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Blazars: The View from AGILE

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Abstract. I review the current status of the AGILE Mission, its performance and timeline. For the first time, simultaneous monitoring of a large number of AGNs per pointing will be possible in the 30 MeV - 50 GeV and 10 - 40 keV energy bands, because of an excellent angular resolution and a large field of view ($\sim 1/5$ of the entire sky above 30 MeV). I also discuss some recent results on the possible AGILE contribution to the study of blazars in the gamma-ray and hard X-ray energy bands.

1. Introduction

AGILE (Tavani et al. 2000), a Small Scientific Mission of the Italian Space Agency (ASI), will study celestial sources emitting in the γ-ray energy band 30 MeV - 50 GeV, combined with monitoring capabilities in the hard X-ray band 10 - 40 keV. The AGILE Mission is planned to operate during the years 2004-2006 and its Science Program emphasizes the quick reaction to transients and rapid communication of science data for fast follow-up multiwavelength observations.

2. The AGILE Instrument

The scientific instrument consists of two imaging detectors: 1) the Gamma-Ray Imaging Detector (GRID), made of a Silicon Tracker and a Mini-Calorimeter, and 2) Super-AGILE (SA), made of four Silicon detector units and an ultra-light coded mask system. The imagers are based on an innovative design aimed at excellent imaging, timing and field of view (FOV) capabilities. The Mini-Calorimeter is also capable of independently detecting transient events.

The GRID is made of 10 Silicon-Tungsten planes with the Mini-Calorimeter positioned at the bottom of the istrument. Super-AGILE, with its 4 Si-detectors and ultra-light coded mask system, is positioned on top of the first GRID tray. The instrument size is $\sim 63 \times 63 \times 58\,\mathrm{cm}^3$, including the Anticoincidence system, for a total weight of the external envelope of $\sim$ 100 kg.

Table 1 summarizes the scientific performance of the AGILE detectors, as obtained by detailed Montecarlo simulations for the GRID (Cocco, Longo, & Tavani 2002; Longo, Cocco, & Tavani 2002; Pittori & Tavani 2002), SA (Lapshov et al. 2001), and the mini-calorimeter (Auricchio et al. 2001).

Table 1. AGILE Detectors' Capabilities

Performance	Value
Gamma-Ray Imaging Detector (GRID)	
Energy Range	30 MeV – 50 GeV
Field of view	$\sim$ 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$5-20 arcmin
Energy Resolution (with MCAL, at 400 MeV)	ΔE/E$\sim$1
Deadtime	$\lesssim 200\,\mu$s
Absolute Timing Accuracy	$\sim 2\,\mu$s
Mini-Calorimeter (MCAL)	
Energy Range	$\sim$ 300 keV – 200 MeV
Energy Resolution	$\sim$ 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)	$\sim 20\,\mu$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°×68°
Sensitivity (5σ in 1 day)	$\sim$ 5 mCrab
On-axis Angular Resolution (Pixel Size)	$\sim$ 6 arcmin
Source Location Accuracy (for S/N$\sim$10)	$\sim$ 3-5 arcmin
Energy Resolution	ΔE <4 keV
Deadtime (single "daisy-chain" unit)	$\lesssim 5\,\mu$s
Absolute Timing Accuracy	$\lesssim 5\,\mu$s

A more detailed description of the AGILE Instrument and its scientific goals can be found in Barbiellini et al. (2001) and Tavani et al. (2001).

3. Instrument Performance

Figure 1 shows the AGILE-GRID effective area (top-left panel) and angular resolution (top-right panel) as a function of energy at different off-axis angles in comparision with that of EGRET. The SA effective area (bottom-left panel) as a function of the off-axis angle and the typical sensitivity for an integration time of 50 ksec (bottom-right panel) are also displayed.

For a typical viewing period of two weeks, the GRID sensitivity will be comparable to that of EGRET on-axis, and substantially better off-axis. SA sensitivity, for one day of observation at 5 sigma, will be about 5 mCrab at 13 keV.

