Mem. S.A.It. Vol. 81, 197

Memorie della

The First AGILE Catalog and First-Year AGILE Highlights

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Abstract. We present an overview of the first catalog of high-confidence γ-ray sources detected by the AGILE satellite during observations performed during the first year of operations. AGILE, launched in April 2007, is an ASI mission with INFN, IASF-CNR e CIFS participation, devoted to γ-ray observations in the 30 MeV – 50 GeV energy range, with simultaneous X-ray imaging capability in the 18–60 keV band. The AGILE First Catalog, recently published on A&A (Pittori et al. 2009), results from a conservative analysis, with a high-quality event filter optimized to select γ-ray events within the central zone of the instrument Field of View (radius of 40°). The catalog includes 47 high-significance γ-ray sources for energies greater than 100 MeV, characterized by a statistical significance above 4 sigma.

Key words. gamma-rays: observations – catalogs

1. Introduction

AGILE (Astrorivelatore Gamma ad Immagini LEggero) (Tavani et al. 2009a) is a mission of the Italian Space Agency (ASI) devoted to γ-ray astrophysics in the 30 MeV – 50 GeV, and 18 – 60 KeV energy ranges. AGILE was successfully launched on April 23, 2007 in a ~550 km equatorial orbit with low inclination angle. AGILE is the first γ-ray mission operating in space after almost ten years since the end of EGRET operations. and it was the only mission entirely dedicated to high-energy astrophysics above 30 MeV during the period April 2007- June 2008. It is currently operating together with the Fermi Gamma-Ray Space Telescope (formerly GLAST), launched on June 11, 2008.

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The AGILE Payload detector consists of the Silicon Tracker (ST) (Barbiellini et al. 2001; Prest et al. 2003), the X-ray detector SuperAGILE (Feroci et al. 2007), the CsI(Tl) Mini-Calorimeter (MCAL) (Labanti et al. 2006), and an anticoincidence system (ACS) (Perotti et al. 2006). The combination of ST, MCAL and ACS forms the Gamma-Ray Imaging Detector (GRID). The highly innovative AGILE instrument is the first of a new generation of high-energy space missions based on solid-state silicon technology, expected to substantially advance our knowledge in several research areas including the study of AGNs, GRBs, pulsars, unidentified γ-ray sources, Galactic compact objects, supernova remnants, etc. During its first year in orbit AGILE surveyed the γ-ray sky and detected many galactic and extragalactic sources. We present here the main results of the conservative data analysis leading to the significance-limited (4σ) first AGILE catalog of high-confidence γ-ray sources, which includes data from July 9, 2007 to June 30, 2008 (Pittori et al. 2009). The catalog sensitivity is nonuniform reflecting the inhomogeneous first year AGILE sky coverage, focused mainly towards the Galactic plane, mostly in the Carina-Crux and in the Cygnus regions, see Fig. 1.

2. The AGILE Data Center at ASDC

The AGILE Data Center (ADC) is the scientific component of the AGILE ground segment, including scientific personnel from both the ASDC and the AGILE Team, and it is part of the ASI Science Data Center (ASDC) located in Frascati, Italy. The ADC is in charge of all the scientific oriented activities related to the analysis, archiving and distribution of AGILE data. 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 ADC. Raw data are received at ADC within $\sim$ 5 min after the end of each contact, archived and routinely 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 ADC is also in charge of the management of the AGILE Pointing Program and of Announcement of Opportunities. More details on the AGILE Data Center organization and tasks will be given in (Pittori et al. in preparation 2000).

2.1. AGILE Cycle-1 Pointing Plan

AGILE pointings are called Observation Blocks (OBs) and typically consist of predefined long exposures (10 - 30 days) drifting about 1 degree per day with respect to the initial boresight direction to match solar panels constraints. Part of the AGILE science program is open to Guest Observers (GO) on a competitive basis through Announcements of Opportunity, managed by ADC. The ADC web pages[1] provide interactive pointing tables for both the predefined AGILE Baseline Pointing Plan and the actual list of pointings, including previously unforeseen ToOs. At the completion of each OB, the AGILE standard analysis removes the data corresponding to repointing slews and occasional losses of fine-pointing attitude. The standardized and cleaned OB Level-2 archive is the basis for creating GO data packets and for the data merge used to build the AGILE first catalog, that includes data of 63 OBs covering the period from July 9, 2007 to June 30, 2008.

