Overview of AGILE Catalogues, GRID & MCAL

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Treasures Hidden in HE Catalogues, Toulouse, May 18, 2018
The AGILE instrument

- AGILE is unique combination of X-ray and gamma-ray detectors -> GW counterpart search
- two co-aligned imaging detectors in hard X-rays (Super-AGILE) and gamma (GRID) + omnidirectional MCAL

Gamma Ray Imaging Detector
- Silicon tracking detector 30 MeV - 50 GeV
- ~2.5 sr FoV

Mini-calorimeter
- non imaging scintillator
- 0.3 - 200 MeV
- almost all-Sky FoV

Super-AGILE Coded aperture
- 18 - 60 keV
- ~1 sr FoV
The AGILE instrument

Gamma-ray imaging detector (GRID)
Energy range 30 MeV–50 GeV
Field of view ~2.5 sr
Flux sensitivity \( (E > 100 \text{ MeV}, 5\sigma \text{ in } 10^6 \text{ s}) \) \( 3 \times 10^{-7} \text{ (ph cm}^{-2} \text{ s}^{-1}) \)
Angular resolution at 100 MeV (68% cont. radius) 4.3 degrees
Angular resolution at 1 GeV (68% cont. radius) 0.7 degrees
Source location accuracy (high Gal. lat., 90% C.L.) ~15 arcmin
Energy resolution (at 400 MeV) \( \Delta E/E \sim 1 \) =>+energy dispersion

In flight Crab radial profile
from AGILE Pointing mode
data compared to the
Fermi/LAT «front» event one
(P7REP).
Sabatini et al. 2015

=>photon-by-photon data
The “two” AGILE lives

- **Pointing mode till Nov 2009, 60° radius FoV**
  coverage: 1/5 of the sky

- **Spinning mode after, sky scanning** (with solar panels constraints)
  coverage: about 80% of the sky in ~ 7 min
• The ADC, based at SSDC c/o ASI-HQ (Rome), is in charge of all the scientific oriented activities related to the analysis and archiving of AGILE data:

  - the processing and archiving of all the data levels, from scientific telemetry (TM) Level-0,
  
  - Preprocessing -> Level-1

  - Creation of main archive -> Level-2 (photon lists and spacecraft files), within Quick-Look & Standard analysis

  - Scientific analysis -> Level-3 scientific maps (counts, exposure and diffuse gamma-ray background maps), for various procedures -> source detections (positions, flux and significances), spectra, light curves

  

INPUT: Row data (TM Level-0)

Preprocessing: Level-1 data

Primary data generation: Quicklook & Standard analysis  Level-2 data (photon list and logfile)

Scientific analysis: Level-3 data

OUTPUT: High level data products (count maps, spectra, light curves...)


AGILE Science Alert System

- The system is distributed among the ADC @ SSDC and the AGILE Team Institutes (Trifoglio, Bulgarelli, Gianotti et al.)

- Automatic Alerts to the AGILE Team are generated within $T_0 + 100$ min (GRID)

- GRID Alerts are sent via email (and sms) both on a contact-by-contact basis and on a daily timescale

- Refined manual analysis on most interesting alerts performed every day (daily monitoring) by dedicated advocates
Standard procedure for AGILE-GRID gamma-ray “all data” catalogues:

catalog of sources on incremental exposure time

0) LV2 archive update: event list creation => AGILE “event filter” based on a Kalman filter → select event of different class types having decreasing probability to be a photon

a) Level-3 scientific products: creation of scientific maps (counts, exposure and diffuse gamma-ray background maps) on the “whole dataset”, integrated, centered at HEALPix pixels, in standard full band \( E > 100 \text{ MeV} \), and in a set of sub-bands to later evaluate source spectra

b) Preliminary blind search algorithms: “source candidate positions” (feeds) extraction, AGILE “spotfinder”, Ximage/detect, SExtractor -> candidate source list

c) scientific analysis: AGILE “multi-source” Maximum Likelihood Estimator (MLE) analysis, evaluating Test Statistics (TS) build as the ratio of the ML functions for the null (background only) and the alternate (source presence) hypotheses. Evaluate source parameters (position, significance, flux, spectral index and errors) and diffuse emission parameters => iterative algorithm, but due to high number of sources & to reduce the parameter space, we execute an iterative procedure:
• **First step:** evaluate first guess for source fluxes and then SINGLE source position refinement and galactic diffuse parameters, keeping fixed a mean spectral index (-2)
• **2nd step:** repeat flux and significance evaluation at fixed position & diffuse par. -> reiterate (?)
• **Final:** estimation of spectra for most significant sources

