The AGILE Mission: X-Ray and Gamma-Ray Astrophysics of Galactic Sources

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ABSTRACT. The AGILE Mission is dedicated to gamma-ray astrophysics above 30 MeV during the period 2005-2007 and beyond. The main characteristics of AGILE are: (1) excellent imaging and monitoring capabilities simultaneously in the γ-ray (30 MeV – 30 GeV) and hard X-ray (15-45 keV) energy ranges (reaching 1-3 arcminute source positioning for intense sources); (2) very large fields of view for the gamma-ray imager (2.5 sr) and hard X-ray imager (0.8 sr); (3) very good timing (improving by almost three orders of magnitude the instrumental deadtime for γ-ray detection compared to EGRET); and (4) optimal imaging and triggering capability for high-energy transients. We emphasise here the prospects for detecting and monitoring gamma-ray and hard X-ray sources in our Galaxy. The AGILE scientific program is being developed emphasizing a quick response to gamma-ray/hard X-ray variable sources and multiwavelength studies of Galactic objects.

1. Introduction

Our Galaxy is hosting a large number of energetic sources and phenomena copiously producing X-rays and gamma-rays. Radiation in the energy range between a few tens of MeV and tens of GeV provides unique information on the most energetic processes originating near relativistic compact objects as well as on the generation, propagation and interaction of energetic cosmic rays. Hundreds of X-ray and gamma-ray sources have been detected in our Galaxy by high-energy instruments during the past two decades: accreting and non-accreting compact objects (especially neutron stars and black holes), isolated and binary pulsars, the mysterious Galactic center region, and the still unidentified population(s) of gamma-ray emitting objects. Despite the growing number of sources and discovered phenomena, many puzzles remain to be solved. The gamma-ray data provide a picture of a very active Galaxy producing and accelerating the large number of cosmic rays we observe directly or indirectly through the diffuse Galactic gamma-ray emission (Hunter 1997), see Fig. 1. This diffuse emission concentrated in the Galactic plane dominates the gamma-ray sky above 30 MeV as detected by all gamma-ray missions: OSO-3, active in the late Sixties (Kraushaar et al. 1972), the SAS-2 satellite active during the period Nov. 1972 – July 1973 (Fichtel et al. 1975), the European Cosmic-Ray Satellite COS-B operating during the period August 1975 – April 1982 (Swanenburg et al., 1981), and the EGRET instrument on board of the *Compton Gamma-Ray Observatory* (CGRO) active during the period April 1991 – June 2000 (Fichtel 1994, Thompson et al. 1993).

Pointlike gamma-ray sources stand out against the diffuse emission background concentrated near the Galactic plane and at the central bulge. Thanks to the remarkable results obtained by the EGRET instrument (that for the first time surveyed the whole sky) we know about 300 gamma-ray sources above 30 MeV including about 70 Active Galactic Nuclei (AGNs) (Hartman et al. 1997, Hartman et al. 1999, Thompson et al. 1995, Thompson et al. 1996), and five isolated pulsars (PSRs) listed in the 3rd EGRET Catalog (Hartman et al. 1999). Yet, the majority of gamma-ray sources are unidentified. Fig. 1 (bottom panel) shows the population of unidentified gamma-ray sources and the handful of isolated gamma-ray pulsars listed in the 3rd EGRET Catalog. A clear concentration of these sources in the Galactic plane and bulge is an indication of a local origin: their ultimate nature is still a mystery.

Addressing and resolving fundamental questions regarding the gamma-ray emission processes of Galactic sources require a substantial improvement in detecting performance of gamma-ray instruments. Three are the areas of improvement that need to be addressed by future gamma-ray missions:

- **optimal angular resolution and a large field of view (FOV)** for gamma-ray detection above 30 MeV (apparently contradictory requests !), improving EGRET error boxes and FOV at least by a factor of 4;

- **microsecond-level timing** for photon tagging, and deadtimes for gamma-ray detection substantially below 1 ms;

- **simultaneous X-ray and gamma-ray detection, and on-board triggering and alert capability for fast X-ray transients**.

We summarize in this paper the main characteristics and scientific prospects for the study of Galactic sources by the AGILE Mission (Tavani et al. 2001, 2003). It turns out that the AGILE instrument configuration is quite different from that of GLAST (e.g., Michelson 2003), both in terms of size and source detection capabilities. AGILE and GLAST instrument configurations are differently optimized. The large area of the GLAST gamma-ray imaging detector (LAT) with a full-size calorimeter, and the operations foreseen for a decade will lead to a large exposures of the whole sky and the detection of very faint and persistent sources with good spectroscopic data. The science goals of a Small Mission such as AGILE are differently focussed as discussed in this paper. It is important to note that the gamma-ray imagers of AGILE and GLAST (both based on solid state technology of Silicon microstrip detectors) are expected to produce equivalent Point-Spread Functions between 100 MeV and 1 GeV, with similar capabilities for the positioning of *γ-ray transients lasting a few days* during phases of the GLAST sky-scanning mode (see Fig. 15). Both Missions can then be considered *complementary for the detection of transient sources* and aimed at reaching an **"arcminute gamma-ray astrophysics"** with different methods: by the combined X-gamma-ray imaging in case of AGILE, and by a large effective area at gamma-ray energies in case of GLAST. It will be exciting to see both Missions developing and reaching their scientific goals during the next years.