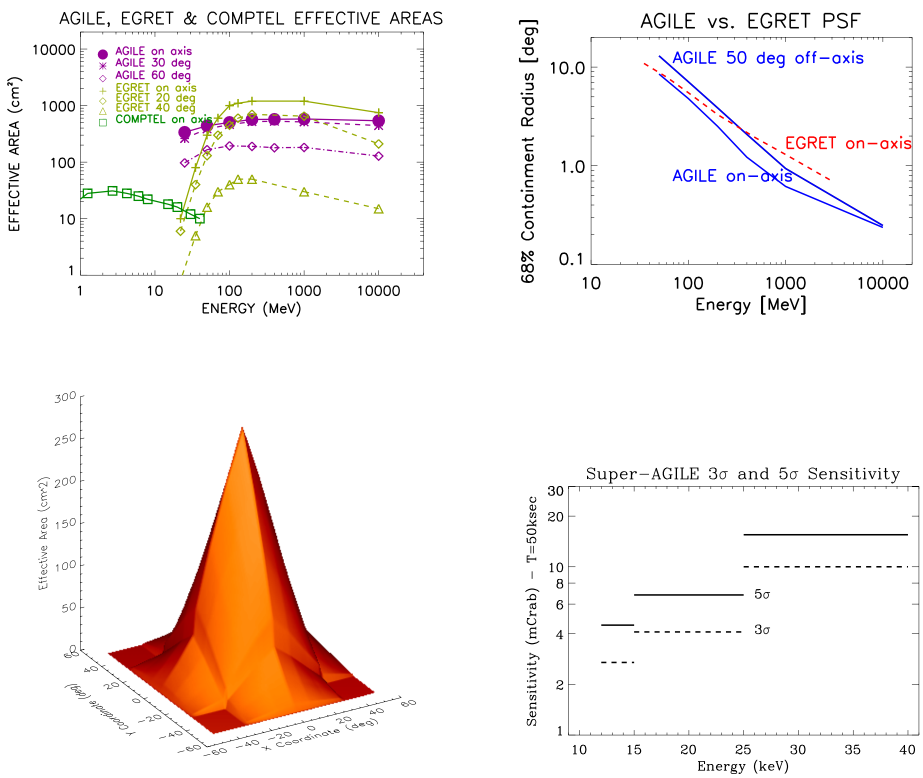

Figure 1. *Top panels:* comparision between the AGILE-GRID and EGRET effective area (left) and angular resolution (right).
Bottom panels: SA effective area (left) and sensitivity (right).

The AGILE γ-ray detector and the hard X-ray monitor will have unprecedented FOVs, respectively $\sim 3\,\mathrm{sr}$ and $\sim 0.8\,\mathrm{sr}$. Taking into account the moderate loss of sensitivity across the FOV, a large number of AGNs per pointing will be monitored, with optimal prospects for γ-ray transient detection. For the first time, simultaneous γ-ray and hard X-ray data on blazars will be collected (e.g., 3C 273 and MKN 501).

The GRID source location 95 % contour radius for a dim γ-ray blazar ($F_{E>100\,\mathrm{MeV}} \sim 30 \times 10^{-8}\,\mathrm{ph\,cm^{-2}s^{-1}}$) observed for two weeks at $\sim 30°$off-axis is simulated to be $r \sim 20$ arcmin, about a factor of two better than EGRET. The same source, if detectable also by SA, could be located with an error box radius $r \lesssim 6$ arcmin.

4. Simulated Observations

4.1. Pointing Strategy

The AGILE satellite imposes some constraints on the AGILE pointing strategy. Due to the spacecraft solar panel constraints, the majority of sources will drift within the AGILE FOV by ~1 deg/day, making the off-axis performance extremely important for our instrument. A possible AGILE pointing strategy for a whole sky coverage (AGILE Cycle-1) could envision 6 pointings lasting 60 days each (see Figure 2).

