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TeV sources analysis with AGILE

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Abstract: AGILE (Astrorivelatore Gamma a Immagini LEggero) is a satellite of the Italian Space Agency (ASI) launched on April 23rd, 2007. The AGILE-GRID instrument onboard of the AGILE satellite is devoted to gamma-ray astrophysics in the 30 MeV - 50 GeV energy range. This contribution presents the results of a systematic study performed on the first three years of AGILE-GRID data to search for GeV and sub-GeV counterparts (or derive flux upper limits) of sources detected at very high-energy by TeV experiments. Many of the TeV sources are still unidentified and deep observations at lower energies are needed to identify their possible counterparts. Results of the AGILE-GRID observations on a selected sample of TeV unidentified sources will be also presented.

Keywords: HE gamma rays: observations - TeV sources

1 Introduction

In the last years, the number of TeV gamma-rays sources has increased up to more than 100 thanks to the observations made by the new generation of ground-based Cherenkov telescopes HESS, MAGIC and VERITAS. The identified sources of VHE photons belong mainly to four classes: Active Galactic Nuclei (AGN), Supernova Remnants (SNRs), Pulsar Wind Nebulae (PWN) and X-ray binaries (XRB). More than 80 TeV sources are galactics; a large fraction of them do not show a clear counterpart and still remains unidentified (UNID). Multi-wavelenght deep observations of the region near the TeV positions are needed to identify the possible counterparts of the UNID TeV sources as well as to constrain the emission mechanisms of the VHE γ-ray photons. In what follows, we will present the results of a search of MeV-GeV counterparts of known and UNID TeV sources using the data taken by the AGILE γ-ray satellite.

AGILE (Astrorivelatore Gamma ad Immagini LEggero) [1], [2] is a small scientific mission of the Italian Space Agency (ASI) dedicated to the observation of astrophysical sources of high-energy γ-rays in the 30 MeV-50 GeV energy range, with simultaneous X-ray imaging capability in the 18-60 keV band. AGILE is the first high-energy mission which makes use of a silicon detector for the γ-rays-to-pairs conversion. The AGILE payload combines for the first time two coaxial instruments: the Gamma-Ray Imaging Detector GRID (composed by a 12-planes Silicon-Tungsten tracker [3], a Cesium-Iodide mini-calorimeter [4] and the anti-coincidence shield [5]) and the hard X-ray detector Super-AGILE [6]. The use of the silicon technology allows to have good performances for the γ-rays GRID imager in a relatively small and compact instrument: an effective area of the order of 500 cm^2 at several hundred MeV, an angular resolution of around 3.5° at 100 MeV, decreasing below 1° above 1 GeV, a very large field of view ($\sim$2.5 sr) as well as accurate timing, positional and attitude information.

Very remarkable is the AGILE Ground Segment which allows to have in 2-2.5 hours after the telemetry from the spacecraft the first production of cleaned event list and housekeeping files.

AGILE was launched on April 23rd, 2007, and placed in a low (550km) equatorial orbit with very small background contamination. Until October 2009, the AGILE spacecraft was operated in "fixed-pointing" mode, completing 101 pointings. In Nov. 2009, the spacecraft has to be reconfigured in the safe "spinning operation mode", converting AGILE in an all-sky γ-ray monitor. The GRID boresight rotation axis now scans the sky with an angular velocity of about 1°/s, accessing about 70-80% of it each day.

AGILE good sensitivity in the 100-400 MeV energy range makes it very suitable to perform the MeV-GeV counterpart search of TeV sources described here.

2 Systematic search of AGILE counterparts of TeV Sources in the AGILE-GRID fixed-pointing data

The analysis presented in this paper has been performed with an automatic procedure for all the sources contained in the web-based catalog TeVCat [7]. At present, the catalog contains more than 100 TeV sources published on refereed journals or newly announced by means of Astronomers Telegrams.

Our analysis is currently being performed in a systematic way on a sample of 116 TeV sources, both galactic and extragalactic, whom centroid positions and extensions have been carefully reviewed using data from literature. An improved catalog of TeV sources will be soon available at the ASI Science Data Center (ASDC) webpages [8].

