Galactic gamma-ray astrophysics with AGILE Highlights

F. Longo

on behalf of the AGILE Galactic WG

Milano, April 23, 2009
The Galactic WG


• SNR and TeV + Diffuse and DM + UnID WGs + X-ray Compact Sources

• Close connection with PSR WG
Technical Activities by the Group

- Likelihood Multi Src Tool
- Galactic Diffuse emission model
- Search for Gamma-ray Transients
- X-Gamma analysis
- AGILE Catalog
The Galaxy
1yr Exposure
1 yr Gamma-ray sky by AGILE
2yr Exposure
2 yr Gamma-ray sky by AGILE
AGILE First Catalog of high-significance gamma-ray sources

AGILE GRID First Source Catalogue
Period July 2007 -- June 2008

average flux above 100 MeV

Flux>200 \times 10^{-8} \text{ph cm}^{-2} \text{s}^{-1}

80<\text{Flux}<200

50<\text{Flux}<80

\text{Flux}<50

Pittori et al., 2009
X-ray sources by SA

Map of X-ray Sources detected and localized by SuperAGILE
July 2007 – December 2008
Main Galactic science topics

- Diffuse gamma-ray emission
- Pulsars (see M.Pilia’s talk)
- SNRs and origin of cosmic rays
- Massive sources
- VARIABLE Galactic sources
- Microquasars, Gal. compact objects
- The Galactic center
## AGILE Source List -- Partial

Fluxes in units of $10^{-8}$ ph/cm$^2$/s, $E > 100$ MeV

<table>
<thead>
<tr>
<th>AGL J</th>
<th>L (deg)</th>
<th>B (deg)</th>
<th>Flux</th>
<th>Counts</th>
<th>sqrt(TS)</th>
<th>Δθ (deg)</th>
<th>Counterpart(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1805-2301</td>
<td>7.39</td>
<td>-0.93</td>
<td>104 ± 13</td>
<td>342 ± 44</td>
<td>8.81</td>
<td>0.62</td>
<td>3EG J1800-2338, W28</td>
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<tr>
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<td>GUEST OBSERVER: T. MINEO</td>
</tr>
<tr>
<td>2021+4032</td>
<td>78.35</td>
<td>2.08</td>
<td>119 ± 6</td>
<td>1778 ± 84</td>
<td>25.87</td>
<td>0.11</td>
<td>3EG J2021+3716?, PSR J2021+3651</td>
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<td>GUEST OBSERVER: D. TORRES</td>
</tr>
<tr>
<td>2032+4106</td>
<td>80.03</td>
<td>0.71</td>
<td>34 ± 5</td>
<td>507 ± 77</td>
<td>7.03</td>
<td>0.41</td>
<td>3EG J2033+4118, TeV J2032+4130, Cyg OB2 #8a</td>
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<td>GUEST OBSERVER: J. HALPERN</td>
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<tr>
<td>2230+6120</td>
<td>106.86</td>
<td>2.94</td>
<td>26 ± 4</td>
<td>301 ± 45</td>
<td>7.50</td>
<td>0.41</td>
<td>3EG J2227+6122, PSR J2229+6114, SAX J2239.3+6116</td>
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<td>GUEST OBSERVER: D. TORRES</td>
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<tr>
<td>0240+6141</td>
<td>135.43</td>
<td>1.49</td>
<td>51 ± 7</td>
<td>225 ± 31</td>
<td>8.69</td>
<td>0.38</td>
<td>3EG J0241+6103, LSI +61° 303</td>
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<tr>
<td>0534+2207</td>
<td>184.50</td>
<td>-5.66</td>
<td>279 ± 10</td>
<td>1646 ± 58</td>
<td>42.85</td>
<td>0.08</td>
<td>Crab</td>
</tr>
<tr>
<td>0617+2235</td>
<td>189.05</td>
<td>3.06</td>
<td>47 ± 5</td>
<td>283 ± 33</td>
<td>10.61</td>
<td>0.22</td>
<td>3EG J0617+2238, IC443</td>
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<tr>
<td>0634+1748</td>
<td>195.13</td>
<td>4.33</td>
<td>315 ± 9</td>
<td>1896 ± 54</td>
<td>60.64</td>
<td>0.05</td>
<td>Geminga</td>
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<tr>
<td>0835-4511</td>
<td>263.57</td>
<td>-2.79</td>
<td>708 ± 24</td>
<td>1364 ± 47</td>
<td>48.55</td>
<td>0.08</td>
<td>Vela</td>
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<tr>
<td>1021-5817</td>
<td>284.32</td>
<td>-0.93</td>
<td>69 ± 6</td>
<td>725 ± 61</td>
<td>13.54</td>
<td>0.23</td>
<td>3EG J1027-5817, WR21a</td>
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<td>GUEST OBSERVER: P. WELTEVREDE</td>
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<tr>
<td>1110-6115</td>
<td>291.15</td>
<td>-0.70</td>
<td>31 ± 5</td>
<td>334 ± 51</td>
<td>7.15</td>
<td>0.47</td>
<td>3EG J1102-6103?, PSR J1105-6107</td>
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<tr>
<td>1170-6429</td>
<td>343.06</td>
<td>-2.63</td>
<td>107 ± 7</td>
<td>870 ± 56</td>
<td>19.04</td>
<td>0.14</td>
<td>3EG J1710-4439, PSR B1706-44</td>
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<td>GUEST OBSERVER: A. POSSENTI</td>
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<tr>
<td>1709-4429</td>
<td>343.06</td>
<td>-2.63</td>
<td>107 ± 7</td>
<td>870 ± 56</td>
<td>19.04</td>
<td>0.14</td>
<td>3EG J1710-4439, PSR B1706-44</td>
</tr>
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<td>GUEST OBSERVER: A. POSSENTI</td>
</tr>
</tbody>
</table>

