A study of the AGILE first catalog galactic γ-ray sources on the 2.3 years AGILE-GRID data

F. Verrecchia[1,4], C. Pittori[1], A.W. Chen[2], A. Bulgarelli[3], on behalf of the AGILE Collaboration
[1] ASDC, ASI Science Data Center, Frascati (RM); [2] INAF-IASF Milano, via E. Bassini 15, I-20133 Milano, Italy; [3] INAF-IASF Bologna, via Gobetti 101, I-40129 Bologna, Italy; [4] Consorzio Interuniversitario Fisica Spaziale (CIFS), villa Gualino - v.le Settimio Severo 63, I-10133 Torino, Italy.

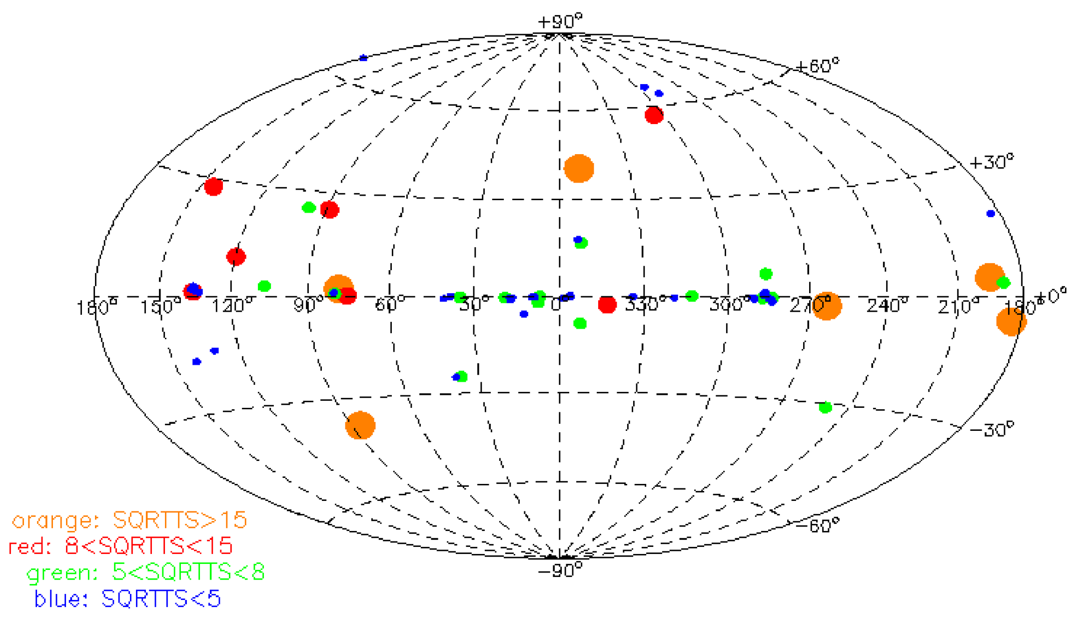


Figure 1: the Aitoff plot of 62 distinct source positions detected in a revision of the original 47 1AGL ones, on all the pointed observations data (colors and symbol sizes are proportional to significance, blue the lowest and orange the highest).

Abstract:

AGILE pointed observations performed from July 9, 2007 to October 30, 2009 cover a very large time interval, with a gamma-ray dataset useful to perform studies of medium to high brightness galactic sources in the 30 MeV -- 50 GeV energy range.
We present a study of the 1AGL galactic sources in the E>100 MeV band, over the complete Agile pointed Observation Blocks (OBs) archive.
The first AGILE Gamma-Ray Imaging Detector (GRID) catalog included a sample of 47 sources (1AGL), detected with a conservative analysis over the first year operations dataset. In this data analysis we used data of an improved full Field of View (FOV) event filter, on a much larger (about 27.5 months) observation dataset, analyzing the merging of all data and each OB separately. The data processing resulted in an improved source list as compared to the 1AGL one, particularly in complex regions of the galactic plane. We present here some results on the revised 1AGL galactic sources and on the variability of some of them.