An automatic procedure, described in [9], search for possible AGILE counterparts to known TeV sources using the AGILE official data archive provided by the AGILE Data center (ADC) hosted at the ASDC.

The analysis has been performed on the full pointing period of AGILE-GRID (2007.07.09−2009.10.31) for a total of 2.3 years of data. The relevant maps (counts, exposure and diffuse background) have been generated with an energy threshold of $E_\gamma > 100$ MeV. All the maps are centered on the selected TeV source position, with a size of $40^\circ \times 40^\circ$, binned at 0.1°. The count maps are generated using the event filter named FM, characterized by the best signal-to-noise ratio.

The source detection step is performed by means of a multi-source Maximum Likelihood (ML) algorithm ([10], [11]), fixing the position and the flux of the known AGILE sources from the First AGILE Catalog (1AGL sources) [12] within a radius of 20° from the TeV source and letting free the position and the flux of its possible AGILE counterpart within a radius of 1°.

The preliminary results show that around one third of TeV AGNs and around one half of TeV Galactic Sources (SNR, PWN, XRB or UNID) have a candidate counterpart in the AGILE data [13].

Refined analysis will be performed on these last classes due to possible source confusion, particularly in the case of PWN and UNID TeV sources.

3 Observations of selected UNID TeV sources in spinning mode

Since Nov. 2009, AGILE is observing the γ-ray sky in spinning mode. In what follows we will present the preliminary results of the analysis of the AGILE-GRID data on a sample of TeV sources, mainly still unidentified. These sources are part of an observation program proposed by the authors (Lucarelli et al.) and approved as targets of the 3rd AGILE Annoucement of Opportunity (AO3).

The AO3 proprietary data cover almost one year of observations in spinning. The expected sensitivity of AGILE-GRID over 1 year of spinning mode observations varies from 15×10^{-8} to 80×10^{-8} $ph\ cm^{-2}\ s^{-1}$, depending on the exposure of the observed region[1].

The analysis of the data was made using the AGILE gamma-ray analysis software, public release AGILE SW 4.0 [11], downloaded from the ADC webpages. Only gamma-like events have been considered to generate binned maps of counts, exposure and models of diffuse emission starting from the cleaned event list and the auxiliary files provided to the Guest Observers. To reduce the Earth albedo contamination, all γ-ray events whose reconstructed directions form angles smaller than 90° with the satellite-Earth vector were rejected. South Atlantic Anomaly event cuts have been also applied.

Table 1 summarizes the preliminary results of the analysis of the GRID data extracted from small regions centered at the proposed TeV sources. Seven of the nine targets proposed in the AO3 program have been analyzed here. A multi-source ML analysis has been applied to estimate the significance of the excess around the target position, expressed as the square root of the ML Test Statistic (TS). All the AGILE 1AGL sources [12] have been included in the multi-source analysis. The γ-ray sources from the 1st year FERMI-LAT Catalog (1FGL) [14] have been included only if their 100-300 MeV flux was above the AGILE sensitivity over one year.

The table also shows the estimated number of excess counts with respect to the galactic diffuse emission and the average flux for energies above 100 MeV. The flux is replaced by the 95% C.L. upper limits when the $\sqrt{TS}$ of the ML analysis is below 3. The last column shows the displacement in degree of the AGILE excess peak position from the best-fit position of the TeV emission, as provided from the literature[2].

Two out of seven target sources show a preliminary (and pre-trial) significance above the standard detection threshold of 3. One source, HESS J1632-478, is close to the detection limit. In what follows, we will briefly review the preliminary results obtained about these three observations.

3.1 HESS J1731-347

HESS J1731-347 (TeVCat name: TeV J1732-347) was discovered during the HESS Galactic plane survey covering the longitude and latitude range -50° $< l <$ 60° and -3° $< b <$ 3°, respectively [15]. No clear counterpart was found at that time and the source was classified as u-

1. The sky regions around the Sun and Anti-Sun positions (roughly circulars with a 50° radius) are not accessible during the scanning. However, these regions shift during the year due to the Earth revolution allowing the observation of the whole sky.