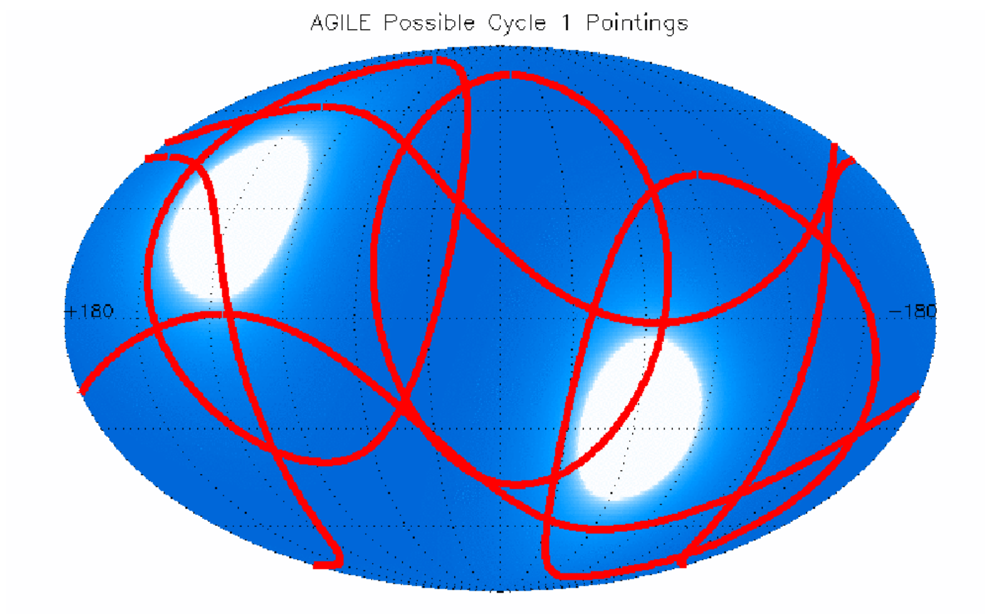

Figure 2. A possible AGILE pointing strategy (AGILE Cycle-1). Red circles are the initial positions of the AGILE-GRID FOV for the six pointings. The blue-scale background represents the Earth occultation factor (for a detailed discussion see Pellizzoni et al. 2001); lighter areas correspond to unocculted sky regions near the Ecliptic Poles. The maximum occultation factor is about 40%.

This strategy can be compared with EGRET Cycle-1 which lasted about 18 months with more than 50 pointings. Our simulations show that AGILE will be able to monitor simultaneously ~10-20 γ-ray AGNs by the GRID, out of which ~2-6 might be detectable by SA. At the completion of AGILE Cycle-1, a typical flux limit at high Galactic latitudes is $F_{\rm E>100MeV} \sim 30 \times 10^{-8}\,{\rm ph\,cm^{-2}s^{-1}}$.

We also studied *how long* AGILE could monitor individual EGRET AGNs (Fichtel 1994; Thompson et al. 1995; Hartman et al. 1999) and their *off-axis angle* distribution. Some preliminary results are summarized in Figure 3. Left panel shows the integration time distribution for the identified and candidate EGRET blazars, obtained with the AGILE Cycle-1 shown in Figure 2. Many sources could be monitored, even if not continuously, for more than 60 days, and