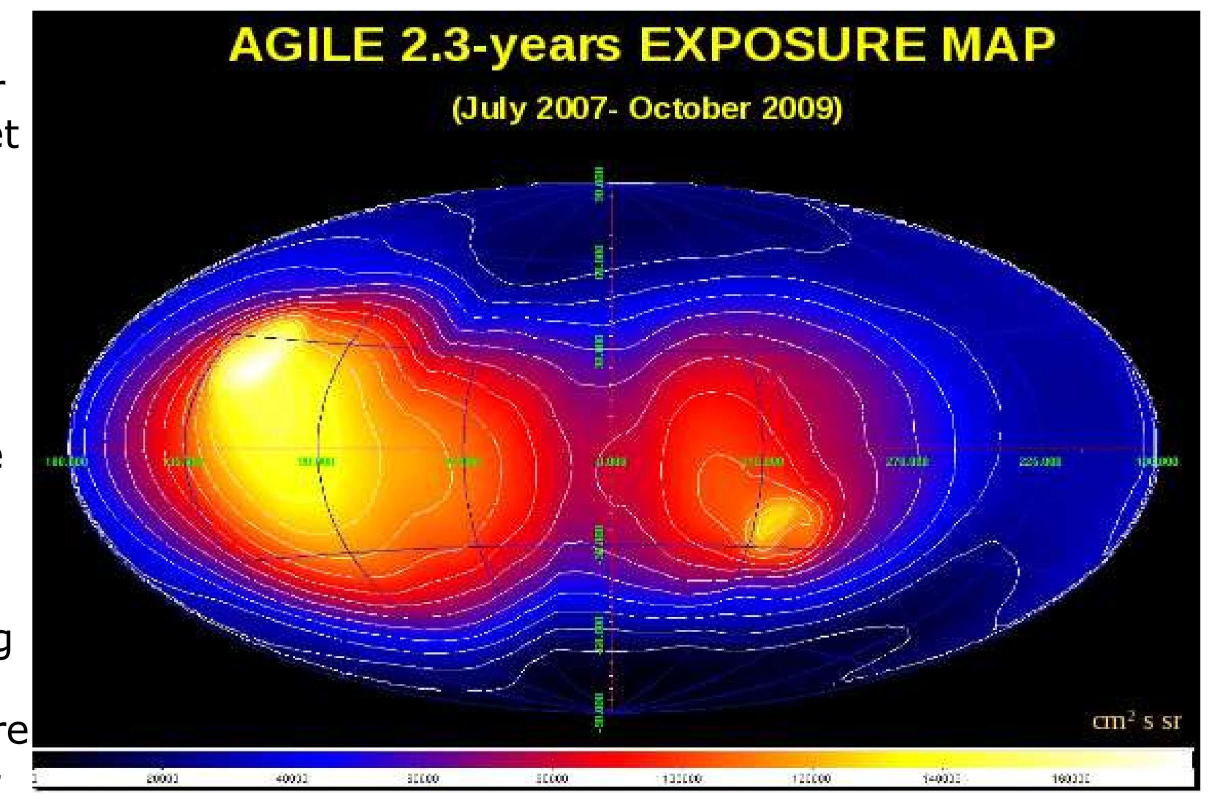


Figure 2: the AGILE-GRID 2.3 years all-sky exposure map in Aitoff projection obtained with the "FM" event filter on all the pointed-observations data (101 OBs).