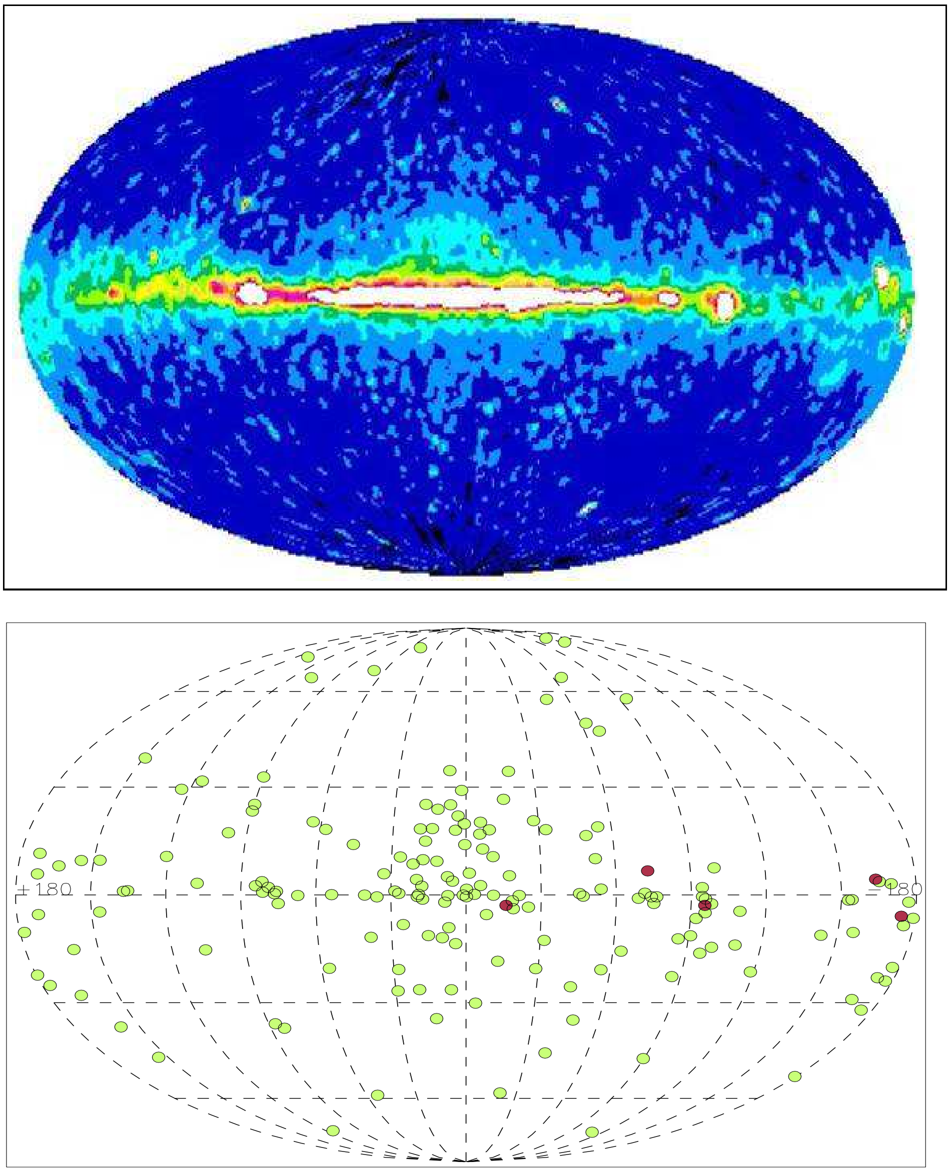

Fig. 1. **Top panel:** Gamma-ray sky (photon intensity map in Galactic coordinates) for photons above 100 MeV detected by the EGRET instrument on board of the Gamma-Ray Observatory (Hartman et al., 1999). The concentration of diffuse gamma-ray emission in the Galactic plane is caused by cosmic ray bombardment and emission in gaseous clouds. Several point-like sources are detectable above the diffuse background both in the Galactic plane and above the plane. **Bottom panel:** Unidentified gamma-ray sources (light filled circles) and isolated gamma-ray pulsars (dark filled circles) listed in the 3rd EGRET Catalog (3EG, Hartman et al. 1999).

2. The AGILE Mission

The heart of the AGILE scientific instrument is based on Silicon microstrip detectors developed in Italian laboratories (Barbiellini et al. 1995 and 2001, Bakaldin et al. 1997, Prest et al. 2003). The instrument is relatively light ($\sim$ 130 kg) and effective in detecting and monitoring gamma-ray sources in the energy range 30 MeV–30 GeV within a large field of view ($\sim$ 2.5 sr, i.e., $\sim 1/5$ of the whole sky). The AGILE instrument consists of three detectors with broad-band detection capabilities (see Fig. 2).

The Gamma-Ray Imaging Detector (GRID) is sensitive in the energy range $\sim$ 30 MeV–50 GeV. It is characterized (Barbiellini et al. 2002) by: (1) analog readout of the Silicon microstrip (121 μm) signal, (2) a spatial resolution reaching 40 μm, (3) the smallest ever obtained deadtime for single gamma-ray detection ($\lesssim$200 μs), and (4) a trigger logic based exclusively on Silicon plane detectors. The GRID consists of a Silicon-Tungsten Tracker, a Cesium Iodide Mini-Calorimeter, an Anticoincidence system made of segmented plastic scintillators, and fast readout electronics and processing units. The GRID is designed to achieve an optimal angular resolution (source location accuracy $\sim 5' - 20'$ for intense sources), an unprecedently large field-of-view ($\sim$ 2.5 sr), and an effective area above 100 MeV about half of that of EGRET for on-axis sources (and substantially better for off-axis, see Fig. 5). The gamma-ray energy resolution is expected to be $\Delta E/E \simeq 1$ at 100 MeV (Giuliani et al. 2004a).

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 plus an ultra-light collimator supporting a Tungsten mask at a distance of 14 cm from the Silicon detectors. 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 (6 arcminute pixel size), fast burst alert and on-board GRB trigger capability.

The CsI Mini-Calorimeter (MC) will also detect and collect events independently of the GRID. The energy range for this non-imaging detector is 0.3–200 MeV, and it can be very useful to provide spectral and accurate timing information of transient events and Gamma-Ray Bursts (GRBs).

AGILE with its combination of GRID, MC, and Super-AGILE is an innovative instrument, with an optimal expected performance for transients (AGNs, GRBs, accreting compact objects, SGRs, some of the unidentified gamma-ray sources) and steady sources (e.g., pulsars). The fast AGILE electronic readout and data processing (resulting in very small detectors' deadtimes) allow in principle a systematic search for millisecond gamma-ray transients with durations comparable with the dynamical timescale of $\sim 1\,M_\odot$ compact objects (Tavani 2004).

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 many space Missions including INTEGRAL, XMM, CHANDRA, SWIFT, ASTRO-E2. Furthermore, it can support ground-based investigations in the radio, optical, and TeV bands. Quicklook data analysis and fast communication of new transients will be implemented as an essential part of the AGILE Science Program.

3. Science with AGILE

3.1. Gamma-Ray Astrophysics with the GRID

The GRID is designed to obtain:

- **excellent imaging capability in the energy range 100 MeV-30 GeV**, improving the EGRET error box radius by a factor of 2 (see Fig. 3);
- **a large field-of-view** ($\sim$ 2.5sr), with an effective area at 400 MeV of $A_{eff} \simeq 550\ cm^2$ on-axis, and $A_{eff} \simeq 350\ cm^2$ for inclination angles of 50 degrees off-axis;
- **excellent timing capability**, with absolute time tagging of uncertainty near 1 μs and very small deadtimes ($\sim 200\,\mu$s for the Si-Tracker and $\sim 20\,\mu$s for each of the individual CsI bars);

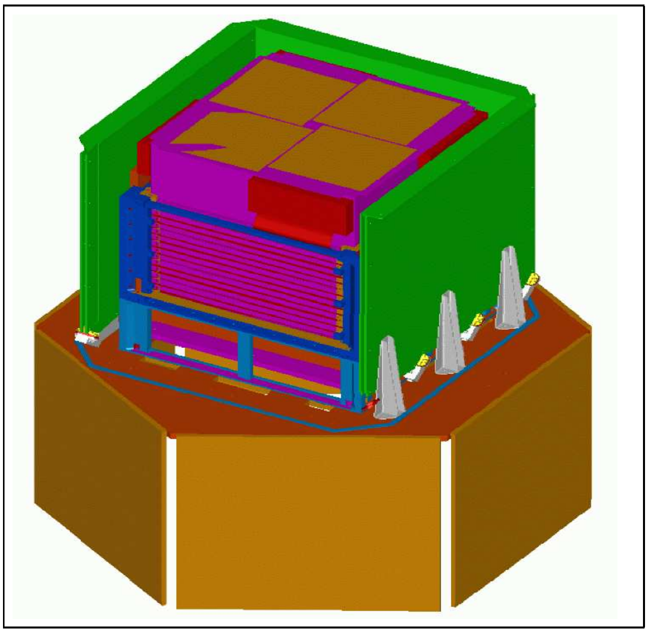

Fig. 2. Lateral view of the AGILE instrument (AC System and spacecraft partially displayed) (from Tavani et al. 2003). The GRID is made of a Silicon Tracker (10 Tungsten and Silicon planes plus 2 additional Silicon-only planes) and a Mini-Calorimeter placed at the bottom of the instrument. Super-AGILE has its detection plane made of 4 Si-detectors placed at the top of the first GRID tray, and an ultra-light coded mask system (CMS) positioned on top (the figure shows the CMS partition configuration). The instrument size is $\sim 63 \times 63 \times 58.5\,\mathrm{cm}^3$, including Super-AGILE and the AC System for a total weight of $\sim$ 130 kg including the electronics and power supply unit positioned inside the spacecraft.

- **good sensitivity above 100 MeV**, with an effective area about half of that of EGRET for *on-axis* sources, and substantially better for *off-axis* sources (see Figs. 4 and 5);
- **good sensitivity in the energy range ~30-100 MeV**, with an effective area above 200 cm^2 at 50 MeV (an energy range not efficiently usable by EGRET);
- **a very rapid response to gamma-ray transients and GRBs**, obtained by a special Quicklook Analysis program and coordinated ground-based and space observations.

3.1.1. Large FOV monitoring of gamma-ray sources

Fig. 6 shows the results of a 10-week simulated pointing by AGILE centered at the Galactic Center. Relatively bright sources flaring with fluxes larger than $10^{-6}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$ (above 100 MeV) can be detected within a few days by the AGILE Quicklook Analysis. Monitoring a large number of gamma-ray sources per pointing requires an efficient Quicklook and data analysis procedure.