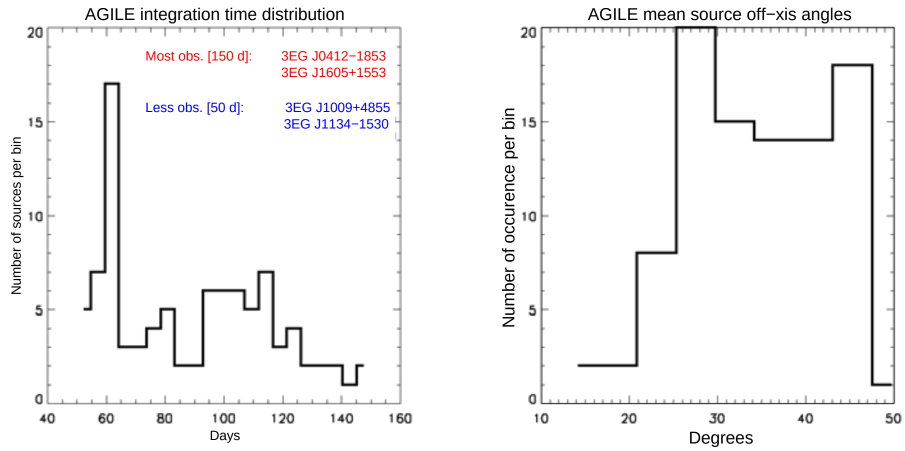

Figure 3. AGILE integration-time (left panel) and mean source off-axis angle (right panel) distributions after one year of observation according to the possible AGILE Cycle-1.

some for more than 100 days, because of pointing overlaps. Right panel shows that most of the EGRET AGNs will be observed by AGILE between 20°and 50°. AGILE is expected to have a modest loss of sensitivity across the FOV (see Figure 1), favouring source detections at off-axis angles much larger than those of EGRET.

4.2. Short-term and Long-Term Monitoring of AGNs

In order to investigate the AGILE short-term and long-term monitoring capabilities of AGNs, we simulated two different scenarios.

For the *short-term* and high intensity case we simulated PKS 1622-297 in a flaring state very similar to the 1995 flare (Mattox et al. 1997). Assuming a peak flux of $F_{\mathrm{E>100MeV}} \sim 1300 \times 10^{-8}\,\mathrm{ph\,cm^{-2}s^{-1}}$, our Quick-look Analysis should be able to report promptly such a strong gamma-ray flare within 1-2 days from the flare onset with error boxes ranging from 15 to 30 arcmin.

In Figure 4 (right panel), the solid line is the total ($cts_{\mathrm{src}} + cts_{\mathrm{bkg}} + cts_{\mathrm{par}}$) lightcurve, while squares with their error-bars are the source reconstructed lightcurve points considering one day of back integration time.

Short-term monitoring of blazars by AGILE could produce quick-look alerts within 2-3 days, depending on source intensity, for multi-λ follow-up observations.

For the *long-term* case we simulated 3C 279, assuming the same lightcurve as derived from EGRET observations (see Figure 5, left panel). The EGRET lightcurve of 3C 279 during the year 1993 (viewing periods *Virgo2, Virgo3a, Virgo3b*, see Hartman et al. 1999) could be approximated, according to the EGRET data, either by a "*flaring*" lightcurve (solid line in Figure 5, left panel) or by a "*steady*" lightcurve (dashed line in Figure 5, left panel). This ambiguity is a consequence of the sparse source monitoring achieved by EGRET.

The assumed AGILE Cycle-1 allows monitoring of this source *continuously* for about 60 days. Such long term monitoring could determine the time sequence

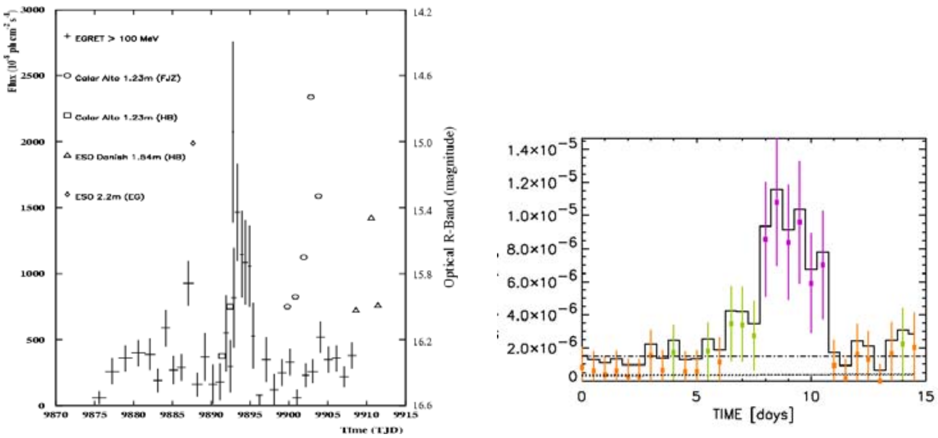

Figure 4. *Left panel:* Time history of PKS 1622-297 in γ-ray (E> 100 MeV) compared to the optical R band during the 1995 flare (Zhang et al. 2002). *Right panel:* Quick-look Analysis reconstrunted light-curve for PKS 1622-297 (for more details see Pellizzoni et al. 2002).