Concluding source selection based on significance and MLE 95% c.l position contours

Other types of catalogues

**II: AGILE-GRID gamma-ray “all data” catalogues of preselected class of sources**

In this case source positions are known in advance -> mainly execution of MLE at fixed position with a lower significance threshold (≥3σ) and/or allowing positions refinement for specific class of sources

=> For Pointed observations:

**III: AGILE-GRID gamma-ray “single observations”**: Similar procedure as first type of catalog but on usually a single or few maps; known dependence of source detection with the off-axis angle with respect of the map center
Review of AGILE-GRID catalogues on long integration time scales…..

….not exhaustive:

→all on Pointing mode
→not considering transients (days)

Treasures in a complete GRID archive still not completely investigated

All catalogs on-line version from ADC web page http://agile.ssdc.asi.it/
47 high confidence 1AGL sources E> 100 MeV:
• 21 confirmed and candidate Pulsars,
• 13 Blazars (7FSRQ, 4BL Lacs, 2 unknown type),
• 2 possible HMXRBs,
• 2 possible SNRs,
• 1 Colliding-wind Binary System (Eta-Car)
• 8 «Unidentified» sources.
An updated list of AGILE bright $\gamma$-ray sources and their variability in pointing mode

Variability study of an **improved source list** compared to 1AGL, preliminarly revised on the 2.3 yrs “all data” maps of the whole AGILE pointed observations (OB)

No complete source blind search executed, similar to type II catalogues

Processing of EACH SINGLE Obs (duration 1-45d) in E > 100 MeV band allowed to detect 54 sources, among which 15 new one =>variability results

**OB time scale light curves**
An updated list of AGILE bright $\gamma$-ray sources and their variability in pointing mode

Variability indices compared with 1FGL, 2FGL: 12 well known variable sources, named 1AGLR

No mean fluxes on “ALL data” maps published.
The AGL-ALL catalogue project: incremental catalogue

The 1AGLR lack of updated **mean fluxes** on all pointing data => new calibration delivered so need to have homogeneous “mean” source parameters.

Executed a data processing in $E > 100$ MeV band on an input list of 65 1AGL + 1AGLR sources on new Pointing dataset maps generated with new calibration =>defined a new procedure at fixed source position (cat of type II)

**Results:**

61/65 significant 1AGL/1AGLR, 4 sources not detected, =>flaring sources or too weak

Source list presented at 2015 13th AGILE Workshop

Then updated with new sources from specific publications
Search of MeV-GeV counterparts of TeV sources with AGILE in pointing mode


Exploring TeV-GeV connection

**TeV sources input list:** 147 Tev source positions taken from the **TeGeVCat** (Carosi et al. 2016 - previous Lucarelli’s talk)

**Procedure:** type III catalogue

- dataset: the **pointing mode** observations (Jul 2007—Oct 2009)
- Input list of TeV source + AGL-ALL reference list
- Iterative analysis procedure based on MLE with source detection and localization in two steps
  - fixed position (at the TeVCat coordinates)
  - free position (near to the original one)
- Spectral analysis for the most significant ones

for TeV source counterparts search possible displacement was investigated, comparing it with TeV source “extension” and poor angular resolution
Results: known and new sources

- **52** TeV sources show a significant *count excess* in the AGILE data in pointed observations period, 35% of the original sample
- **26** have a spatial association with already known AGILE sources from 1AGL/1AGLR catalogs: 15 galactic, 6 extra-galactic, 5 unassociated
- **26** detections represent new AGILE sources (with respect to the reference catalogs): 15 galactic, 7 extra-galactic, 4 unidentified