Introduction

AGILE (Astrivelatore Gamma ad Immagini LEggero) ([2], [3]) is an Italian Space Agency mission dedicated to γ-ray astrophysics in the 30 MeV -- 50 GeV and hard X-ray in 18 -- 60 KeV energy ranges, in orbit since April 23 2007. AGILE has been the first instrument of a new generation of high-energy space missions based on solid-state silicon technology, permitting us to substantially advance our knowledge on many source classes such as active galactic nuclei, γ-ray bursts, pulsars (PSRs), unidentified γ-ray sources, Galactic compact objects and supernova remnants. On June 11, 2008 the Fermi Gamma-Ray Space Telescope ([4], [5]) was launched, and is concurrently operating with AGILE. The AGILE spacecraft operated in "fixed-pointing" mode until October 2009 (completing 101 pointings or "Ob-servation Blocks", OBs), when the attitude control system had to be reconfigurated and the scientifc operations changed into "spinning mode". Currently the instrument pointing direction scans the sky with an angular velocity of about 1deg/s, accessing about 80% of it each day. The significance-limited (4 sigma) sample of 47 1AGL sources were detected in the E>100 MeV band with a conservative analysis of the inhomogeneous first-year sky coverage dataset. We present here some preliminary results of a variability study of a sample of 62 sources (Fig. 1) analyzing separatedly each OB in the 2.3 years AGILE pointing mode dataset. The sample was obtained with a revision of the 1AGL sample on the maps obtained from the whole dataset ("deep" maps from now on).

The AGILE Instrument

The AGILE Payload detector consists of the silicon tracker (ST; [6], [7]), the X-ray detector SuperAGILE ([8]), the CsI(Tl) Mini-Calorimeter (MCAL; [9], [10]), and an anti-coincidence system (ACS; [11]). The combination of ST, MCAL, and ACS forms the Gamma-Ray Imaging Detector (GRID). GRID, sensitive to photon energies in 30 MeV-50 GeV band, has a wide FOV(~2.5 sr in pointing) and accurate timing (a few μs), positional and attitude information (15' location accuracy for > 10σ detection).

The AGILE satellite raw data, down-linked about every 100 minutes, are transmitted from the Mission Control Center at Telespazio, Fucino, to the AGILE Data Center (ADC), part of the ASI Science Data Center (ASDC) located in Frascati (Italy). The ADC has the duties of data reduction, scientific processing and archiving and finally to distribute standard Level-2 data to Guest Observers (GOs) or, when data become public, to all the scientific community (see ADC web page http://agile.asdc.asi.it).

The OB data archive and source detection procedure

The standard analysis OB pipeline at the ADC was executed at the end of an OB, to remove data corresponding to slews and occasional losses of fine-pointing attitude and build the official OB data archive. Moreover scientific maps were created selecting confirmed events and excluding albedo contaminated time intervals. The ``pointing mode'' OB archive is composed of 101 OB covering a wide timespan with non uniform exposures (ranging from 1d to 45dd). All the OB were recently reprocessed with the last software release.
The procedure developed for this analysis on the whole archive is based on source detection at fixed preselected positions using the AGILE Maximum Likelihood (ML). It consists of two main steps: I) preliminary revision of the 1AGL source list, based on updated "deep" maps and on more recent published AGILE reults; II) execution of a ML multi-source task in E>100 MeV band on each OB map in a specific pipeline, keeping reference source positions fixed to those previously determined. In the analysis no automatic source detection process is implemented. A check leaving the position free is implemented to verify the goodness of candidate transient sources. Both steps were repeated for 5 main iterations to improve the multi-source detection in complex regions (see next section).

Source detection method

The detection method used is the ML. The significance of a source detection is given by the "test statistic" TS, defined as -2 times the log of the likelihood ratio, which according to the Wilks' theorem follows the χ^2 distribution ([12], [13]).
We express this source significance as a number of standard deviations "n" of a Gaussian distribution. Likelihood ratio is built considering for the background only hypothesis the AGILE diffuse γ-ray model ([14], [15]). We used the task "AG_multi2" included in the AGILE software for the ML "multi-source"analysis.