Fluxes in units of $10^{-8}$ ph/cm$^2$/s, $E > 100$ MeV
AGILE Observations vs Model
(-90 < l < 90)
In about 9 months of scientific life, AGILE reached EGRET exposure level in the Vela region.


<table>
<thead>
<tr>
<th>PSR</th>
<th>Pulsed Counts</th>
<th>Pulsed Flux$^c$</th>
<th>Exposure$^b$</th>
<th>$\chi^2_r$ (d.o.f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vela</td>
<td>9,170±580</td>
<td>930±60</td>
<td>1.24</td>
<td>225.51 (9)</td>
</tr>
<tr>
<td>Geminga</td>
<td>1,900±480</td>
<td>280±70</td>
<td>0.85</td>
<td>10.44 (9)</td>
</tr>
<tr>
<td>Crab</td>
<td>2,000±530</td>
<td>270±70</td>
<td>0.92</td>
<td>10.71 (9)</td>
</tr>
<tr>
<td>J1709-4429</td>
<td>2,370±720</td>
<td>190±60</td>
<td>1.56</td>
<td>9.11 (9)</td>
</tr>
</tbody>
</table>

$^a$Pulsed counts (G+L event class) with $E>100$ MeV, 5 deg max from PSR position, 60 deg max from FOV center, 10 bins.

$^b$Good observing time after dead-time and occultation corrections.

$^c$Calculated with the expression $C_P f/E$, where $C_P$=pulsed counts, $E$=exposure, $f$=factor accounting for source counts at angular distance $>5$ deg from source position according to the point spread function ($f$~1.3).
AGILE’s new gamma-ray pulsars