3. AGILE Data Analysis

For the first AGILE catalog a conservative analysis was adopted, with a high-quality gamma event filter ("F4" filter) with relatively low effective area, optimized to select gamma-ray events within the central zone of the Field of View (radius of 30 degrees). Data were processed with the most recent software and in-flight calibrations available at the time of writing. In order to merge the data from different observing periods over the whole sky, sets of counts and exposure maps in FITS format (Galactic coordinates) were produced. The centers of the maps were chosen according to the HEALPix algorithm (Górski et al. 2005) with $N_{side} = 4$, for the coverage of the full sky with 192 maps, hereafter called "rings".

AGILE source detection methods use a Maximum Likelihood (ML) analysis to derive the best parameters estimate for candidate sources, such as source significance, flux, and location. The ML statistical technique compares measured counts with the predicted counts derived from source and background gamma-ray model, to find excesses above the predicted diffuse gamma-ray flux taking into account the instrument response functions. In the data analysis the AGILE diffuse emission model (Giuliani et al. 2004; Giuliani et al. in preparation 2000) was used for diffuse background-count predictions.

To build the first catalog two automatic source detection methods were used in cross-

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

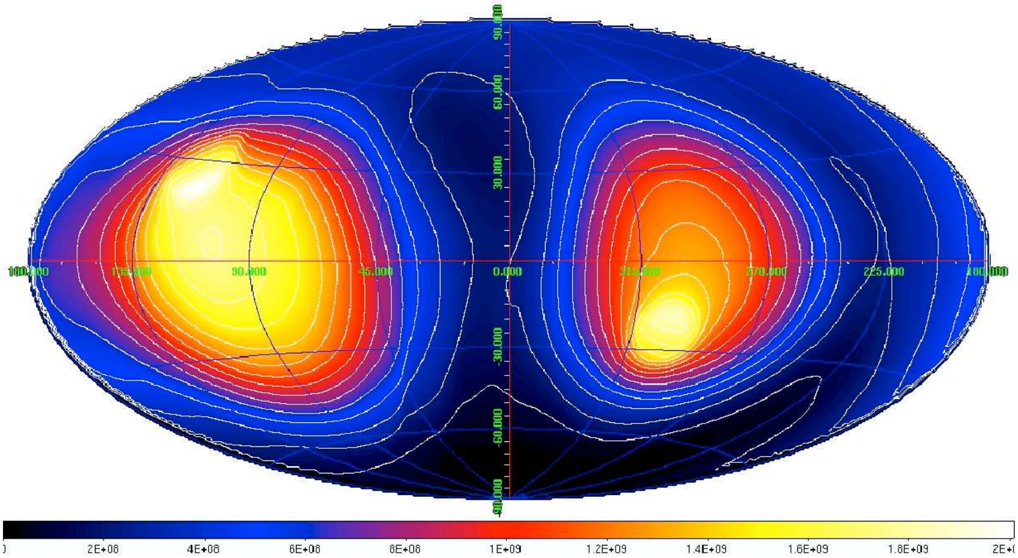

Fig. 1. Total AGILE-GRID exposure sky map in Aitoff projection and Galactic coordinates, for energies > 100 MeV in units of cm^2 s, accumulated during the period July 9, 2007 - June 30, 2008 (with the F4 event filter). The regions of deeper exposures (whiter in the color scale) are a consequence of the AGILE specific pointings at the Galactic plane, combined with the effect of Earth occultation.

correlation, one which uses a single-source likelihood analysis, and typically optimizes detections of isolated γ-ray sources in extragalactic sky-regions, whereas the other is more efficient in complex regions such as on the Galactic plane, where multiple source contributions may contaminate the result. To select high-confidence galactic and extragalactic source candidates a cross-correlation between the two independent dataset was performed, including only detections with statistical significance above 4σ. Then a manual refined analysis was performed with a multi-source likelihood analysis task to confirm the detections and derive optimized source parameters.