of the flaring and quiescient levels of γ-ray AGNs on time-scales of months. As shown in Figure 5 (right panel), AGILE can distinguish between different alternatives.

The AGN γ-ray duty-cycle will be extensively studied by AGILE by comparing exposures obtained at different epochs.

4.3. Super-AGILE Monitoring Capabilities

For the first time, γ-ray astrophysics will benefit from *simultaneous* observations of blazars in the hard X-ray energy band. We simulated MKN 501 *Beppo*SAX observation on April 7^{th}, 1997 (Pian. et al. 1998). We assumed a peak flux of $\sim$10 mCrab, and an integration time of 50 ksec. The field sources were taken from the *Rossi*XTE ASM X-ray Weather Map, assuming a Crab-like spectrum to convert the RXTE band to the SA one.

Figure 6 shows the imaging and spectral capabilities of SA for such an intense blazar. Left panel shows the SA X and Y zoomed sky images ($5° \times 5°$). Two sources are clearly visible as two peaks at $\gtrsim 10\sigma$ level: Her X-1 (the highest peak) and MKN 501.

SA has also moderate spectroscopic capabilities for such a weak class of sources. Figure 6, Right panel, shows the expected SA spectrum of MKN 501 at different flux levels, respectively, from top to bottom, $(\sim 44, \sim 14, \sim 10)$ mCrab (data from Pian et al. 1998) and simulated ~ 5 mCrab quiescent state.

5. Multi-wavelength Campaigns

5.1. AGILE & the SED of Blazars

Broad-band studies of celestial sources, from the *U, B, V, R, I* photometry to the soft (0.1–2 keV) and hard (2–100 keV) X-ray imaging and spectral analysis are

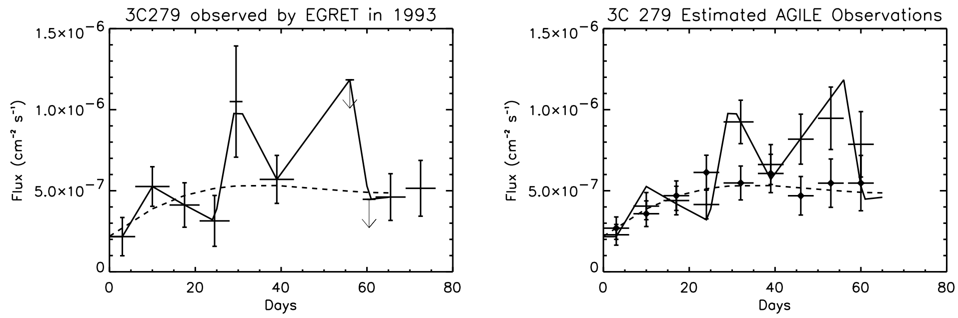

Figure 5. *Left panel:* 3C 279 lightcurve (crosses and upper limits, Hartman et al. 1999) with two possible approximated lightcurves ("*steady*", dashed line and "*flaring*", solid line). *Right panel:* AGILE results after a long-term monitoring program of 3C 279 (for more details see Chen et al. 2002).

now common in astrophysics. For the AGN class, the *broad-band* concept needs to be enlarged to a *multi-*λ approach. Figure 7 shows the AGILE-GRID and Super-AGILE energy bands superimposed on the average SEDs of blazars binned according to radio luminosity. AGILE already will add crucial broad-band spectral information on blazars. Obviously, the science results on γ-ray blazars will benefit from simultaneous and coordinated multi-λ observations involving other energy bands.