The First AGILE catalog revision on the 2.3 yrs dataset

The first AGILE catalog ([1]) was built from data of the first year (July 2007 - June 2008). The data analysis based on a conservative event filter ([16]), and the nonuniform sensitivity due to inhomogeneous first-year AGILE sky coverage, limited the results in complex galactic regions. A preliminar revision of 1AGL sources in regions such as the Carina, Cygnus, Crux and Galactic Center fields, was realized on updated merged maps from data up to October 2009 (see Fig. 2), using data from a new AGILE event Filter ("FM3.119"). In this revision were considered new "candidate" source and some of them with significance between 3 and 4 were also included in the reference list to check their variability among all the OBs (see Fig. 3 and 4). Moreover recent AGILE results obtained in these regions were taken into account ([17], [18], [19], [20], [21]). We considered also preliminary results from a Quick Look processing on week timescale. In this way, we obtained an updated reference source list. A new source detection procedure on deep maps of all AGILE data in pointing mode has been realized for the next AGILE catalog and results will be reported in Bulgarelli et al. 2011. The procedure results in the first 4 iterations suggested further revision of the source list.

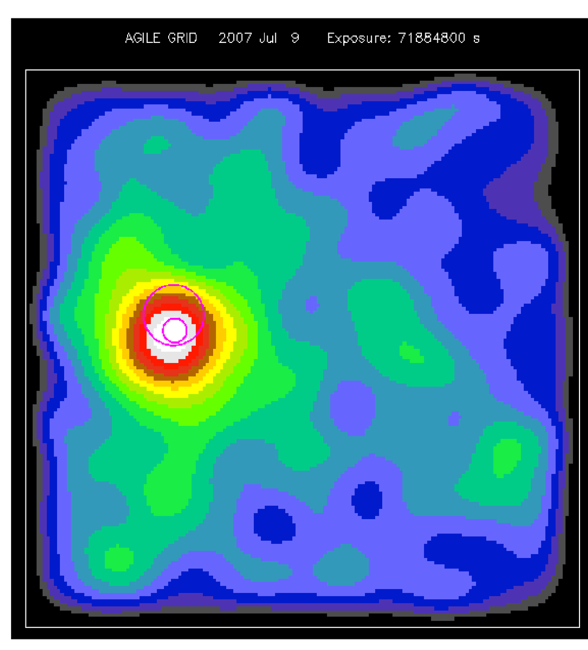


Figure 3: on the left a simple case of position refinement, the high latitude 1AGL J1846+6714. The new smaller error circle is indicated inside the 1AGL one.

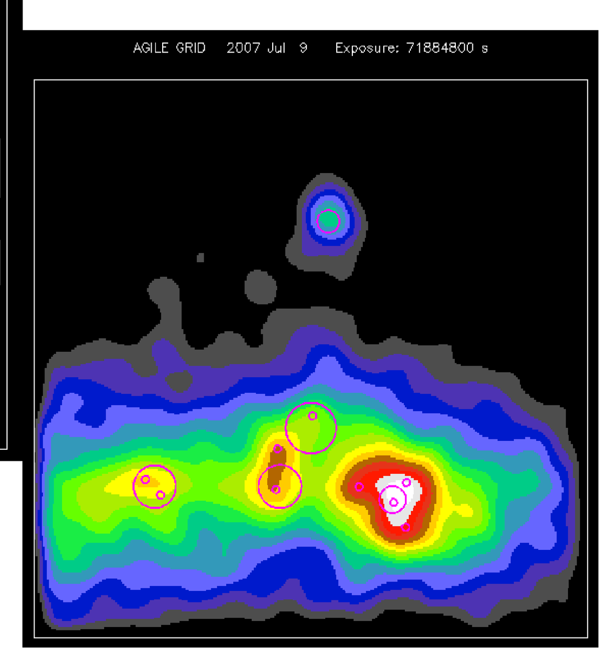


Figure 4: right, a difficult position refinement case, the Carina region . New positions are indicated with small squares, with sizes not proportional to errors, while the 1AGL error circles are reported.

