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AGILE DATA CENTER AT ASDC AND AGILE HIGHLIGHTS

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Abstract. We present an overview of the main AGILE Data Center activities and the AGILE scientific highlights during the first 5 years of operations. AGILE is an ASI space mission in joint collaboration with INAF, INFN and CIFS, dedicated to the observation of the gamma-ray Universe. The AGILE satellite was launched on April 23rd, 2007, and is devoted to gamma-ray astrophysics in the 30 MeV ÷ 50 GeV energy range, with simultaneous X-ray imaging capability in the 18 ÷ 60 keV band. Despite the small size and budget, AGILE has produced several important scientific results, including the unexpected discovery of strong and rapid gamma-ray flares from the Crab Nebula over daily timescales. This discovery won AGILE PI and the AGILE Team the prestigious Bruno Rossi Prize for 2012, an international award in the field of high energy astrophysics. Thanks to its sky monitoring capability and fast ground segment alert system, AGILE is substantially improving our knowledge of the gamma-ray sky, also making a crucial contribution to the study of the terrestrial gamma-ray flashes (TGFs) detected in the Earth atmosphere. The AGILE Data Center, part of the ASI Science Data Center (ASDC) located in Frascati, Italy, is in charge of all the science oriented activities related to the analysis, archiving and distribution of AGILE data.

Keywords: gamma-rays: observations, catalogs.

1. Introduction

The AGILE satellite [23], launched on April 23rd, 2007, is the first of a new generation of high-energy space missions based on solid-state silicon technology, substantially improving our knowledge about various known gamma-rays sources, such as supernova remnants and black hole binaries, pulsars and pulsar wind nebulae, blazars and Gamma Ray Bursts. Moreover, AGILE has contributed to the discovery and study of new galactic gamma-ray source classes, of peculiar star systems and of mysterious galactic gamma-ray transients, including the observation that the energy spectrum of terrestrial gamma-ray flashes (TGF) extends well above 40 MeV.

The 2012 Bruno Rossi international Prize was awarded to the PI, Marco Tavani, and the AGILE team for the discovery of rapid gamma-ray flares over daily timescales from the Crab Nebula, thought to be a steady enough source of energy in all wavebands from optical to gamma rays [15]. There is no evidence of correlation between the rapid high energy gamma-ray flares and the decennial variation ($\sim 7\,\%$) of the hard X-ray emission reported from 2005 on by several instruments [29, and references therein]. AGILE observations challenge emission models of pulsar wind interaction and particle acceleration processes.

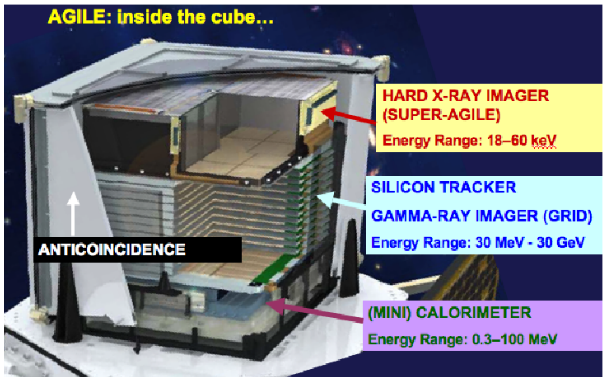

Figure 1. The AGILE payload.

2. The AGILE instrument

The AGILE instrument shown in Fig. 1 (a cube of 60 cm side, weighting only about 100 kg) consists of two detectors using silicon technology: a gamma-ray imager (AGILE-GRID) [4, 20] and a hard X-ray detector (SuperAGILE) [10] for the simultaneous detection and imaging of photons in the 30 MeV ÷ 50 GeV and in the 18 ÷ 60 keV energy ranges. The instrument is completed by a calorimeter (energy range 250 keV ÷ 100 MeV) [13], and by an anti-coincidence system [16].

AGILE is characterized by a very large field of view (~ 3 sr), good angular resolution (~ 36 arcmin at 1 GeV for the GRID, and a spatial resolution of 6 arcmin for SuperAGILE corresponding to a positional accuracy of $\sim 1 \div 2$ arcmin for detections of significance above 10σ in the energy range 18 ÷ 60 keV), as well as a small dead time (100 µs). These features make it a very good instrument to study persistent and transient gamma-ray sources even on very short timescales.