4. Results

The final list of validated sources, detected by AGILE-GRID from July 9, 2007 to June 30, 2008 with the method and criteria summarized in previous section includes 47 high-confidence sources (Pittori et al. 2009). The first AGILE catalog sources are plotted in Fig. 2 in galactic sky coordinates, and classified in Table 1, including both confirmed and possible associations.

Table 1. Census of the 47 First AGILE high-confidence gamma-ray sources.

Classification	Confirmed	Possible
Pulsar	7	14
Blazar FSRQ type	4	3
Blazar BL Lac type	4	–
Blazar Unknown type	–	2
CWB	1	–
SNR	2	–
HMXRB	1	1
Unidentified	–	8

Note that the first AGILE Catalog includes only high-significance sources characterized by a prominent mean gamma-ray flux above 100 MeV when integrated over the total one-year long exposure period, and it is not a complete sample due to the nonuniform first-year sky coverage. Source detections during flaring state and determination of peak fluxes were not included in the firts catalog and will be the subject of forthcoming publications.

Preliminary versions were previoulsy published on the ADC webpages to allow AGILE Cycle-2 guest observers to benefit of the catalog in the preparation of their proposals. The interactive final version of the First AGILE Catalog is now available on-line from the ADC web page (*http://agile.asdc.asi.it/*). Available from the webpage are also all the standard interactive ASDC tools, which allow to browse each source sky-region and to make cross-correlations with all available catalogs in other wavebands, see Fig. 3.

5. First year AGILE highlights

5.1. AGILE blazar studies summary

AGILE, as it has been observed by EGRET and now confirmed by Fermi, detects only few objects with flux greater than 100×10^8 ph cm^{-2} s^{-1} above 100 MeV. Whether this is due to selection effects or there is a subclass of blazar with peculiar characteristics is still an open question. Moreover AGILE observations have brought to light a more complex behaviour of blazars with respect to the standard models, indicating the presence of two emission components in any BL Lacs, and the possible contributions of an hot corona as source of seed photons for the External Compton in FSRQs, see also (Vercellone these proc. 2000). The study of multiwavelength correlations is the key to understand the structure of the inner jet and the origin of the seed photons for the Inverse Compton process (Vercellone et al. 2008)-(Donnarumma et al. 2009).

5.2. AGILE pulsar main results

The first AGILE Catalog includes the detection of all the 6 already known EGRET pulsars, see also (Pellizzoni et al. 2009a), and 2 new confirmed pulsars: PSR J2229+6114, providing a reliable identification for the previously unidentified EGRET source (Pellizzoni et al. 2009b), and the GO source PSR J2021+3651, see (Halpern et al. 2008), plus several other pulsar candidates. From the independent timing analysis performed by the AGILE Pulsar working group, up to now data were published for a total of 7 new AGILE pulsar sources (Pellizzoni et al. 2009b). Among the newcomers from timing analysis (not present in the first Catalog) there is the remarkable PSR B1509-58 with very high rotational energy losses, with a magnetic field in excess of 10^{13} Gauss and the powerful millisecond pulsar B1821-24, in the globular cluster M28. Structured energy-dependent peaks (more than two) are evident in pulsar light curves, and multiple gap models may be invoked.

5.3. AGILE study of galactic transients

The study of galactic gamma-ray transients is an "hot topic" for the AGILE mission, which brought already two very important results: the first gamma-ray detection of a colliding wind massive binary system in the eta-Carinae region with AGILE (Tavani et al. 2009b), and the AGILE detection for the first time of a weak persistent emission above 100 MeV and of several gamma-ray flares from the Cygnus X-3 microquasar (Tavani et al. 2009c).

5.4. Impulsive events: AGILE GRBs and TGFs

The X-ray imager SuperAGILE detects several GRBs in its energy band (18-60 keV) at a rate of about 1 per month (Del Monte et al. 2008), while the AGILE MCAL observes about 1 GRB per week in the energy range 0.7-1.4 MeV on several time scales (Marisaldi et al. 2008). At GRID energies only three confirmed GRBs with high energy component $E >$ 50 MeV were observed up to now (Giuliani et al. 2008). The AGILE MCAL also detects very interesting events on timescales < 5 ms, which are currently under study as Terrestrial gamma-ray flashes (TGF) candidates (Marisaldi et al. 2009).