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Detected / Total</th>
<th>Source Class</th>
<th>Detected / Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra-galactic</td>
<td>13 / 61 (21%)</td>
<td>Blazar</td>
<td>0 / 1 (0%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HBL</td>
<td>5 / 44 (11%)</td>
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<tr>
<td></td>
<td></td>
<td>IBL</td>
<td>2 / 5 (40%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LBL</td>
<td>2 / 3 (67%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FSRQ</td>
<td>2 / 3 (67%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sbs</td>
<td>0 / 2 (0%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FRI</td>
<td>2 / 3 (67%)</td>
</tr>
<tr>
<td>Galactic</td>
<td>30 / 58 (52%)</td>
<td>PWN</td>
<td>11 / 28 (39%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SNR</td>
<td>7 / 11 (64%)</td>
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<tr>
<td></td>
<td></td>
<td>PWN/SNR</td>
<td>2 / 2 (100%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SNR/MC</td>
<td>5 / 8 (63%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BIN/XRB</td>
<td>3 / 5 (60%)</td>
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<tr>
<td></td>
<td></td>
<td>GC</td>
<td>1 / 1 (100%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WR</td>
<td>1 / 3 (33%)</td>
</tr>
<tr>
<td>Unidentified</td>
<td>9 / 28 (32%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
THE SECOND AGILE CATALOG OF GAMMA-RAY SOURCES: THE FINAL REVIEW

A. BULGARELLI, N. PARMIIGIANI, V. FIORETTI, M. TAVANI, G. PIANO, M. CARDILLO (INAF)
C. PITTORI, F. VERRECCHIA, F. LUCARELLI (SSDC AND INAF)
A. RAPPOLDI, P. CATTANEO (INFN-PV)
A. ABOUDAN (CISAS)
The 2th AGILE Catalog of gamma-ray sources: the final review

Evolved a lot through the last years following various calibration versions and sw improvements.

After development of new BUILD sw (SCI) and new calibration files (IRFS)

AGILE/GRID observations covering the time period July 4, 2007, to October 15, 2009 (the AGILE POINTING MODE).

The analysis is based on data in the

- 100 MeV to 50 GeV energy range
- A check in the "low" energy range 30 MeV - 100 MeV has been performed for the most significant sources

Source detection is based on the integrated data set, i.e., sources are detected according to their average fluxes over about 27 months.
UPDATES

• A long path:
  • The catalog adopts now different spectral shapes
    • Simple Power Law
    • Power Law with exponential cutoff
    • Power Law with super exponential cutoff
    • Log Parabola
  • The NEW BUILD25 (AGILE/GRID Science Tools) has been used, that include also the energy dispersion correction factor (EDP)
  • New Instrument Response Functions: H0025 -> energy range
  ➔ spectral comparison with Fermi/LAT: same spectral bins till 10GeV
NEW BUILD25: CURVED SPECTRAL ANALYSIS

Vela region
30 MeV - 10 GeV

Magenta: 3FGL
Brown: 2AGL

\[
dN/dE = N_0 \left( \frac{E}{E_0} \right)^{\gamma_1} \exp \left( - \left( \frac{E}{E_c} \right)^{\gamma_2} \right)
\]

\[\gamma_1 = 1.71 \pm 0.04\]
\[E_c = 3913 \pm 530 \text{ MeV}\]
\[\gamma_2 = 1.34 \pm 0.30\]
• Cross check with previous BUILD22@SSDC: only confirmed detections are included in the catalog

• The gamma-ray diffuse model used in the analysis has been improved. The diffuse model is particularly important for sources from low to mid Galactic latitudes.
First step: the seeds
source blind search

W A V E L E T A L G O R I T H M ( T H E S E E D M E T H O D N ° 1 )
Second step

**MANUAL ANALYSIS**

• From the list of seeds using all methods...

• Manual analysis

• Final determination of position and flux

Third step

**CHECK THE RESIDUAL TS MAP**
Spectra (100-10000 MeV)

Light curves (4 days)

Curvature Index

Variability Index
RESULTS

190 2AGL sources
PRELIMINARY ASSOCIATIONS

- Positional coincidence only

- These associations are not in general to be taken as firm identifications: a physical relationship is not established between gamma-ray sources and sources in other wavelengths.