Radio (high-spatial resolution and polarimetry) and γ-ray simultaneous observations could set tight constraints on the γ-ray emission sites along the jets. Moreover, the correlation between radio plasmoid ejection in jets and γ -ray flares (Jorstad et al. 2001), still a debated issue because of the EGRET sparse data, will be extensively studied during the AGILE Mission.

Figure 4 (left panel) shows the time history of PKS 1622-297 in γ-ray (E> 100 MeV) compared to the optical R band during the 1995 flare (Zhang et al. 2002). Unfortunately, the sparse sampling in the optical does not allow identifing flux correlations between optical and γ-ray data. Accurate optical–IR observations during γ-ray flares are important in low-energy peaked BL-Lac objects (LBL) to investigate the seed photon regions of γ-ray Inverse Compton radiation and its properties. Networks of optical telescopes, as well as single observatories, could provide the necessary coverage for coordinated optical and γ-ray monitoring of AGNs with AGILE.

Super-AGILE will provide both hard X-ray monitoring of γ-ray AGNs and a prompt alert to TeV ground-based observatories when detecting a flaring source within its FOV. Simultaneous observations of the synchroton and IC spectral bands of high-energy peaked BL-Lac objects (HBL) will provide invaluable information on the physics of the emitting regions.

5.2. Prospects and Strategies

The AGILE Mission will give emphasis to multi-λ campaigns by means of coordinated observation with ground-based and space observatories. The AGILE

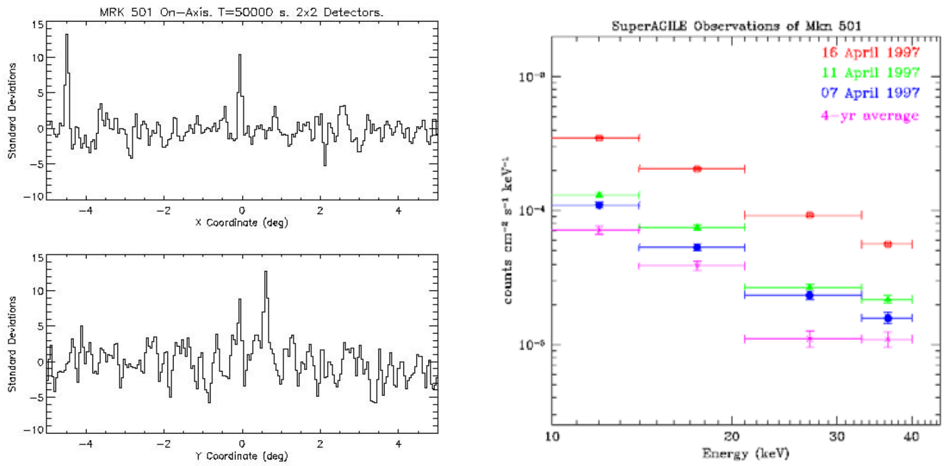

Figure 6. *Left panel:* SA simulated sky images (X and Y views) for MKN 501.The AGN is the less intense between the two peaks. *Right panel:* SA simulated spectrum for different emission levels of MKN 501. See Feroci et al. 2002 for more details.

Team is establishing the "*AGILE-AGN Science Group*" for multi-λ studies of blazars, open to the international community.

Figure 8 shows an example of coordinated multi-λ observations of known γ-ray blazars by AGILE and by ground-based observatories located in the Northern Hemisphere. Red circles and squares are, respectively, identified and candidate EGRET AGNs; green triangles represent unidentified sources. Blue circles are the GRID and the SA FOVs; the black line is the time-dependent AGILE allowed pointing direction; the red line is the accessibility limit ($DEC \gtrsim 15°$) for northern observatories. Filled symbols are the sources that could be monitored simultaneously by AGILE and by ground based observatories.

A dozen sources in the AGILE FOV is a typical number to be considered as possible targets for multi-λ follow-up observations in the radio, optical, IR and TeV energy bands. If a source flares within the GRID FOV but *outside* that of SA, AGILE could repoint, depending on solar panel constraints, to include the flaring source within the SA FOV.