Detection selection and variability analysis

The results from the last execution (the fifth iteration) of the ML multi-source task on sources in the reference list, were filtered taking into account off-axis angle and significance. Our goal was to investigate the variability within the OB dataset for established sources on deep maps, and possibly search for flare episodes for some low significance source. As final selection only those sources having at least one detection at significance higher than 3σ were accepted, for all sources having high significance (>=4) on deep maps. Then all detections with sqrt(TS) ≥2 were included in the variability analysis. Source γ-ray flux variability among all OBs was tested according to the method developed by Mc Laughlin et al. (1996; [22]) and recently reported in an analysis of 1AGL J2022+4032 data ([23]). The variability index V=-log(Q) is evaluated after the calculation of the weighted mean flux and its error and so also the relative χ^2. Q is the probability of having a value of $\chi^2 \geq \chi^2_{observed}$ for a source with constant flux. Sources with V<0.5 are usually classified as "non variable", with 0.5 ≤V<1 as "uncertain" and with V≥1 as "variable". Another index was calculated (used in Fermi catalogs; [24], [25]), a simple χ^2. Both indeces were computed also adding a systematic component of 10% to flux errors (V_{sys}, χ^2_{sys}), to take into account the not well known particle background variable contribution. The 10% figure is based on Monte Carlo simulation, pre-flight beam tests and post-flight analysis of photons from sources with known positions.

Results and future developments:

Applying our selection criteria, we obtained a sample of 1619 detection of 62 distinct sources (Fig. 1). For all sources a revi-sion of single detections is ongoing as a verification and improvement of the more recent calibrations and of the multi-source ML analysis.
The non uniform exposures among the OBs, from 1 to 45 days, together with the pointing strategy, constrain our ability to "resolve" complex regions in a large number of OBs and also to the variability analysis.

The light curve of the brightest sources with stable flux, such as Geminga, have been preliminarily checked (see Fig. 3). A particular case is the one of the Crab, which has been recently reported to have a ``non stable'' γ-ray emission ([26],[27]). In Fig.4 is shown the Crab light curve showing the October 2007 flare episode, discussed in [26], at an higher flux compared to the 2010 flare. We obtained a V_{sys} of 0.4 for Geminga and 3.36 for Crab.

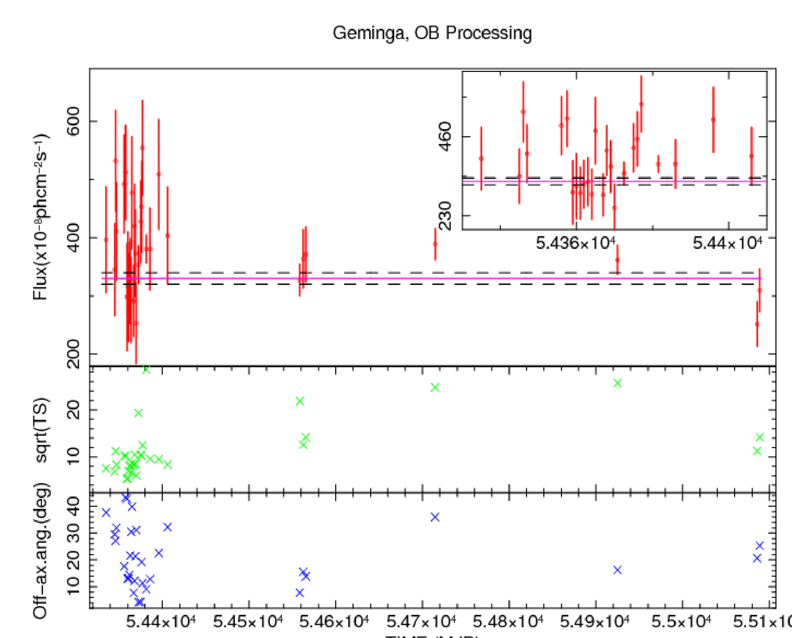


Figure 3: we show the E>100 MeV light curve of Geminga PSR together with the significance and the off-axis angle. The 1AGL flux value and the 1 sigma error levels are shown as magenta and black dashed lines.