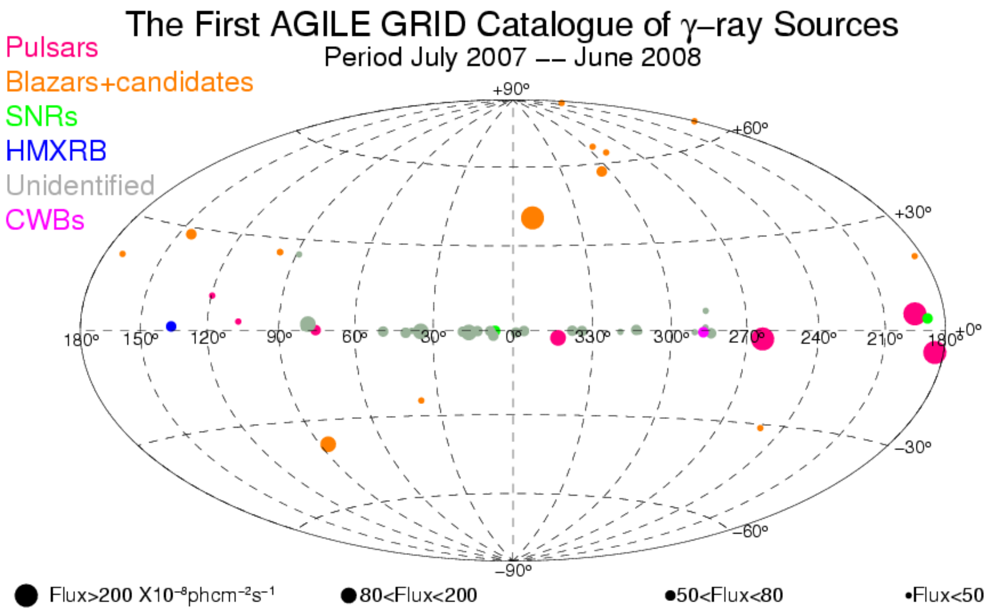

Fig. 2. The First AGILE-GRID Catalog of high-confidence sources, plotted in in Aitoff projection and galactic sky coordinates. Symbol sizes are proportional to source flux values, and symbol colors indicate different source classes.