2. The Galactic positions of the center of gravity of the TeV targets have been taken from the Catalog of TeV Sources in preparation at ASDC [8]

Table 1: Preliminary results of the AGILE-GRID observations of selected UNID TeV sources.

TeV source	Date Interval	MJD	Exposure [$\times 10^8$ cm^2 s]	$\sqrt{TS}$ [a]	Counts	Flux [b] (E>100 MeV) [$\times 10^{-8}$ ph cm^{-2} s^{-1}]	Shift [c] [deg]
HESS J1614-518	2010.01.15−2010.10.15	55211.5−55484.5	4.3	1.3	<135	<32	–
HESS J1632-478	2010.02.05−2010.10.15	55232.5−55484.5	3.8	2.8	<187	<49	–
HESS J1702-420	2010.02.05−2010.10.15	55232.5−55484.5	3.6	0	<28	<7.8	–
HESS J1731-347	2010.02.05−2010.10.15	55232.5−55484.5	3.6	4.3	147 ± 38	41 ± 11	0.34
HESS J1841-055	2010.02.05−2010.10.31	55232.5−55500.5	3.6	5.8	229 ± 44	63 ± 12	0.56
HESS J1843-033	2010.02.05−2010.10.31	55232.5−55500.5	3.6	0.9	<111	<31	–
HESS J1857+026	2010.02.28−2010.11.15	55255.5−55515.5	4.0	1.3	<139	<35	–

Notes
[a] Square root of the Maximum Likelihood Test Statistic (TS) representing the statistical significance of the detection [10].
[b] Gamma-ray flux for E>100 MeV (or 95% C.L. upper limits) estimated applying the multi-source ML analysis on the proposed target.
[c] Displacement of the AGILE excess peak position from the best-fit position of the TeV target.

nidentified. In 2008, Tian et al. [16] reported the discovery of a new radio SNR, G353.6-0.7, spatially coincident with HESS J1731-347. Very recently, the HESS Collaboration has re-analysed the region using a deep integration, confirming the detection in TeV γ-rays of a large shell-type structure with similar position and extension (r$\sim$0.25°) of the SNR G353.6-0.7 [17].

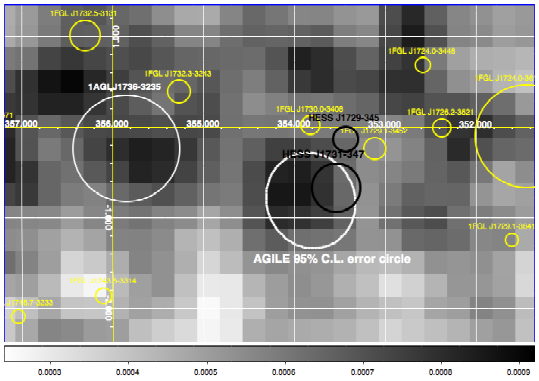

Figure 1: AGILE-GRID γ-ray intensity map in Galactic coordinates of the HESS J1731-347 region above 100 MeV. Data have been collected from Feb. till Oct. 2010, with AGILE observing in spinning mode. The central white ellipse indicates the 95% Confidence Level (C.L.) error circle of the AGILE detection obtained applying the multi-source ML analysis. The extended TeV source HESS J1731-347 (black circle), target of this observation, is well within the AGILE error circle. The 95% positional error circle of the AGILE source 1AGL J1736-3235 [12], unclassified, and the 1FGL FERMI-LAT sources [14] are also shown in the map along with the newly announced UNID TeV source HESS J1729-345 [17]. The grey bar scale is in units of photons cm^{-2} s^{-1} pixel^{-1}. Map with 0.25° pixel size, with a two-pixel Gaussian smoothing.

The analysis described here concerns the GRID data from Feb. till Oct. 2010. Figure 1 shows the intensity map of the region centered at the target position, as seen in E>100 MeV γ-rays by AGILE-GRID. Applying a multi-source ML analysis as described in section 2 produces a detection with a $\sqrt{TS}$ above 4 within 0.35° from the centroid of the TeV emission. HESS J1731-347 (black circle in the figure) is well contained within the 95% CL error circle of the AGILE detection. Neither 1AGL nor 1FGL sources are present within the AGILE contour. Spectral studies and analysis including the whole GRID public data are ongoing.