- 20 AGILE-only (no 3FGL) sources

<table>
<thead>
<tr>
<th>Description</th>
<th>number</th>
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</thead>
<tbody>
<tr>
<td>BCU (Blazar candidate of uncertain type)</td>
<td>10</td>
</tr>
<tr>
<td>BLL (BL Lac type of blazar)</td>
<td>17</td>
</tr>
<tr>
<td>FSRQ (FSRQ type of blazar)</td>
<td>31</td>
</tr>
<tr>
<td>RDG (Radio galaxy)</td>
<td>2 (CenA, NGC1275)</td>
</tr>
<tr>
<td>BIN (Binary)</td>
<td>1 (Eta Carinae)</td>
</tr>
<tr>
<td>GLC (Globular cluster)</td>
<td>1 (Terzan 5)</td>
</tr>
<tr>
<td>HMB (High-mass binary)</td>
<td>3</td>
</tr>
<tr>
<td>PSR (positional only)</td>
<td>50</td>
</tr>
<tr>
<td>PWN</td>
<td>3</td>
</tr>
<tr>
<td>SNR</td>
<td>9</td>
</tr>
<tr>
<td>SPP</td>
<td>7</td>
</tr>
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<td>134</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HMB (High-mass binary)</th>
<th>LSI+61 303, 1FGLJ1018.6-5856, Cygnus X-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR</td>
<td>IC443, CTB37A, W28, W30, W44, W49B, W51, GammaCygni, HB21</td>
</tr>
<tr>
<td>PWN</td>
<td>Crab Nebula, HESSJ1632-478, PWNG0.13-0.11</td>
</tr>
</tbody>
</table>
FUTURE:

• New catalogue «integrated» maps: including Spinning mode data → lower acquisition efficiency, currently used in specific work

• New homogeneous «transient» source catalogue: on both archives; Variability catalog(s) based on experience from 2AGL and using ADC light curve tool (ALCE) and LV3 tool (Lucarelli’s talk)
SSDC Data Explorer Tool
Quick Look AGILE database and automatic light curves

Example of the ALCE Tool, simple version
MCAL catalogues
MCAL GRB Catalog
(M. Galli et al., 2013)

Photon-by-photon data from launch till Oct 2009: high-energy emission from GRB. → detected 85 GRB, 24 with spectral data
• Similar bimodal T90 distribution to lower energies, with 21% short GRB

→ a new catalog is in progress after development of new pipeline for GW counterpart searches
MCAL Terrestrial Gamma-ray Flash Catalogs

First catalog of MCAL TGF published in Marisaldi et al. 2014
“Properties of Terrestrial Gamma-Ray Flashes detected by AGILE MCAL below 30 MeV” on data from March 2009 to July 2012
->detected 308 TGF below 30 MeV
- Longitudinal distribution similar to previous ones; comparison with RHESSI and Fermi/GBM sample; correlation with WWLLN radio on ground → larger durations due to AC dead time (100 μs)

Catalog web page to access light curves and new dedicated tool
MCAL Terrestrial Gamma-ray Flash Catalogs

2nd catalog of MCAL TGF published in Marisaldi et al. 2015

“Enhanced detection of Terrestrial Gamma-Ray Flashes by AGILE” on data from 23 March to 24 June 2015 ONLY with the AC Veto disabled!

- detected 279 TGF below 30 MeV
- TGF rate increased by 1 order of mag! Most with duration < 100 µs as expected
- First unbiased by dead time sample → correlation with Fermi/GBM sample
- Better correlation with WWLLN

![Map of TGF detections with duration distribution inset](image)

- CNT < 12
- 12 < CNT < 16
- 16 < CNT < 30
- CNT > 30 (CNT are MJD cts)
Enhanced detection of Terrestrial Gamma-Ray Flashes by AGILE
TGF (E < 30 MeV) observed from March 2015 to June 2015

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Online version of the second AGILE Terrestrial Gamma-ray Flashes (TGF) catalog below 30 MeV detected by the Minikinoalorimeter (MCAL) instrument. It was a configuration change aimed at the inhibition of the anti-coincidence veto signal on the MCAL instrument in order to improve the TGF detection per entry with respect to the previous configuration.

The interactive web table includes 279 TGF detected by AGILE MCAL selected to have the maximum photon energy up to 30 MeV, and a maximum latitude of 60° north.

Columns description:
The first AGILE/MCAL TGF catalog on-line web table, Marzidi et al. 2015

Entry number
TGF ID
Section
Geolat
Date (UTC)
Trigger Time (Relative TGF time)
UG-Metro (ps)
TSF (ms)

This view includes 279 entries:
AGILE Total Intensity Map (E> 100 MeV):
Pointing + Spinning (up to Sep 30, 2017)

AGL-ALL: 1AGL/1AGLR + some new one from TeV processing
AGILE Total Intensity Map (E> 100 MeV):
Pointing + Spinning (up to Sep 30, 2017)

Short summary:
very soon news from GRID
but more still to discover in Spinning data archive

News will follow soon about MCAL “short” time scale events

Thank you!