3.1.2. Fast reaction to strong high-energy transients

The existence of variable gamma-ray sources (e.g., Hartman et al. 1999) makes necessary a reliable program for quick response to transient gamma-ray emission. Prompt

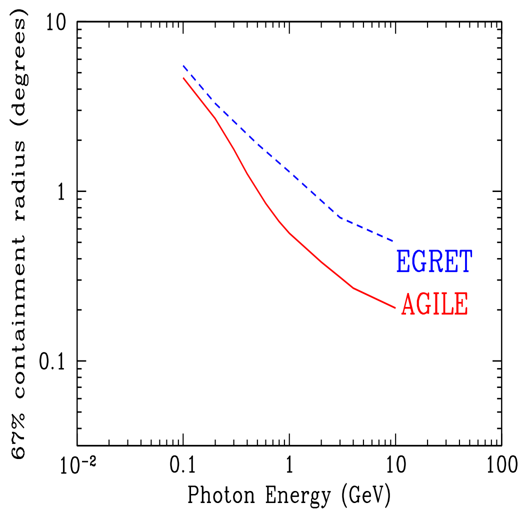

Fig. 3. Three dimensional PSF (67% containment radius) as a function of photon energy for the AGILE-GRID and EGRET (on-axis photons). From Tavani et al. 2003.

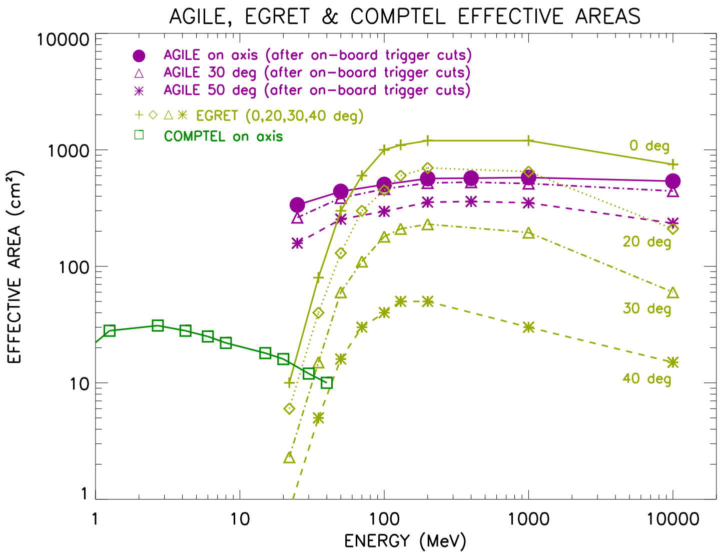

Fig. 4. Effective area as a function of photon energy for the AGILE-GRID, EGRET (Thompson et al. 1993), and COMPTEL (Schoenfelder et al. 1993).

communication of results regarding gamma-ray transients (typically requiring $\sim$3 days to be detected with high confidence for bright sources) will be ensured. Detection of short timescale (seconds/minutes/hours) transients (soft gamma-ray repeaters, 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 by dedicated communication channels.

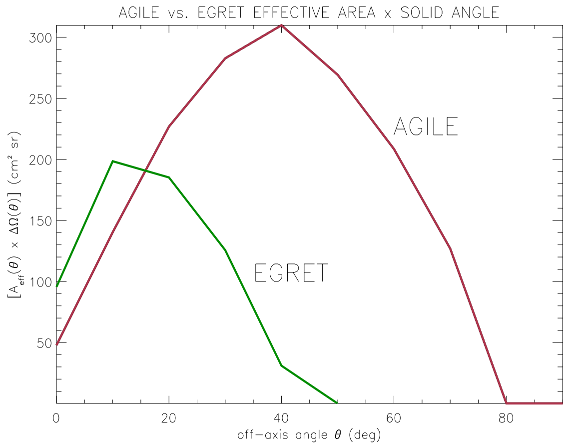

Fig. 5. The quantity $A_{eff}(\theta) \times \Delta\Omega(\theta)$ (at 100 MeV) is shown as a function of the off-axis angle θ for EGRET *(green curve)* and AGILE *(red curve)* with $\Delta\Omega(\theta)$ the bin-integrated solid angle centered at θ (Tavani et al. 2003). The comparison shows that despite a smaller on-axis effective area, the combination of a shallow A_{eff} and a large field-of-view is expected to produce a coverage by AGILE of a wide portion of the sky with very good sensitivity.

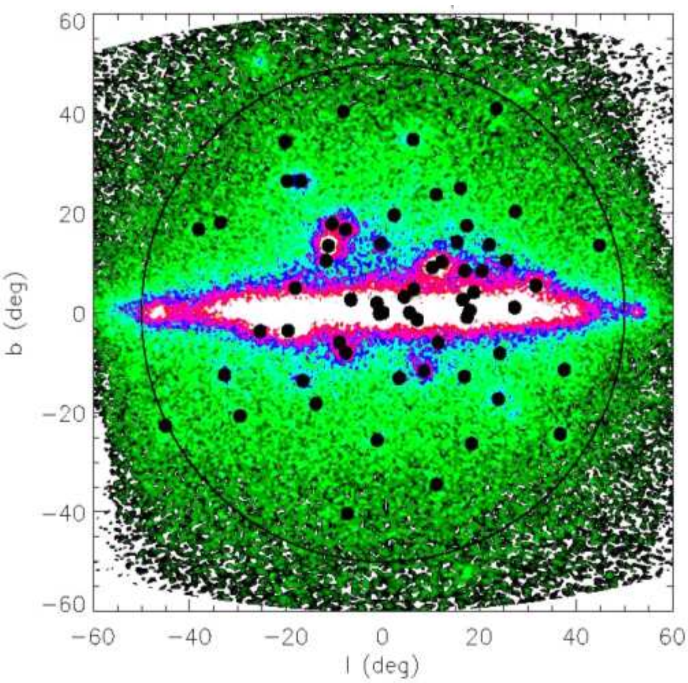

Fig. 6. AGILE simulated counts map (above 100 MeV) for a 10-week pointing at the Galactic Center. Filled circles are the AGILE-detectable sources of the 3rd EGRET Catalogue. The circle indicates the AGILE-GRID field of view ($\sim$ 2.5 sr). Only 3rd EGRET catalog sources, with constant flux equal to the combined Phases 1-4 flux, were included in the simulation; no additional 3-sigma sources were included. The AGILE likelihood detection used an iterative search procedure from the most significant to the least significant gamma-ray source. In all cases, the source location was left as a free parameter for optimization. As each new source was added, the source fluxes and locations were iteratively re-optimized. The threshold for source detection was set to $TS > 6$, equivalent to $\sim$ 2.5 sigma threshold, with the additional constraint of a meaningful source location determination. The analysis found 72 sources.

3.1.3. Large Exposures

The AGILE average exposure per Galactic source will be larger by a factor of ~ 4 for a 1-year sky-survey program compared to the typical exposure obtainable by EGRET during the same time period (see Vercellone et al. 2004). After a 1-year all-sky pointing program, AGILE average sensitivity to a generic gamma-ray source above the Galactic plane is expected to be better than EGRET by a factor conservatively given as ~ 2. Deep exposures for selected regions of the sky can be obtained by a proper program with repeated overlapping pointings. For selected sky areas, AGILE can then achieve a flux sensitivity better than 5×10^{-8} ph cm^{-2} s^{-1} at the completion of its scientific program.

3.1.4. High-Precision Timing

AGILE detectors will have optimal timing capabilities. The on-board GPS system allows to reach microsecond absolute time tagging for individual photons: $1.5\,\mu$s for the Silicon-Tracker, and $3-4$ μs for the individual detecting units of the Mini-Calorimeter and Super-AGILE.

The GRID deadtime will be of order of $200\,\mu$s (improving by almost three orders of magnitude the EGRET capability). 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 MC elements and 16 Super-AGILE elements) the effective deadtimes will be much less than those of individual units. The goal is to achieve a multi-detector response with optimal time-tagging and deadtime capabilities.