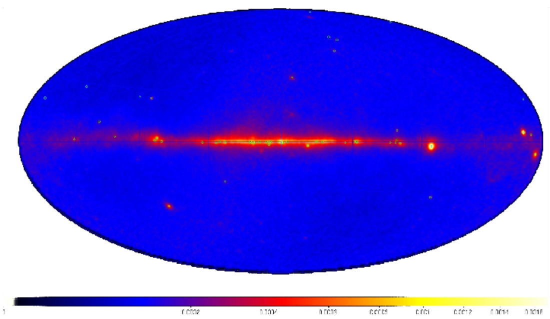

Figure 2. Whole sky AGILE intensity map (ph cm^{-2} s^{-1} sr^{-1}) in Galactic coordinates and Aitoff projection, for energies $E > 100$ MeV, accumulated during the first $\sim$ 5 years of observations, up to December 31, 2011 (pointing + spinning observing modes). Green circles: AGILE First Catalog source positions [18].

3. The AGILE data center and data flow

The AGILE Data Center (ADC) is in charge of all the science-oriented activities related to the analysis, archiving and distribution of AGILE data. It is part of the ASI Science Data Center (ASDC) located in Frascati, Italy, and it includes scientific personnel from both the ASDC and the AGILE Team.

AGILE Telemetry raw data (Level-0) are down-linked every $\sim$ 100 min to the ASI Malindi ground station in Kenya and transmitted first to the Telespazio Mission Control Center at Fucino, and then to the ADC within $\sim$ 5 min after the end of each contact. Raw data are routinely archived, transformed in FITS format through the AGILE Pre-Processing System [27] and processed using the scientific data reduction software tasks developed by the AGILE instrument teams and integrated into an automatic quick-look pipeline system developed at ADC. The AGILE-GRID ground segment alert system is distributed among ADC and the AGILE Team Institutes, and it combines the ADC quick-look [19] with the GRID Science Monitoring system [5] developed by the AGILE Team. Automatic alerts to the AGILE Team are generated within $\sim$ 100 minutes after the TM down-link start (T0) at the Ground Station. GRID Alerts are sent via email (and sms) both on a contact-by-contact basis and on a daily timescale. This fast ground segment alert system is very efficient, and leads to alerts within $\sim$ $(2 \div 2.5)$ hours from an astrophysical event. Refined manual analysis on most interesting alerts are performed every day (quick-look daily monitoring).

Public AGILE data and software are available at the ADC web pages at ASDC[1]. More details on the ADC organization and tasks will be given in a forthcoming publication [19].

[1] http://agile.asdc.asi.it

During the first $\sim$ 2.5 years AGILE was operated in "pointing observing mode", characterized by long observations called Observation Blocks (OBs), typically of 2–4 weeks duration, mostly concentrated along the Galactic plane following a predefined Baseline Pointing Plan. On November 4, 2009, AGILE scientific operations were reconfigured following a malfunction of the rotation wheel that occurred in mid October, 2009. The satellite is currently operating regularly in "spinning observing mode", surveying a large fraction (about 70 %) of the sky each day. The instrument and all the detectors are operating nominally producing data with quality equivalent to that obtained in pointing mode.

In these new attitude conditions, AGILE continuously scans a much larger fraction of the sky, with smaller exposure to each region, and the SuperAGILE X-ray data analysis pipeline required to be fundamentally modified [8]. In nominal pointing conditions, the SuperAGILE fluxes were estimated with an exposure of about 3 ks while, in spinning mode, longer integration times (3.5 and 7 days) are now required to obtain equivalent exposures.

The AGILE Guest Observer Program has not suffered any interruption.

Figure 2 shows the total gamma-ray intensity above 100 MeV as observed by AGILE up to December 31, 2011, during the first $\sim$ 5 years of observations (pointing plus spinning). The AGILE Collaboration has published 98 Astronomical Telegrams (ATels) (42 in pointing + 56 in spinning) and 37 GCN up to May, 2012. Following the success of the mission, the AGILE operational lifetime has been currently extended by ASI at least up to June, 2013.

4. Five years of AGILE: main discoveries and surprises

Thanks to its sky monitoring capability and fast ground segment alert system, AGILE is very effective in detecting bright gamma-ray flares from blazars [28, and references therein], Gamma-Ray Bursts [9, and references therein], and galactic gamma-ray transients [7, and references therein]. We present here a selection of the main AGILE science highlights during the first five years of operations, up to May 2012.

