understanding of the most energetic phenomena of our Universe.

REFERENCES

1. V. Cocco et al., "The Science of AGILE: Part I", these proceedings.
2. Barbiellini, G. et al., GAMMA 2001 Symposium, AIP Conf. Proceedings 587 (2001) 754 and Nucl. Instr. and Meth. A, *in press.*
3. C. Pittori and M.Tavani, astro-ph/0202221, Nucl. Instr. and Meth. A, *in press.*
4. C. Pittori et al., GAMMA 2001 Symposium, AIP Conf. Proceedings 587 (2001) 739.
5. A. Giuliani, Laurea Dissertation, Università degli Studi di Pavia, (2001).
6. N. Auricchio et al., GAMMA 2001 Symposium, AIP Conf. Proceedings 587 (2001) 749.
7. A. Pellizzoni et al., GAMMA 2001 Symposium, AIP Conf. Proceedings 587 (2001) 759.
8. S. Vercellone et al. GAMMA 2001 Symposium, AIP Conf. Proceedings 587 (2001) 764.
9. I. Lapshov et al., GAMMA 2001 Symposium, AIP Conf. Proceedings 587 (2001) 769.