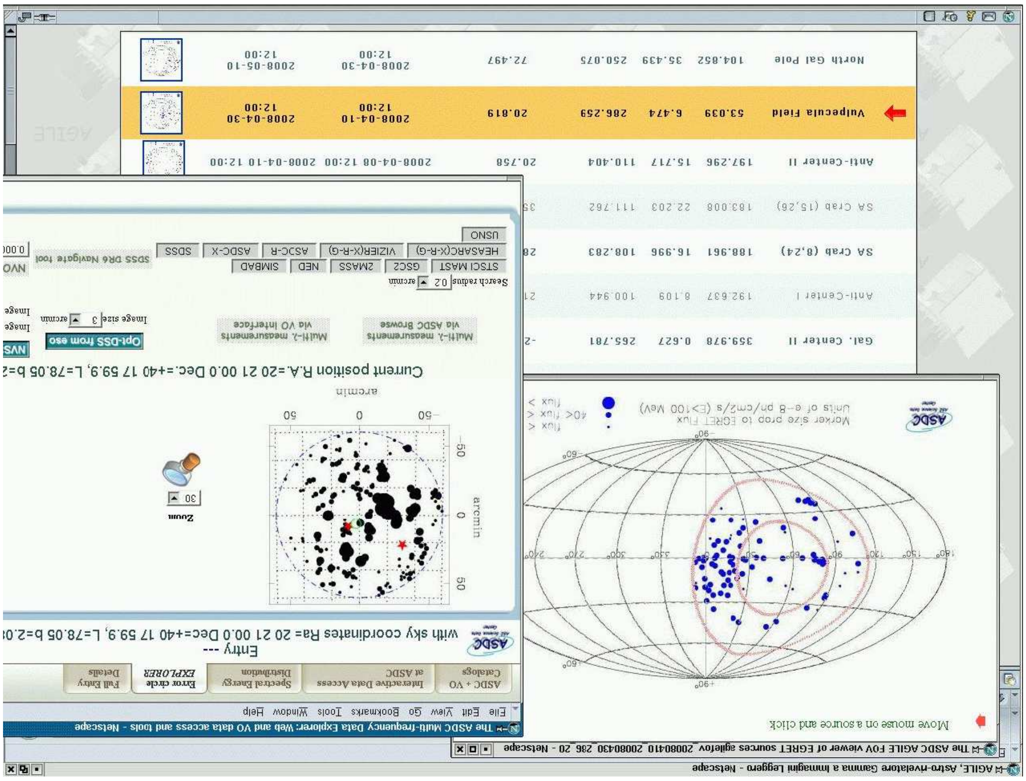

Fig. 3. Exaple of interactive ASDC tools available from the ADC webpage.

6. AGILE data distribution

The Cycle-1 Guest Observer Program (GOP) for AGILE observations carried out during the observing time from December 1st, 2007 to November 30th, 2008 is now completed. In response to the 1st Announcement of Opportunity (AO1) by ASI for obtaining data rights on gamma-ray sources observed by the AGILE-GRID instrument during Cycle-1, ADC received 122 target requests, of which 100 were approved for the GOP by the AGILE Mission Board (39 pulsars, 31 AGN, 30 3EG sources). The schedule of the Cycle-1 data distribution was the following: the first dataset (17 OBs) was delivered to the GOs of successful AO1 proposals on June 5, 2008. A second delivery (3 OB) was done on July 17, 2008 and the Cycle-1 data release was completed on Dec 23, 2008. The Cycle-2 started on Dec. 1, 2008 and is ongoing. For the AGILE AO2, 93 target requests were received for the Cycle-2 GOP, and all of them were approved (21 pulsars, 62 AGN, 10 3EG sources). According to the AGILE Science Management Plan, all AGILE-GRID data (i.e. both from the AGILE PI-Team Projects and from the Guest Observer Program) are subject to the proprietary rules normally applied to observatory space data: there is a one-year proprietary period after which they are available via the public AGILE Data Archive at the ASDC. The one-year proprietary period starts from the date when the Guest Observer (or the AGILE Team) receives the data in a format that is suitable for analysis and publication. The first AGILE software package for scientific analysis (SW build 3.0) available not only to GOs, but also to the general public was delivered, together with a test dataset, on May 22, 2009[2]. The current set of public AGILE-GRID data corresponds to the first 20 AGILE observations of Cycle-1, from December 1, 2007 to June 30, 2008, and are available from the ASDC Multi Mission Interactive Archive webpage: *http://www.asdc.asi.it/mmia/*.

[2] A new SW release (4.0) is currently available from ADC webpage since October 13, 2009.

7. DISCUSSION

ANDRZEJ ZDZIARSKI: Which high-mass binaries has AGILE seen?

CARLOTTA PITTORI: AGILE detected $E > 100$ MeV gamma-ray emission from LSI 6103. Other HMXRB candidates are LS 5039 and Cyg X-3, not confirmed yet. **Note added for Vulcano 09 workshop proceedings:** the AGILE detection of Cyg X-3, not yet confirmed at the time of the workshop, has been confirmed recently, see (Tavani et al. 2009c).

GENNADI BISNOVATYI-KOGAN: How did you manage to find periods of pure γ-ray pulsars, from which there are less (or much less) registered photons per period? In the similar object Geminga the period was found only after it was observed in soft X-rays.

CARLOTTA PITTORI: AGILE has not yet detected γ-ray only pulsars. Fermi satellite, which has a larger effective area than AGILE, was the first to succeed in the blind search for γ-ray only pulsation by applying a new search technique based on photon arrival time differencing. The CTA1 γ-ray pulsar discovered by Fermi is the first example of a new class of pulsars. AGILE in the first catalog detects gamma-ray emission from the CTA1 region, but the AGILE search for gamma pulsation is still under way.

Acknowledgements. We acknowledge funds from ASI grant I/089/06/2.

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