First detection of a colliding wind binary system in gamma-rays by AGILE AGILE provided the first gamma-ray detection above 100 MeV of a colliding wind binary (CWB) system in the η-Carinae region, a phenomenon never observed before [24]. The AGILE satellite repeatedly pointed at the Carina region for a total of $\sim$ 130 days during the time period 2007 July–2009 January. AGILE detected a gamma-ray source (1AGL J1043-5931) consistent with the position of the CWB massive system η-Car. A 2-day gamma-ray flaring episode was also reported on 2008

Oct. 11–13, possibly related to a transient acceleration and radiation episode of the strongly variable shock in the system.

Detection of gamma-ray emission from the Vela-X Pulsar Wind Nebula with AGILE AGILE provided the first experimental confirmation of gamma-ray emission ($E > 100$ MeV) from a pulsar wind nebula (PWN). Pulsars are known to power winds of relativistic particles that can produce bright nebulae by interacting with the surrounding medium. The AGILE detection of gamma-ray emission from the PWN Vela-X, described in a Science paper [17], is the first experimental confirmation of gamma-ray emission ($E > 100$ MeV) from a pulsar wind nebula. This result constrains the particle population responsible for the GeV emission and establishes a class of gamma-ray emitters that could account for a fraction of the unidentified galactic gamma-ray sources. Subsequently the NASA Fermi satellite has confirmed the Vela-X gamma-ray detection, and has also firmly identified 4 other pulsar wind nebulae plus a large number of candidates.

AGILE detections of microquasars in the Cygnus region Microquasars are accreting black holes or neutron stars in binary systems with associated relativistic jets. Before AGILE and Fermi they had never been unambiguously detected emitting high-energy gamma rays.

Episodic transient gamma-ray flaring activity for a source positionally consistent with Cygnus X-1 microquasar was reported twice by AGILE [6, 21, 22]. AGILE extensive monitoring of Cygnus X-1 in the energy range 100 MeV $\div$ 3 GeV during the period 2007 July–2009 October confirmed the existence of a spectral cutoff between 1 $\div$ 100 MeV during the typical hard X-ray spectral state of the source. However, even in this state, Cygnus X-1 is capable of producing episodes of extreme particle acceleration on 1-day timescales. AGILE first detection of a gamma-ray flare above 100 MeV adds to the even shorter lived detection in the TeV range by MAGIC in 2006 [3].

Remarkably, AGILE also detected several gamma-ray flares from Cygnus X-3 microquasar and also a weak persistent emission above 100 MeV from the source for the first time [25]. There is a clear pattern of temporal correlations between the gamma-ray flares and transitional spectral states of the radio-frequency and X-ray emission: flares are all associated with special Cygnus X-3 radio and X-ray/hard X-ray states. Gamma-ray flares occur either in coincidence with low hard X-ray fluxes or during transitions from low to high hard X-ray fluxes, and usually appear before major radio flares. AGILE findings have also been confirmed by Fermi-LAT, which also detected the orbital period (4.8 hours) in gamma-rays, an unambigous temporal signature of the microquasar [1]. In the 9 days from December 2 to December 11, 2009

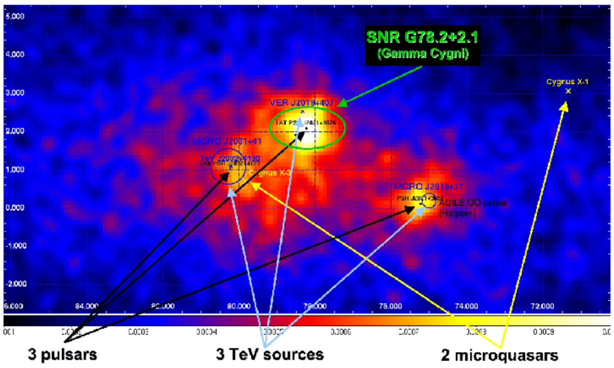

FIGURE 3. The Cygnus region in gamma-rays: AGILE intensity map from 100 MeV to 10 GeV. Data taken in $\sim$ 2-year pointing observing mode, from Nov. 2007 to Oct. 2009, corresponding to $\sim$ 13 Ms net exposure time. Figure adapted from G. Piano presentation, 9th AGILE Workshop, 2012.

a long-lasting mystery wass solved: Cygnus X-3 is able to accelerate particles up to relativistic energies and to emit gamma-rays above 100 MeV.