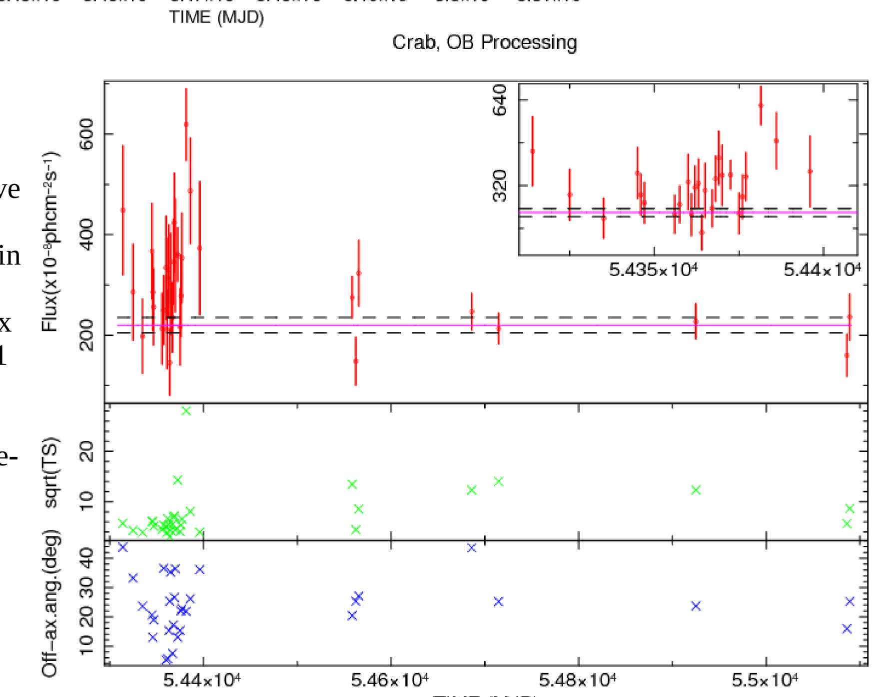


Figure 3: the E>100 MeV Crab light curve with the same parameters as in previous plot. The 1AGL flux value and the 1 sigma error levels are shown as magenta and black dashed lines.

The V_{sys} and χ^2_{sys} gave compatible results. The source class which included more variable sources were the Blazars according to both parameters, the most variable one being 3C 454.3. The complete refined results on the OB timescale will be presented in Verrecchia et al. 2011.

Examples of long-term light curves

As an example of long term monitoring light curves in the E>100MeV band obtained in this analysis at the OB timescale, we show below (Fig.4 and 5) the results for the two known galactic sources 1AGL J1836+5923 associated to the LAT PSR J1836+5925 and of 1AGL J1058-5239 associated with the PSR J1057-5226..

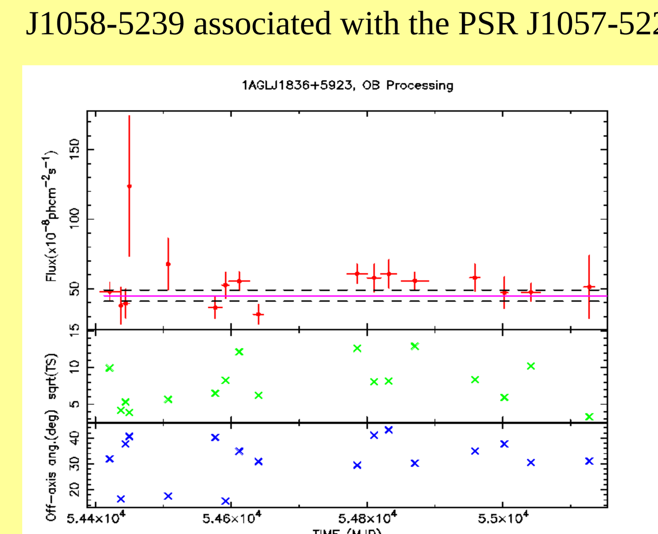
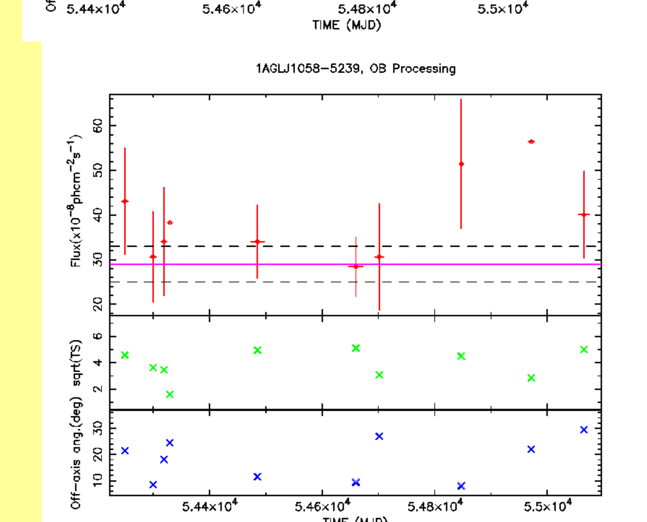