3.2. Super-AGILE

A hard X-ray imager (Super-AGILE) co-aligned with an innovative gamma-ray Tracker is the new twist of the AGILE mission. Super-AGILE is a very light coded-mask detector positioned on top of the GRID and inside the Anticoincidence system. The optimal energy range for photon detection and imaging is 15-45 keV and its FOV is ~ 0.8 sr (see Fig. 7). Super-AGILE can provide important information including:

- **source detection and spectral information in the energy range ∼15-45 keV** to be obtained simultaneously with gamma-ray data (∼12 mCrab sensitivity at 15 keV ($5\,\sigma$) for a 50 ksec integration time, and about 30 mCrab/orbit);
- **accurate localization (∼2-3 arcmins) for GRBs, SGRs, and other transient events** obtained by an on-board imaging algorithm implemented after a 'burst alert' (the expected GRB detection rate is $\sim 1-2$ per month). Super-AGILE can also trigger a 'burst alert' for significant outbursts from Galactic sources (e.g., Sco X-1, GRS 1915-104, Cyg X-1 and others);
- **fast link to the Earth to communicate data from a 'burst alert'**, obtained through a special transceiver connected to the ORBCOMM satellite network. Coordinate and flux data can be made available within 1-2 minutes;
- **good timing**, with absolute time tagging uncertainty and deadtime near $4\,\mu$s for each of the 16 independent readout units of the Super-AGILE Si-detector;
- **continuous long-timescale monitoring of Galactic hard X-ray sources**, for typical pointings lasting 2-3 weeks;
- **hard X-ray response to γ-ray transients detected by the GRID**, obtainable by special re-pointings of the AGILE spacecraft to include the γ-ray flaring source in the Super-AGILE FOV.

Table 1 - AGILE Science Capabilities

Gamma-ray Imaging Detector (GRID)	
Energy Range	30 MeV – 30 GeV
Field of view	$\sim$ 2.5 sr
Sensitivity at 100 MeV (ph cm^{-2} s^{-1} MeV^{-1}, 5σ in 10^6 s)	6×10^{-9}
Sensitivity at 1 GeV (ph cm^{-2} s^{-1} MeV^{-1}, 5σ in 10^6 s)	4×10^{-11}
Angular Resolution at 1 GeV (68% cont. radius)	36 arcmin
Source Location Accuracy (S/N$\sim$10)	$\sim$5–20 arcmin
Energy Resolution (at 300 MeV)	ΔE/E$\sim$1
Absolute Time Resolution	$\sim 1\,\mu$s
Deadtime	$\sim 100\,\mu$s
Hard X–ray Imaging Detector (Super-AGILE)	
Energy Range	15 – 45 keV
Field of View (FW at Zero Sens.)	$107^\circ\times68^\circ$
Sensitivity at FOV center (@ 15 keV, 5σ in 1 day)	$\sim$12 mCrab
Angular Resolution (pixel size)	$\sim$ 6 arcmin
Source Location Accuracy (S/N$\sim$10)	$\sim$2-3 arcmin
Energy Resolution	ΔE<4 keV
Absolute Time Resolution	$\sim 4\,\mu$s
Deadtime (for each of the 16 readout units)	$\sim 4\,\mu$s
Mini-Calorimeter	
Energy Range	0.3 – 200 MeV
Energy Resolution (above 1 MeV)	$\sim$ 1 MeV
Absolute Time Resolution	$\sim 3\,\mu$s
Deadtime (for each of the 30 CsI bars)	$\sim 20\,\mu$s

As discussed in the following section, the combination of simultaneous hard X-ray and γ-ray data is needed for the study of Galactic high-energy sources. Given the GRID and Super-AGILE sensitivities, for the first time simultaneous hard X-ray/γ-ray information will be obtainable for a large number of sources: (1) unidentified variable γ-ray sources, (2) pulsars, (3) accreting neutron stars and black holes, (4) soft gamma-ray repeaters (SGRs), (5) Compton-thick accreting sources. Table 1 summarizes the main characteristics of the AGILE instrument.

4. Astrophysics of Galactic Gamma-ray Sources

- **The Enigma of the Unidentified Gamma-Ray Sources.**

Understanding the origin of the unidentified gamma-ray sources concentrated in the Galactic plane and bulge (see Fig. 1) is a primary goal of future gamma-ray Missions. In addition to the "young" PSR population concentrated in the Galactic plane, no obvious candidates stand out among the known X-ray binaries and supernova remnants (SNRs) (see also Chen et al. 2004). Probably more than one class of sources (accreting compact objects in binaries, SNRs, colliding winds, exotic objects) make the observed population. AGILE will contribute to solve the enigma of the ultimate origin and behavior of these sources in different ways: (1) a better PSF compared to that of EGRET will produce gamma-ray error boxes reduced in area by a factor of 4-5; (2) larger exposures (by a factor of 5-10 after 2 years) of the Galactic plane will lead to improved positions and long-timescale monitoring of variable sources (e.g., 2CG 135+01, Tavani et al. 1998) with joint multifrequency observations; (3) an improved Galactic gamma-ray diffuse model (Giuliani et al. 2004b) together with larger exposures will lead to a more reliable source positioning and monitoring; (4) simultaneous hard X-ray and gamma-ray data will contribute to the monitoring of many gamma-ray sources simulta-