Evidence of proton acceleration from AGILE observations of Supernova Remnant W44 AGILE discovered a pattern of gamma-ray emission from the supernova remnant W44 that, combined with the observed multifrequency properties of the source, can be unambiguously attributed to accelerated protons interacting with nearby dense gas. The AGILE gamma-ray imager reaches its optimal sensitivity just at the energies in the 50 MeV $\div$ a few GeV range at which neutral pions (produced by proton–proton interactions) radiate with an unambiguous signature. Up to now a direct identification of sites in our Galaxy where proton acceleration takes place was elusive. This important AGILE result is reported in [12].

AGILE contribution to TGF science The AGILE space mission, primarily focused on the study of the gamma-ray Universe, can also detect phenomena originating in the Earth atmosphere. The AGILE Minicalorimeter is indeed detecting Terrestrial Gamma-Ray Flashes (TGFs) associated with tropical thunderstorms. They typically last a few thousandths of a second, and they produce gamma-ray flashes up to 100 MeV, on timescales as low as < 5 ms [14]. AGILE joins other satellites in detecting TGFs, but its unique ability to detect photons of the highest energies within the shortest timescales makes it an ideal istrument for studying these impulsive phenomena. The crucial AGILE contribution to TGF science is the discovery that the TGF spectrum extends well above 40 MeV, and that the high energy tail of the TGF spectrum is harder than expected. TGFs can also be localized from space using high-energy photons detected by the AGILE-GRID detector [11].

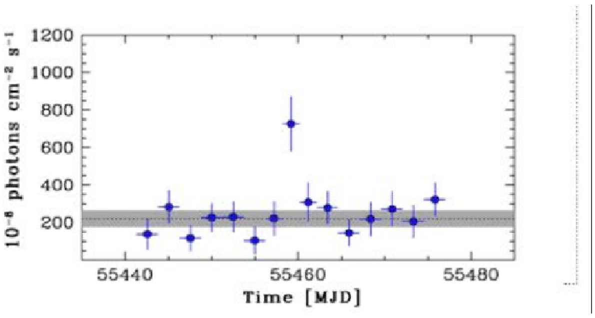

Figure 4. The Crab Nebula flare in September 2010, as observed by AGILE at energies above 100 MeV [26].

Crab Nebula variability During 2010, the AGILE discovery of Crab Nebula variability above 100 MeV astonished the scientific community [2, 26].

Astronomers had long believed the Crab to be a constant source at a level of a few percent from optical to gamma-ray energies, an almost ideal standard candle [15]. Although small-scale variations in the nebula are well-known in optical and X-rays, when averaged over the whole inner region (several arcminute across) the Crab Nebula had been considered essentially stable. However, on September 2010 AGILE detected a rapid giant gamma-ray flare over a daily timescale, see Fig. 4, and due to its rapid alert system, made the first public announcement on September 22, 2010. This finding was confirmed the next day by the Fermi Observatory. AGILE detected a flare from the Crab also in October, 2007 and in Sect. 6.1 of the First AGILE Catalog paper [18], it was reported that anomalous flux values observed from the Crab in 2007 were under investigation.

From 2005 onwards several instruments (Swift, RXTE, INTEGRAL, the Fermi GBM, etc.) have also reported long-term flux variations in the hard X-ray range. Combined observations carried out from 2008 to 2010 with different instruments in overlapping energy bands agree with observing a $\sim 7\,\%$ decline in the Crab $15 \div 50$ keV flux over a ~ 3 year timescale, and a similar decline is also observed in the $3 \div 15$ keV data [29, and referencees therein]. The pulsed flux measured since 1999 is consistent with the pulsar spin-down, indicating that the observed changes are nebular. No evidence of a correlation between the rapid high energy gamma-ray flares and the decennial variation of the hard X-ray emission has been found.

Gamma-ray data provide evidence for particle acceleration mechanisms in nebular shock regions more efficient than previously expected from current theoretical models.

The 2012 Bruno Rossi international Prize has been awarded to the PI, Marco Tavani, and the AGILE team for this important and unexpected discovery.