<table>
<thead>
<tr>
<th>PSR Name</th>
<th>G.Lon.</th>
<th>G.Lat.</th>
<th>P</th>
<th>(\tau^a)</th>
<th>(D^a)</th>
<th>(\log \dot{E})</th>
<th>(\chi^2_{\text{red}}(N_{\text{st}})^b)</th>
<th>(\sigma_{\text{time}}^c)</th>
<th>(\sigma_{\text{space}}^d)</th>
<th>(F^d)</th>
<th>(\log L_{\gamma}^e)</th>
<th>(L_{\gamma}/\dot{E})</th>
</tr>
</thead>
<tbody>
<tr>
<td>J2229+6114</td>
<td>106.65</td>
<td>2.95</td>
<td>51.6</td>
<td>1.0 \times 10^4</td>
<td>12.0</td>
<td>37.35</td>
<td>6.0(36)</td>
<td>5.0</td>
<td>7.5</td>
<td>26\pm4</td>
<td>35.36</td>
<td>0.01</td>
</tr>
<tr>
<td>J1513–5908</td>
<td>320.32</td>
<td>-1.16</td>
<td>150.7</td>
<td>1.6 \times 10^3</td>
<td>5.8</td>
<td>37.25</td>
<td>4.2(3)</td>
<td>4.0</td>
<td>6.4</td>
<td>34\pm6</td>
<td>35.04</td>
<td>0.006</td>
</tr>
<tr>
<td>J1016–5857</td>
<td>284.08</td>
<td>-1.88</td>
<td>107.4</td>
<td>2.1 \times 10^4</td>
<td>9.3</td>
<td>36.41</td>
<td>6.0(69)</td>
<td>4.8</td>
<td>12.3</td>
<td>62\pm6</td>
<td>35.71</td>
<td>0.2</td>
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<tr>
<td>J1824–2452</td>
<td>7.80</td>
<td>-5.58</td>
<td>3.0</td>
<td>3.0 \times 10^7</td>
<td>4.9</td>
<td>36.35</td>
<td>4.2(1)</td>
<td>4.2</td>
<td>3.6</td>
<td>18\pm5</td>
<td>34.62</td>
<td>0.02</td>
</tr>
<tr>
<td>J1357–6429</td>
<td>309.92</td>
<td>-2.51</td>
<td>166.1</td>
<td>7.3 \times 10^3</td>
<td>4.1</td>
<td>36.49</td>
<td>5.2(7)</td>
<td>4.7</td>
<td>1.8</td>
<td>&lt;14</td>
<td>&lt;34.35</td>
<td>&lt;0.007</td>
</tr>
<tr>
<td>J2043+2740</td>
<td>70.61</td>
<td>-9.15</td>
<td>96.1</td>
<td>1.2 \times 10^6</td>
<td>1.1</td>
<td>34.75</td>
<td>4.1(1)</td>
<td>4.2</td>
<td>0.6</td>
<td>&lt;6</td>
<td>&lt;32.84</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>J1524–5625</td>
<td>323.00</td>
<td>0.35</td>
<td>78.2</td>
<td>3.2 \times 10^4</td>
<td>3.8</td>
<td>36.51</td>
<td>4.6(4)</td>
<td>4.3</td>
<td>1.0</td>
<td>&lt;16</td>
<td>&lt;34.34</td>
<td>&lt;0.007</td>
</tr>
</tbody>
</table>
Anticenter – Molecular Clouds Complex

Gamma-ray intensity map

Gamma-ray model based on CO maps

Intensity map – ph/cm² sec sr
EGRET source
(Hartman et al. 1999)

TeV source
(MAGIC, VERITAS)
Proton acceleration in IC 443?

• 100 MeV source and TeV source are non coincident!

• Absence of IC emission above 10-100 GeV at the gamma-ray peak:
  – electron/proton ratio \( \sim 10^{-2} \) (see also Gaisser et al. 1998)

• Absence of prominent TeV emission along the SN shock front (and of non-thermal X-ray emission):
  – electron contribution subdominant

• The Northeastern SNR shock environment provides the target for proton-proton interaction and pion production/decay
  – Hadronic model at the NE shock is the only viable
Cygnus Region  2007 -2008
ATEL #1308  Chen et al.

AGILE gamma-ray detection of a strongly variable source in the Cygnus region

Observed November 9-25, 2007

1-day flare on November 23-24, 2007

Significance and flux

3 days: \((1.2 \pm 0.3) \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}\) at \(4.9 \sigma\)

1 day: \((2.6 \pm 1.0) \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}\) at \(3.8 \sigma\)

Position \((l,b) = (74.4, -0.5)^\circ\), error \(\sim 0.8^\circ\)
AGLJ2022+3622 -- Light Curve

\[
\text{mean} = 1.32700 \times 10^{-6}, \quad \text{chi}^2 = 4.2377315, \quad \text{prob} = 0.0015704235
\]
Cygnus Region