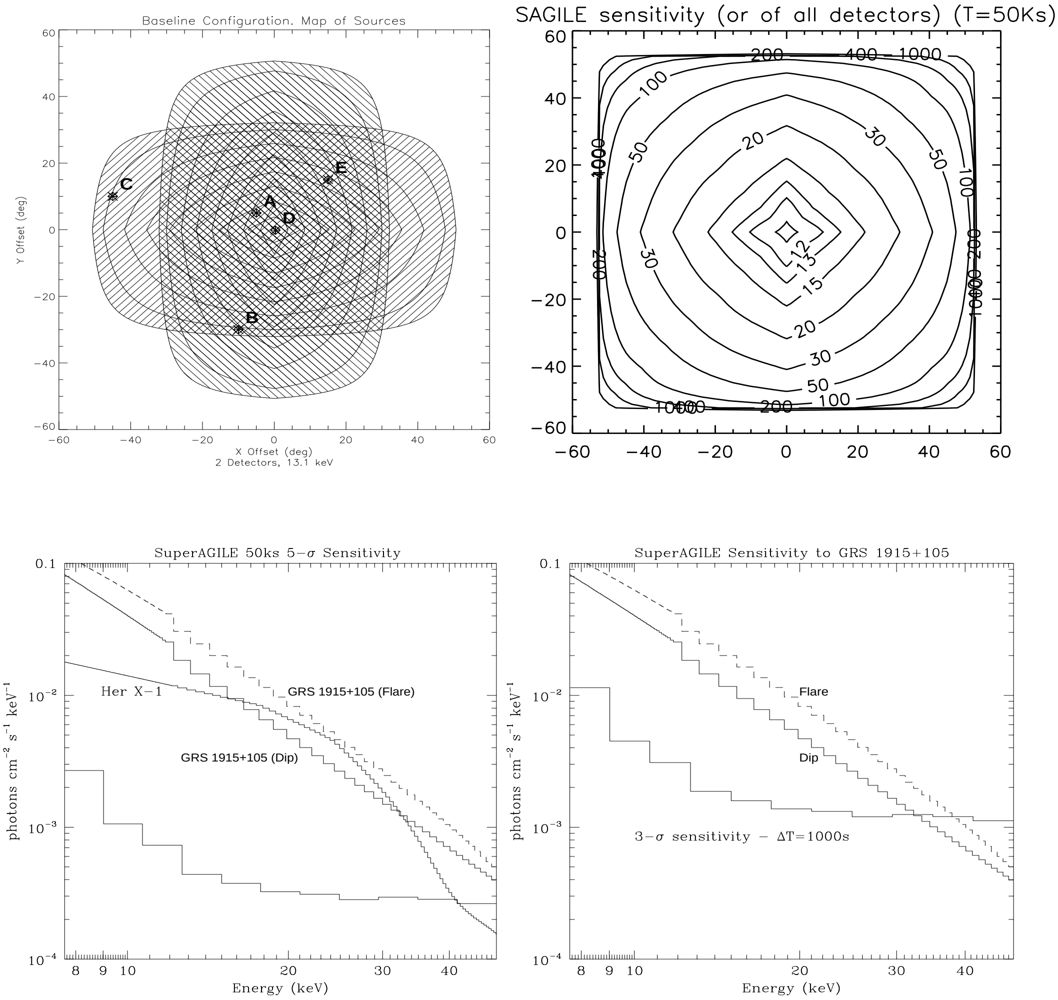

Fig. 7. **Left Top Panel:** Super-AGILE simulated Field of View in the energy range 15-45 keV by combining all four detectors' units. **Right Top Panel:** simulated Super-AGILE sensitivity contour levels (in mCrab) for detection in either one of the two orthogonal detectors (50 ksec integration and 5σ). **Left Bottom Panel:** The solid line at the bottom of the plot shows the Super-Agile hard X-ray spectral sensitivity reachable in 50 ksec (5σ). Several spectra of known Galactic sources are shown: the X-ray pulsar Her X-1, and typical high and low states of the black hole candidate GRS 1915-104. **Right Bottom Panel:** Super-AGILE X-ray spectral sensitivity reachable in 1 ksec (3σ) compared with the observed spectrum of GRS 1915+105 in two different states (Feroci et al. 1999).

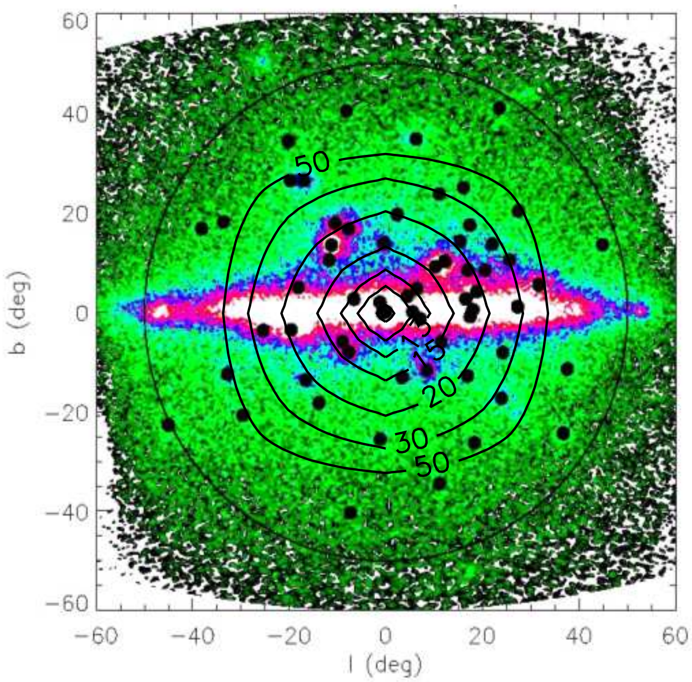

Fig. 8. AGILE simulated counts map (above 100 MeV) for a 10-week pointing at the Galactic Center. Filled circles are the AGILE-detectable sources of the 3rd EGRET Catalogue. The contour levels indicate the Super-AGILE (15-45 keV) sensitivity in mCrab (4-day exposure) obtained by requiring source detection in both orthogonal mono-dimensional units. The large circle indicates the AGILE-GRID field of view (~ 2.5 sr).

neously with optimal sensitivity to transient emission (12-30 mCrab in the energy range 15-45 keV, and $(10 - 100) \times 10^{-8}$ photons cm^2 s^{-1} above 100 MeV). Fig. 8 shows the AGILE gamma-ray and hard X-ray simultaneous imaging capabilities for a pointing at the Galactic Center.

• **Diffuse Galactic emission.**

The AGILE angular resolution and large average exposure will further improve our knowledge of cosmic ray origin, propagation, interaction and emission processes in our Galaxy. A comprehensive AGILE model of the diffuse Galactic gamma-ray emission is being developed (Giuliani et al. 2004b). This model takes into account new data from radio surveys of the Galactic hydrogen and CO emission and new theoretical modelling. AGILE can obtain substantially larger exposures (compared to those of EGRET) of complex regions such as the Cygnus and Orion regions in addition to the Galactic Center.

• **Gamma-ray pulsars**.

Isolated pulsars (PSRs) are currently the only well established class of Galactic gamma-ray emitters above 30 MeV. AGILE will contribute to the study of gamma-ray pulsars in several ways: (1) improving timing and lightcurves of known gamma-ray PSRs; (2) improving photon statistics for period searches of new gamma-ray pulsars; (3) studying unpulsed gamma-ray emission from isolated plerions in SNRs and searching for time variability of pulsar wind/nebula interactions, e.g., in the Crab nebula; (4) studying binary plerions such as PSR 1259-63. Particularly interesting for AGILE are the ~ 30 new young PSRs discovered (e.g., D'Amico et al. 2001) in the Galactic plane by the Parkes survey. An accurate timing (photon time-tagging within 2 μs for gamma-rays above 30 MeV) allows to study, simultaneously with the radio monitoring, PSR macro-glitch activity and possible transient high-energy emission features (for a discussion of several issues regarding PSRs and AGILE see Pellizzoni et al. 2004).

• **Supernova remnants and the cosmic ray origin**.
Despite the large number of positionally coincident gamma-ray sources with SNRs in the Galactic plane, no unambiguous evidence exists for gamma-ray emission from SNRs. We know from several studies that cosmic rays most likely originate in our Galaxy (e.g., Sreekumar et al. 1993, Fichtel & Trombka 1997). The optimal PSF and large exposures of AGILE will lead to a systematic search for SNR/gamma-ray source associations in the Galactic plane. In some favorable cases, the imaging capabilities and large exposures can possibly lead to the detection of the "smoking gun", i.e., gamma-rays produced by interaction and radiation of accelerated particles in SNR ejecta.

• **Search for highly variable non-blazar gamma-ray sources in the Galactic plane**, currently a mysterious class of unidentified gamma-ray sources (e.g., GRO J1838-04, Tavani et al. 1997) requiring a special investigation and prompt response to outburst alerts for follow-up observations in other wavelengths.

• **Accreting neutron stars and black holes**.
Galactic black hole sources (such as Cyg X-1, Cyg X-3, GRS 1915+10, GRO J1655-40 and others) can produce detectable gamma-ray emission for favorable accretion states and geometries. The so-called micro-quasars are of particular importance, i.e., solar mass accreting black holes showing a complex phenomenology with moderately relativistic jets. The AGILE capability of simultaneous hard X-ray/gamma-ray detection of these outbursts is of crucial relevance (see Fig. 7). It is important to note that *Integral* is detecting above 20 keV a surprisingly large number of hard X-ray sources in our Galaxy (Lebrun et al. 2004, Bird et al. 2004, Revnivtzev et al. 2004) belonging to known populations of accreting compact objects (low-mass X-ray binaries – LMXBs– and black hole candidates – BHCs) plus what appears to be a new class of accreting sources with a highly absorbed spectrum (Walter et al. 2003). This (partially unexpected) large number of Galactic hard X-ray sources detected above 20 keV is a big plus for AGILE. The X-ray imaging and monitoring capability of Super-AGILE will be crucial to study these sources, and we expect a number of order 5-10 for every AGILE pointing of the Galactic plane (e.g., see Figs. 9 and 12 for the case of the Galactic center region).