5. Conclusions

AGILE is substantially improving our knowledge of the gamma-ray sky. In several cases new gamma--ray data provide evidence for particle acceleration mechanisms more efficient than previously expected. Gamma-ray emission from cosmic sources at these energies is intrinsically non-thermal, and the study of the wide variety of gamma-ray sources, such as Galactic and Extragalactic compact objects, and of impulsive gamma-ray events such as far away GRBs and very near TGFs, provides a unique opportunity to test theories of particle acceleration, and radiation processes in extreme conditions and it may help to shed light on the foundations of physics itself.

Full exploitation of the AGILE sensitivity near and below 100 MeV, for which the AGILE exposure is competitive with that of Fermi, is in progress.

Acknowledgements

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References

[1] Abdo, A. A., et al. 2009, Science, 326, 1512

[2] Abdo, A. A. et al., 2011, Science Vol. 331, 739

[3] Albert J. et al, 2007, ApJ, 665, L51

[4] Barbiellini, G. et al., 2001, AIP Conf. Proc. 587, 754

[5] Bulgarelli, A. et al, ASP Conference Series, 411, 362 (2009)

[6] Bulgarelli, A. et al., 2010, ATel #2512

[7] Chen., A. et al., 2010, PoS (Texas 2010) 095

[8] Del Monte, E. et al., 2010, SPIE 7732, section 4.

[9] Del Monte, E. et al., 2012, Mem. S.A.It, Vol. 83, 302

[10] Feroci, M. et al., 2007, NIM A 581, 728

[11] Fuschini, F. et al., 2011, GRL 38, L14806

[12] Giuliani, A. et al., 2011, ApJ 742, L30

[13] Labanti, C. et al., 2006, SPIE, Volume 6266, 62663Q

[14] Marisaldi, M. et al., 2010, JGR 115, A00E13

[15] Meyer, M. et al., 2010, A&A, 523

[16] Perotti, F. et al., 2006, NIM A 556, 228

[17] Pellizzoni, A. et al., 2010, Science, Vol. 327 no. 5966, 663

[18] Pittori, C. et al., 2009, A&A 506, 1563–1574

[19] Pittori, C. et al. 2012, *in preparation*

[20] Prest, M. et al., 2003, NIM A, 501, 280

[21] Sabatini, S. et al.,2010a, ATel #2715

[22] Sabatini, S. et al., 2010b, ApJ 712, L10

[23] Tavani, M. et al., 2009a, A&A, 502, 1015

[24] Tavani, M., et al., 2009b, ApJ 698, L142

[25] Tavani, M. et al., 2009c, Nature 462, 620–623

[26] Tavani, M. et al., 2011, Science Vol. 331, 736–739

[27] Trifoglio, M., Bulgarelli, A., Gianotti, F. et al., 2008, Proceedings of SPIE, Vol. 7011, 70113E

[28] Vercellone, S. et al., 2010, Mem. S.A.It, Vol. 81, 248

[29] Wilson-Hodge, C.A. et al., 2011, ApJ, 727, L40

Discussion

Matteo Guainazzi — Can the "standard candle" quality of the Crab Nebula be retained if flares are identified and removed?

Carlotta Pittori — I recall that the pulsed gamma-ray emission of the Crab does not vary. The Crab steady state (pulsar plus nebula) flux above 100 MeV detected by AGILE is: $F_{\mathrm{steady}} = (2.2 \pm 0.1)10^{-6}\,\mathrm{ph\,cm^{-2}\,s^{-1}}$. By looking at Fig. 4, where the dotted line and band marked in grey color show the average Crab flux and the 3σ uncertainty range, we can see that at this uncertainty level variations outside the flares cannot currently be identified within errors, but a refined analysis is ongoing on this delicate subject. In summary I would say that in the majority of exposure windows the total gamma-ray flux, carefully excluding periods of enhanced emission, is consistent within errors with the standard candle value.

Andrzej Zdziarski — Is there a difference in spectral index between AGILE and Fermi observations of Cygnus X-3?

Carlotta Pittori — There is a paper in progress on the gamma-ray flaring behavior and spectral constraints of Cygnus X-3 (Piano et al. 2012, Accepted for publication in A&A). For the moment I refer you to the 9th AGILE workshop presentation by Giovanni Piano, in which the AGILE-GRID flaring spectrum of the source is shown. Within errors the spectra of the two instruments appear to be consistent.