- Persistent Emission
  - \((1.20 \pm 0.07) \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}\) at 23\(\sigma\) \& 4\(\sigma\)

- Position: \((l,b) = (78.37, 2.04)\)°, error \(\sim 0.12°\)
  - 1-day flare on April 27-28, 2008 [ATel #1492]
    - \((2.9 \pm 0.8) \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}\) at 3.7\(\sigma\)
    - Position: \((l,b) = (78.1, 2.0)\)°, error \(\sim 0.8°\)
  - 1-day flare on June 20-21, 2008 [ATel #1585]
    - \((2.5 \pm 0.7) \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}\) at 4.9\(\sigma\)
    - Position \((l,b) = (78.6, 1.6)\)°, error \(\sim 0.7°\)
  - 1-day flare on November 16-17, 2008 [ATel #1848]
    - \((2.5 \pm 0.7) \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}\) at 4.8\(\sigma\)
    - Position \((l,b) = (78.6, 2.1)\)°, error \(\sim 0.7°\)

- Gamma association: 3EG J2020+4017 - 0FGL J2021.5+4026
Very difficult to react in such a short time
Transient in the Carina Region

2 days integration maps - counterclockwise

Gamma light curve vs RXTE light curve

Tavani et al., 2009

F.Longo et al. -- 25
Cygnus X-3

15 - 18 April 2008

Giant radio flare of Cygnus X-3 detected by RATAN-600 radio telescope
Radio flux increasing of a factor $\sim 10^3$, from $\sim 10$ mJy to $\sim 10$ Jy
S.A.Trushkin et al., ATel #1483
10 Jy is typical flux for plasmoids emission!

In the same period SuperAGILE revealed an X-ray flare
Cygnus X-3

FT3ab_2
28/30 Aprile
sqrt(TS) = 4.42
A different kind of variability
AGL J1835+5927

Light curve of AGL J1835+5927 (temporal bin of 5 days)

Bulgarelli et al., 2009  2008A&A...489L..17B
Cyg X-1

Likely the longest continuous hard X-ray monitoring of Cyg X-1

Total Observation Time: ~ 4.5 Ms   (1196 Orbits)

\( \approx 1.3 \text{ Crab Flare} \)

(see also INTEGRAL ATels #1533,1536)
41.5 d orbital period

The regular flares 1-2 days before periastron...
And the 680s X-ray Pulsar

Evangelista et al. in preparation
Galactic Center as seen by SuperAGILE

- 4U 1820-303
- 4U 1700-377
- GX 340+0
- AX J1749.1-2639
- GX 5-1
- Ginga 1826-24
- Sco X-1
- GX 17+2

- Sco X-1
- AX J1749.1-2639
- GX 5-1
- Ginga 1826-24
- 4U 1820-303
- 4U 1820-303
Galactic Center as seen by SuperAGILE

Daily variability in the Galactic Center

- 4U 1820-303
- Ginga 1826-24
- GRS 1758-258
- Sco X-1
- GX 17+2
- AX J1749.1-2639
- GX 1+4

9 Days Integration

F.Longo et al. -- 34
Galactic Center

X-ray sources detected by SuperAGILE on Gamma-ray map by AGILE-GRID (March, 28/29)
Searching for transient sources: the maps subtraction method

Residual maps contain:

1) fluctuations due to statistical noise
2) fluctuations due to possible transient sources appearing in the map of the day

Statistical significance of fluctuations can be assigned and tested towards a null hypothesis
Variability of 1AGL sources

Observation Block (OB) timescale (typically 1 month) and intra-OB weekly timescale.

⇒ Monitoring (flux history) of 1AGL sources on shorter timescales over a period of almost 2 years (from July 2007 to January 2009)
TeV sources search

Search for AGILE counterparts of TeV Catalog sources
Future prospects for AGILE…

- Erratic variability of accreting micro-QSOs
- Need simultaneous and well-sampled X-ray and gamma-ray coverage!
- Gamma-ray emission rare, if any.

- Analysis of SNR & PSR/PWN
- Study of diffuse emission