• **A new class of highly absorbed ("Compton-thick") sources**.
The discovery of the source IGR J16318-4848, first detected by *Integral* on Jan. 29, 2003 with a variable flux between 50 and 100 mCrab in the band 15-40 keV (Courvoisier et al. 2003), uncovered a new class of Galactic high-energy sources. This object shows a highly absorbed spectrum below 10 keV ($N_H \sim 10^{24}$ cm^{-2}) with very strong fluorescent X-ray emission lines (Fe Kα, Fe Kβ, Ni Kα as determined by a subsequent *XMM-Newton* observation, Matt & Guainazzi 2003). The spectrum resembles that of Seyfert-2 galaxies, most likely because of a similar combination of geometry and absorption throughout the accretion flow. The source IGR J16318-4848 was subsequently observed by *Integral* during the period March 10-14, 2003: it was detected above 15 keV in what we can call a "low state" compared to the original discovery. Fig. 11 shows the combined (not simultaneous) *XMM-Newton* and low-state *Integral* spectra. The dramatic effect of absorption and fluorescent emission from the source is evident. No counterpart of IGR J16318-4848 is known, and the ultimate nature of the source (accreting black hole or neutron star in a binary system) is currently debated. *Integral* is detecting other sources with similar characteristics: they can substantially contribute to the total hard X-ray emission from the Galactic plane (Lebrun et al. 2004, Walter et al. 2003). AGILE can monitor this type of sources in an effective way, and alert the community for hard X-ray outbursts.

• **Gamma-ray vs. hard X-ray sources**.
No obvious candidate for joint gamma-ray/hard X-ray emission is evident from a posi-

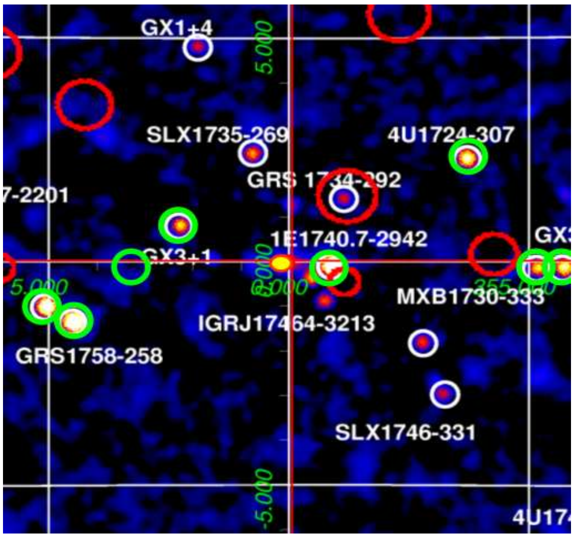

Fig. 9. *Integral* source map (18-60 keV) of the central region ($\sim 10^o \times 10^o$) of our Galaxy (Revnivtsev et al. 2004) superimposed with the positions of known gamma-ray sources (red ellipses representing their error boxes) of the 3rd EGRET Catalog (Hartman et al. 1999). The position of the gamma-ray source near the Sgr A* position (Mayer-Hasselwander et al. 1998, Hartman et al. 1999, Hooper & Dingus 2002) is marked in filled yellow color. Hard X-ray sources detectable by Super-AGILE above 20 mCrab at 20 keV are marked in green.

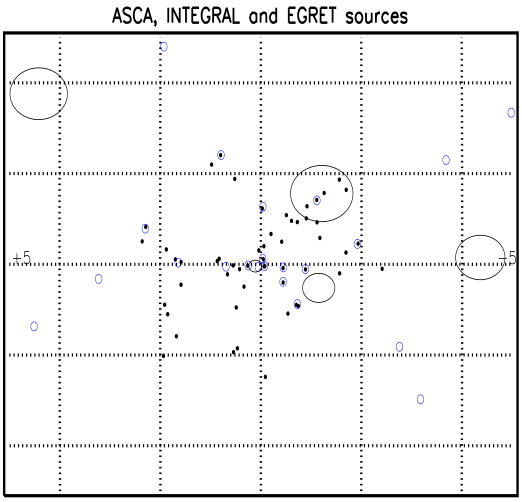

Fig. 10. Source map of the central region ($10^o \times 10^o$) of our Galaxy showing the *ASCA* sources (filled black dots) detected in the energy range 2-10 keV within 2.5 degrees from the Galactic Center (Sakano et al. 2002) superimposed with the positions of *Integral* sources (open blue circles, Revnivtsev et al. 2004) and gamma-ray sources (ellipses representing their error boxes) of the 3rd EGRET Catalog (Hartman et al. 1999).

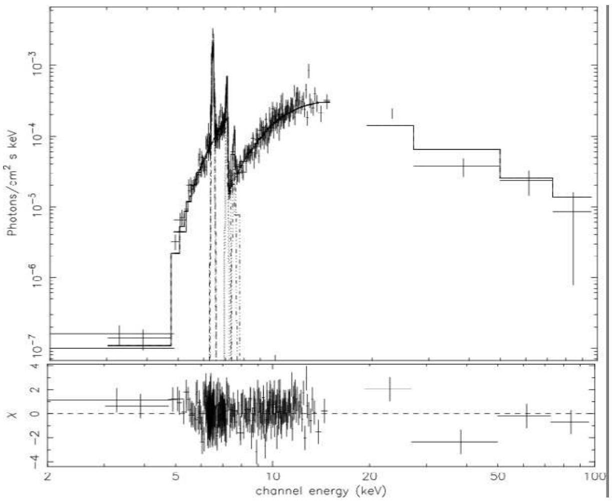

Fig. 11. Non-simultaneous spectra of the highly-absorbed source detected by *Integral* IGR J16318-4848 obtained by combining: (1) the Feb. 21, 2003 observation by *XMM-Newton*, and (2) the *Integral* observations during the period March 3-14, 2003 (Walter et al. 2003). The source is detected by *Integral* in a low-state of a few mCrab above 15 keV, i.e., substantially weaker than at the discovery (50-100 mCrab on Jan. 29, 2003, Courvoisier et al. 2003). Super-AGILE cannot detect such a low-state, but can easily detect and monitor its high-states.

tional comparison between the known gamma-ray source error boxes of the 3rd EGRET Catalog and the hard X-ray sources detected by *Integral* above 20 keV (as listed in the catalogs of Bird et al., 2004, and Revnivtzev et al., 2004). Gamma-ray sources detected by EGRET near the Galactic plane and the *Integral* sources appear to be two disjoint sets (with a possible exception of a few controversial cases out of more than 123 sources listed by Bird et al., 2004). This fact might reflect two distinct physical conditions for Galactic sources: (1) compact objects (LMXBs and BHCs) emitting mostly X-ray and hard X-ray emission with negligible or erratic emission above 30 MeV, and (2) optically-thin conditions and efficient particle acceleration in gamma-ray sources showing weak (if any) X-ray emission. Future simultaneous observations in the X-ray and gamma-ray energy ranges will crucially contribute to resolving the problems related with this apparent dichotomy. An analysis of the hard X-ray emitting states of Galactic sources with low-statistic gamma-ray emission by the AGILE imagers will substantially enhance the detection capability of simultaneous hard X-rays/gamma-rays from accreting neutron stars and black holes.

• **Soft Gamma-Ray Repeaters**.

A special class of neutron stars shows the SGR phenomenon, i.e., the activation with no apparent external action of intense (and occasionally very intense) X-ray/gamma-ray outbursts. What makes SGRs different from the more common non-bursting neutron stars is probably their large magnetic field ($\sim 10^{14}$ G). At least four SGRs are active in our Galaxy: their outbursts provide an invaluable information to study plasma-loaded magnetospheres under extreme conditions. The combination of hard X-ray and gamma-ray imagers of AGILE will lead to a substantial improvement of our understanding of these impulsive phenomena. SGR outbursts on scales from millisecond to tens of seconds can trigger the AGILE on-board burst alert procedure and generate the activation of the Fast Link through the ORBCOMM satellites.