3.2 HESS J1841-055

The detection of HESS J1841-055 (TeVCat name: TeV J1841-055) was also announced in [15] like the previous source. This source appeares highly extended at TeV energies and it is still unassociated.

The ML analysis applied to the GRID maps produced from the AO3 AGILE data (Feb. to Oct. 2010), centered at the HESS J1841-055 position, reveals an excess of E>100 MeV γ-rays within 1° from the target (see Fig. 2). The 95% C.L. AGILE contour slighty overlaps the extended TeV emission of HESS J1841-055. The confused source 1FGL J1839.1-0543c lays within the AGILE contour along with the pulsar PSR J1838-0549.

3.3 HESS J1632-478

HESS J1632-478 (also known as TeV J1632-478) was discovered during the HESS survey of the inner part of the Galactic plane [19]. Very recently, a multi-wavelength campaign identified a possible counterpart of the TeV emission with a relic PWN [20]. Applying the multi-source ML procedure described in Section 3 to the GRID AO3 data, including the close 1AGL J1639-4702 and 1AGL J1624-4946 sources in the analysis, gives a preliminary $\sqrt{TS}$ just below 3 (see Table 1). If the very near 1AGL J1639-4702 (distance $< 1.5°$) is not included in the multi-source analysis, a $\sqrt{TS}$ >5 is obtained. The resulting 95% C.L. AGILE contour slighty overlaps the extension of HESS J1632-478.

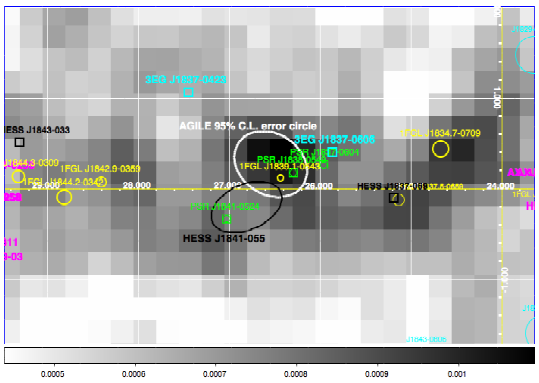

Figure 2: AGILE-GRID γ-ray intensity map in Galactic coordinates of the HESS J1841-055 region above 100 MeV. Data have been collected from Feb. till Oct. 2010, with AGILE observing in spinning mode. The central white ellipse indicates the 95% C.L. error circle of the AGILE detection obtained applying the multi-source ML analysis. The black ellipse is the best-fit extension found in [15] for HESS J1841-055. The AGILE 95% error circle slightly overlaps the extended TeV source. The 1FGL FERMI-LAT [14] and the 3EG γ-ray sources [18] are also shown in the map along with the closest known pulsars. Smoothed map and scale units as in Fig 1.

We notice, that another UNID TeV source, HESS J1634-472, lays within the AGILE contour. Four 1FGL sources are also present in this region: they actually are all catalogued as confused sources. Refined analysis of the HESS J1632-478 region in the AO3 proprietary data is still ongoing.

4 Conclusions

This work presented the results of a systematic search of MeV-GeV counterparts of TeV sources in the first 2.3 years of AGILE-GRID "fixed-pointing" data. The results of the analysis found significant γ-ray excesses within 1° from the TeV emission centroid for more than half of the TeV targets (116 in total). Detailed analyis of the most significant cases is undergoing.

A large fraction of the TeV sources is still unidentified. The observation of a selected sample of UNID TeV sources has been proposed and accepted for the 3rd AGILE Announcement of Opportunity. We also have presented here the analysis of these data, taken while AGILE was observing in spinning mode. The preliminary results show significant detections of E>100 MeV photons within 1° from the target in two of the seven sources observed: HESS J1731-347 and HESS J1841-055. In the first case, the TeV source (recently associated to a shell-type SNR) is well within the AGILE error position.

Spectral analysis of these two cases, which include the whole AGILE public data, is undergoing and will be presented in dedicated papers in progress.

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