We expect AGILE to discover ~ 100 new AGNs, improving our knowledge of γ-ray duty-cycles, and of blazars SEDs with simultaneous γ-ray and hard X-ray data. Depending on source intensity and spectrum we expect to locate blazars within 6–20 arcmin for moderately intense AGNs at high Galactic latitudes.

6. Conclusions

AGILE will be the only mission entirely dedicated to γ-ray astrophysics in the energy band above 30 MeV during the period 2004–2006. The AGILE Science Program will overlap and be complementary to those of many other high-energy missions as INTEGRAL, NEWTON, CHANDRA, HETE-II, SWIFT, and others.

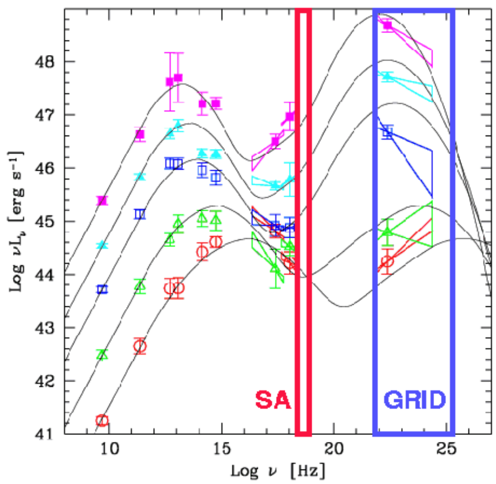

Figure 7. AGILE-GRID and Super-AGILE energy bands superimposed on the average SEDs of blazars binned according to radio luminosity (adapted from Fossati et al. 1998).

The AGILE Mission can contribute to study several AGN "*hot topics*":

1. The study of the *acceleration and radiation processes of AGNs jets*, thanks to multi-λ studies and γ-X-ray detections.
2. The *AGN duty-cycle* of the γ-ray flare and "plateau" states, because of its large FOV and long-term monitoring programs.
3. The study of AGN *SEDs with X-ray and γ-ray simultaneous data*.
4. The study of the suggested *correlation between γ-ray flares and radio plasmoid ejections*.

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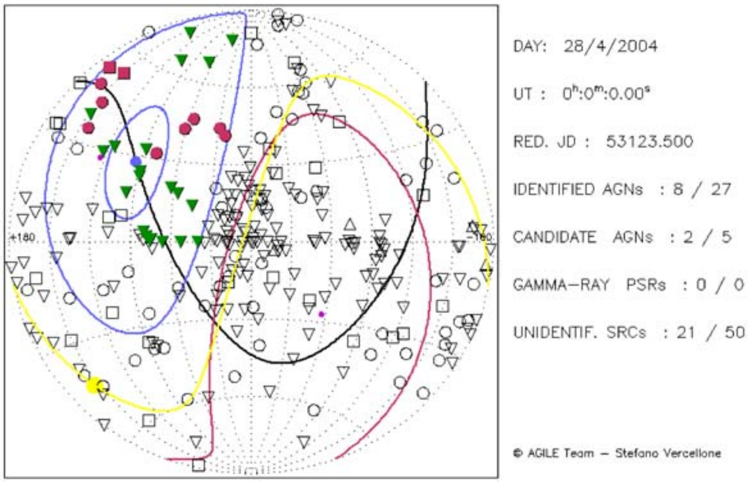

Figure 8. Example of simultaneous γ-ray and hard X-ray monitoring of known γ-ray AGNs by AGILE. Red circles and squares are identified and candidate EGRET AGNs, respectively; green triangles represent unidentified sources. Blue circles are the GRID and the SA FOVs; the black line is the time-dependent AGILE allowed pointing direction; the red line is the accessibility limit ($DEC \gtrsim 15°$) for northern observatories. Filled symbols are the sources that could be monitored simultaneously by AGILE and by ground based observatories.

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