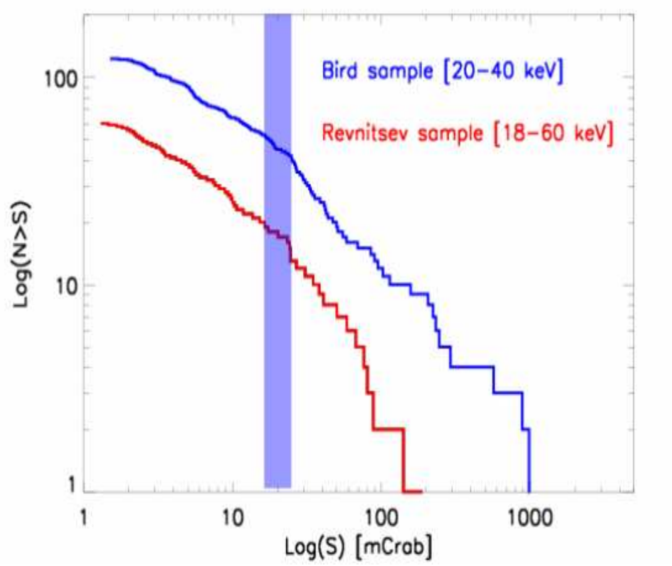

Fig. 12. LogN-logS distribution of the *Integral* sources detected for a total exposure of 2 Msec of the Galactic Center region (Revnivtsev et al. 2004) and 5 Msec for the Galactic plane and bulge (Bird et al. 2004). The shaded light blue area indicates the average sensitivity thresholds obtainable by Super-AGILE within 1-week and 1-day exposures.

• **Mystery at the Galactic Center**.
The central region of our Galaxy hosts a wealth of transient and puzzling high-energy sources. The dynamical center of our Galaxy is gravitationally (but not radiatively !) dominated by a black hole of $\sim 3 \times 10^6\ M_\odot$ associated with the radio/X-ray source Sgr A*. Several transient X-ray sources are within 0.1 degrees from Sgr A*: Fig. 14 shows an X-ray ray image by *Chandra* of the region around Sgr A* (Muno et al. 2003) with the positions of several X-ray sources detected by the *Ariel, Granat, Asca* satellites. They are all transients, with variability timescales ranging from hours-days-months. The remarkable discovery in October 2000 of short timescale (10,000 sec) X-ray flaring from Sgr A* (from $\sim 10^{33}$ to $\sim 10^{35}$ erg/s, Baganoff et al. 2001) during a short observation of the Galactic Center (GC) region by *Chandra*, and the detection of IR flaring (Ghez et al. 2004) demonstrates that the central black hole is dynamically active despite its underluminous output in high-energy emission.

Recently, new important data are provided by *Integral*. Repeated scans of the GC region provide evidence for a hard X-ray source in principle consistent with the position of Sgr A* even though the angular resolution of the IBIS instrument (pixel size: 12') does not allow an unambiguous identification (Belanger et al. 2004). A source called IGR J1745.6-2901 was detected in the energy range 20-40 keV and flux ∼5 mCrab for an effective exposure time of $8 \cdot 10^5$sec obtained by summing up short (37 min.) pointings between February 28 and May 1, 2003. As shown in Fig. 14, its error box (of radius 4') contains several sources in addition to Sgr A*, most notably the *Asca* source (eclipsing X-ray burster) AX J1745.6–2901, and the *Ariel* source A 1742-289. The *Integral* source does not show significant flux variation in the data reported by Belanger et al.

An additional set of data (about 10^6 sec each) was obtained by *Integral* during the period between August 23rd and September 24th, 2003 (Revnivtsev et al. 2004). These data confirm the existence of a $\sim$ 5 mCrab hard X-ray source[1] near the position of

[1] We note that the source table reported by Revnivtsev et al. 2004 has a serious typing error reporting

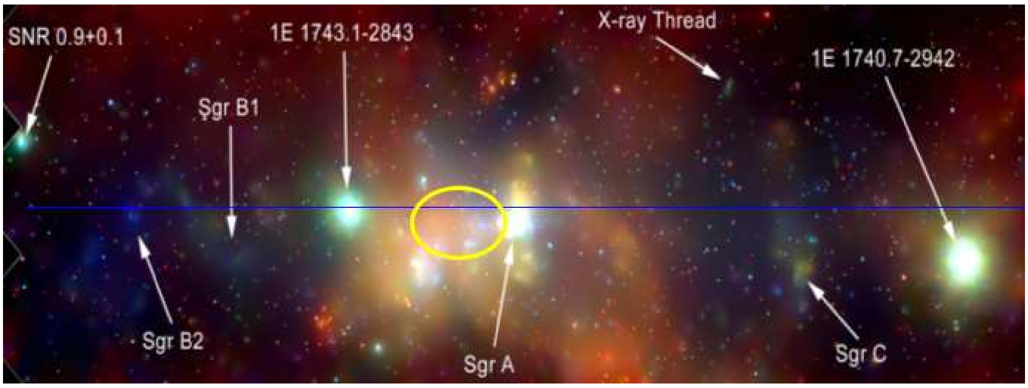

Fig. 13. *Chandra* map (2-10 keV) of the Galactic plane ($\sim 2^o \times 0.8^o$) near the Galactic center (Wang et al. 2002). The ellipse represents the 3EG error box of the gamma-ray source detected near the Galactic Center (Mayer-Hasselwander et al. 1998, Hartman et al. 1999, Hooper & Dingus 2002).

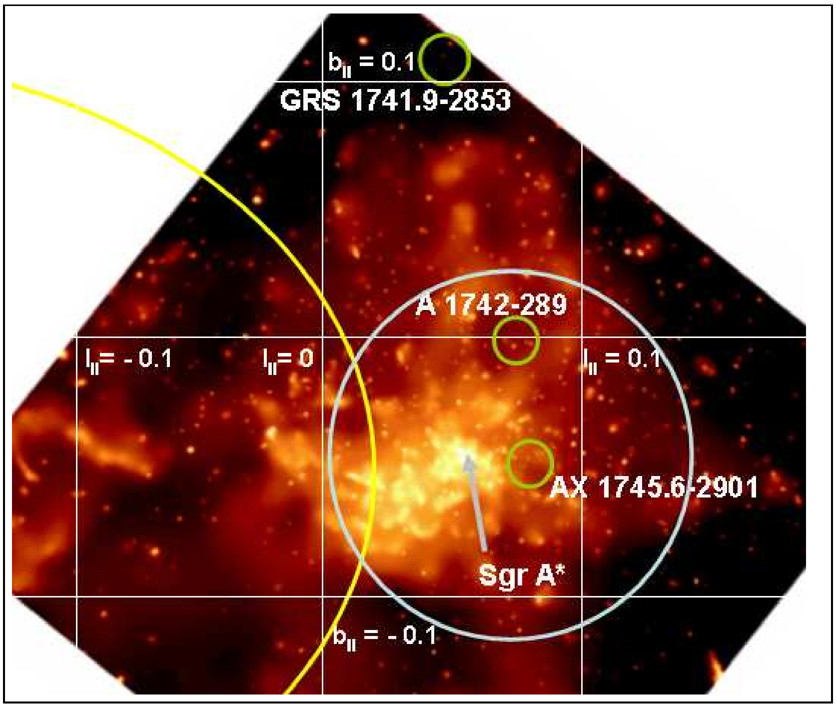

Fig. 14. *Chandra* map (2-10 keV) of the Galactic center region near Sgr A* (Muno et al. 2003) with the positions of relevant transient X-ray sources in the field. The circle surrounding the region around Sgr A* represents the error box (4' radius) of the 5 mCrab hard X-ray source IGR J1745.6-2901 detected by *Integral* near the Galactic Center (R.A.(J2000)=266.41, decl.(J2000)= -29.02; $l_{II} = -0.07, b_{II} = -0.047$) (Belanger et al., 2004). The portion of the off-centered ellipse encloses the 3EG error box of the gamma-ray source detected at the Galactic Center (Mayer-Hasselwander et al. 1998, Hartman et al. 1999, Hooper & Dingus 2002). Note that the $0.1^o \times 0.1^o$ squares marked in the map correspond to the Super-AGILE pixel size: depending on the source intensity, positioning of transients in this region can be significantly better than the pixel size.

Sgr A*, as also subsequently checked by Goldwurm et al., 2004.

It is clear that the identification of the hard X-ray source near Sgr A* requires more data. Belanger et al. and Goldwurm et al. tentatively attribute this source to Sgr A* itself; Revnivtsev et al. instead attribute the flux originating from this source to the well know low-mass X-ray binary AX J1745.6–2901 originally discovered by *Asca*. To resolve this crucial issue a continuous monitoring of the Galactic Center region is required for an extended period of time. AGILE will provide this monitoring with good angular resolution and excellent alert capability in case of activation of the GC hard X-ray source.