Figure 4: the 1AGL J1836+5923 light curve for E>100 MeV flux (in 10^{-8} ph cm^{-2} s^{-1}; upper panel), together with the sqrt(TS) and the off-axis angle (in degrees) as function of time (in MJD). The magenta line is the 1AGL flux and the two black dashed lines are the levels for 1σ errors.



Below the same plot for 1AGL J1058-5239.

References

[1] Pittori, C., Verrecchia, F., Chen, A., et al. 2009, A&A, 506, 1563
[2] Tavani, M., Barbiellini, G., Argan, A., et al. 2008, for the AGILE Collaboration, NIM A, 588, 52 [arXiv:0807.4254]
[3] Tavani, M., Barbiellini, G., Argan, A., et al. 2009a, for the AGILE Collaboration, A&A, 502, 1015
[4] Michelson, P. F. 2008, APS Meeting Abstracts, TSSP, L2002
[5] Atwood, W. B., Abdo, A. A., Ackermann, M., et al. 2009, ApJ, 697, 1071
[6] Barbiellini, G., Bordignon, G., Fedel, G., et al. 2001, AIP Conf. Proc., 587, 754
[7] Prest, M., Barbiellini, G., Bordignon, G., et al. 2003, NIM A, 501, 280
[8] Feroci, M., Costa, E., Soffitta, P., et al. 2007, NIM A, 581, 728
[9] Labanti, C., Marisaldi, M., Fuschino, F., et al. 2006, SPIE, 6266, 62663
[10] Labanti, C., Marisaldi, M., Fuschino, F., et al. 2009, NIM A, 598, 470
[11] Perotti, F., Fiorini, M., Incorvaia, S., Mattaini, E., & Sant'Ambrogio, E. 2006, NIM A, 556, 228
[12] Chen, A.W., et al. 2011, in preparation
[13] Mattox, J. R., Bertsch, D. L., Chiang, J., et al. 1996, ApJ, 461, 396
[14] Giuliani, A., Chen, A., Mereghetti, S., et al. 2004, Mem. SAIt Suppl., 5, 135
[15] Giuliani, A., et al. 2011, in preparation
[16] Giuliani, A., Cocco, V., Mereghetti, S., Pittori, C., & Tavani, M. 2006, NIM A, 568, 692
[17] Tavani, M., Sabatini, S., Pian, E., Bulgarelli, A., et al. 2009a, ApJL, 698, L142
[18] Tavani, M., Bulgarelli, A., Piano, G., et al. 2009b, Natur, 462, 620
[19] Sabatini, S., et al. 2010, ApJL, 712, L10
[20] Giuliani, A., et al. 2010, accepted by A&A, [arXiv:1005.0784]
[21] Bulgarelli, A., et al. 2010, submitted to A&A
[22] McLaughlin, M. A., Mattox, J. R., Cordes, J. M., Thompson, D. J., 1996, ApJ, 473, 763
[23] Chen, A.W., et al. 2010, submitted to A&A
[24] Abdo, A.A., et al. 2009, ApJS, 183, 46
[25] Abdo, A.A., et al. 2010, ApJ, 715, 429
[26] Tavani, et al. 2011, Science, 331, 736
[27] Abdo, A.A., et al. 2011, Science, 331, 739