The remarkable gamma-ray source detected by EGRET at a position near the Galactic Center is only marginally consistent with Sgr A* (Mayer-Hasselwander et al. 1998, Hartman et al. 1999, Hooper & Dingus 2002). The isotropic gamma-ray luminosity above 100 MeV is $2 \cdot 10^{37}$ erg s^{-1} if positioned at the GC distance. Fig. 13 shows the position of this source with respect of a *Chandra* (2-10 keV) map of the Galactic plane near the center. No obvious counterpart candidate is evident within its error box. A detailed analysis shows that the EGRET error box, to be refined and confirmed by AGILE and GLAST, contains hundreds of X-ray sources. We also note the very remarkable detection of an apparently constant TeV source consistent with the position of the EGRET source near the GC (Kosack et al. 2004, Tsuchiya et al. 2004). Furthermore, *Integral* confirmed the existence of a strong source of e^+/e^- annihilation radiation at 511 keV from the Galactic bulge (9^o of FWHM) centered at the GC (for a preliminary analysis of SPI data, see Knoedlseder et al. 2003).

More data are clearly needed to clarify the nature of the gamma-ray source near the GC and its possible connection with Sgr A*, the TeV source, the 511 keV source, and the nearby X-ray sources. A variability study of the gamma-ray source simultaneously with hard X-ray potential counterparts is clearly very important. A long-term monitoring of the GC in the hard X-ray and gamma-ray ranges can be obtained by AGILE for uninterrupted observations lasting several weeks/months.

• **Galactic TeV sources**.

A new generation of ground-based Cherenkov telescopes is starting being operational and will be completed during the next years with interesting prospects of discovery (*CANGAROO, HESS, MAGIC, VERITAS, STACEE, CELESTE*). Until a few years ago, the Crab nebula was the only Galactic source detected above 1 TeV. Today, the observational situation is rapidly evolving, and the new generation of TeV telescopes allows a systematic search for high-energy emission from a variety of extragalactic and Galactic sources. The improved sensitivity (a few mCrab in the TeV energy range), angular resolution (a few arcminutes) and energy threshold (50-100 GeV) of these telescopes compared to the previous ones will substantially boost the detection and positioning capabilities. At present, only a few TeV-sources in our Galaxy are confirmed: the Crab nebula, the source near the Galactic Center, an unidentified TeV-source in the Cygnus region (TeV J2032+4130, Horns et al. 2004), the plerionic binary pulsar PSR B1259-63 near periastron (Beilicke et al. 2004), and possibly several SNRs. Many more sources will be searched for and monitored in the near future. Simultaneous TeV observations from the ground and gamma-ray observations from space will be of great relevance. Gamma-ray and TeV observations clearly complement each other, and in specific cases only their simultaneous occurrence can shed light on specific particle acceleration and radiation phenomena. AGILE first and then GLAST will be strongly synergic to the ground-based TeV telescopes, and coordinated observing programs are being planned.

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57 mCrab instead of about 5 mCrab for the hard X-ray flux associated to the source near the Galactic Center, that these authors attribute to AX J1745.6–2901.

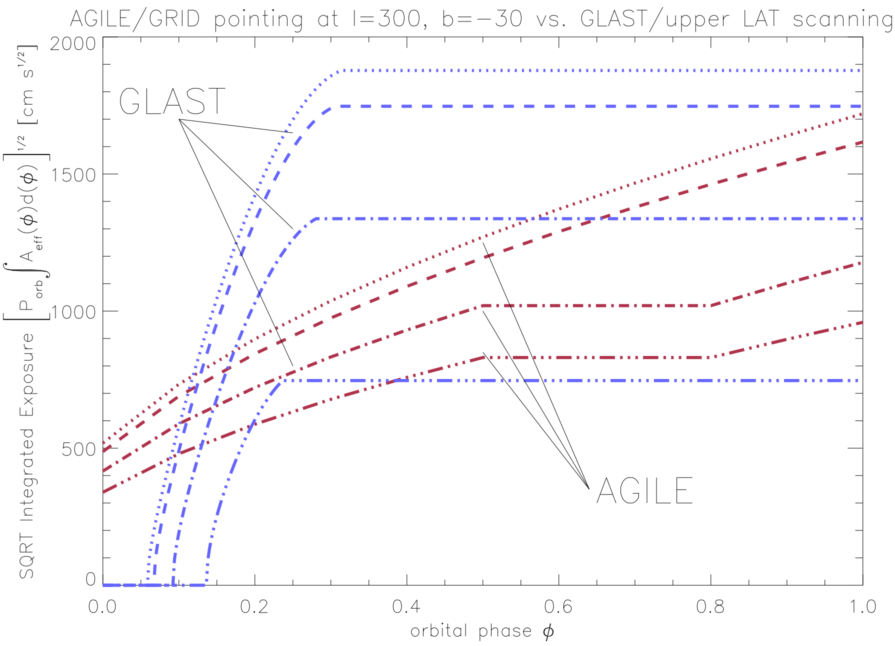

Fig. 15. Comparison of the simulated performance of AGILE and GLAST in detecting gamma-ray transients lasting a few days (Tavani et al. 2003) (typical of AGN and Galactic source γ-ray flares) during the first year of the GLAST sky scanning mode and for an AGILE pointing centered at a celestial pole (minimizing Earth occultations). The Figure shows the quantity determining the source sensitivity, i.e., the square-root of the integrated exposure (at 100 MeV) of sources within a given sky region as a function of the orbital phase for the AGILE/GRID *(red curves)* and the GLAST/LAT *(blue curves)*. We assumed the AGILE/GRID effective area as a function of angle shown in Fig. 4, and a (revised) GLAST/LAT on-axis effective area of 4,000 cm^2 and off-axis dependence on angle similar to that of the GRID. We considered an AGILE fixed pointing centered in an unocculted sky region (celestial South pole), and the exposure of the same region obtained during the GLAST sky-scanning mode. Only one (first) orbit is shown. The exposures are obtained for sources on-axis *(dotted lines)*, at 20° off-axis *(dashed lines)*, at 40° off-axis *(dotted-dashed lines)*, and at 60° off-axis *(dot-dotted-dashed lines)* for both instruments. The ratios of curves representing the AGILE and GLAST capabilities at the end of the first orbit are indicative of the asymptotic values reached after several orbits. The conclusion is that during the first phase of the GLAST sky-scanning mode the γ-ray imaging capabilities of the GRID and LAT are comparable for gamma-ray transients lasting hours-days occurring in the AGILE's FOV.

5. Conclusions

The study of Galactic high-energy sources is a crucial objective of the AGILE Mission. We briefly outlined in this paper the main characteristics and scientific objectives of the Mission in light of recent developments. The main feature of AGILE is the combination of two co-aligned imaging detectors sensitive in the hard X-ray range (optimized between 15 and 45 keV, reaching 2-3 arcmin resolution) and in the gamma-ray range between 30 MeV and 30 GeV (error box radius of 10-20 arcmins, depending on intensity). AGILE can then provide excellent imaging simultaneously in the hard X-ray/gamma-ray energy bands. The AGILE pointing strategy will be optimized taking into account possible simultaneous source observations from the ground. The typical duration of each pointing during the first Mission Cycle (approximately 1 year) will be of 2-3 weeks. Subsequently, longer pointings for sky regions of special interest can be achieved. In this paper, we considered several interesting classes of Galactic sources for AGILE, and emphasized the importance of long-duration monitoring of the Galactic Center region.

We also note that the gamma-ray sensitivity to transients lasting hours/a few days and occurring in the AGILE's FOV is similar for AGILE and GLAST during the first phase of sky-scanning by GLAST (see Fig. 15). The two Missions can complement each other: AGILE can provide long-timescale monitoring in the hard X-ray band for transients detected in the gamma-ray energy band.

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