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Early Fermi-LAT results

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Summary. — The Large Area Telescope (LAT), onboard the Fermi Gamma-ray Space Telescope (formerly GLAST, launched June 11, 2008) is a pair conversion telescope designed to study the gamma-ray sky in the energy range from 20 MeV up to 300 GeV. In its first three months of scientific activity (from August to October 2008) the LAT observed several sources, producing a deeper and better-resolved map of the gamma-ray sky than any previous space mission. The first bright Fermi LAT list includes the 205 most significant (statistical significance greater than 10 sigmas) gamma-ray associated sources in these data. Among these sources, the AGN (121 sources) and the pulsar (29 sources) classes form the largest groups. Some examples of the analysis on the most significant objects will be illustrated.

PACS 98.70.Rz – γ-ray sources; γ-ray bursts.
PACS 07.85.Fv – X- and γ-ray sources, mirrors, gratings, and detectors.
PACS 97.60.Gb – Pulsars.
PACS 98.54.Cm – Active and peculiar galaxies and related systems (including BL Lacertae objects, blazars, Seyfert galaxies, Markarian galaxies, and active galactic nuclei).

1. – Introduction

The Gamma-ray Large Area Space Telescope (GLAST) was launched on June 11, 2008, and renamed "Fermi Gamma Ray Space Telescope" shortly after entering its scientific operating mission, which began on August, 4 2008. The Large Area Telescope (LAT) [1], onboard Fermi, provides an increase in sensitivity by more than an order of magnitude over its predecessor EGRET [2], the Energetic Gamma Ray Experiment Telescope on the Compton Gamma Ray Observatory and the Italian Space Agency Satellite AGILE [3] (Astro-rivelatore Gamma a Immagini Leggero). In sky survey mode, the LAT provides a full sky coverage every 3 hours, providing effectively uniform exposure on longer timescales. One of the major scientific goals of the Fermi Gamma Ray Space Telescope, is to provide new data about gamma-ray activity of Active Galactic Nuclei (AGN) and new information about gamma-ray pulsars.

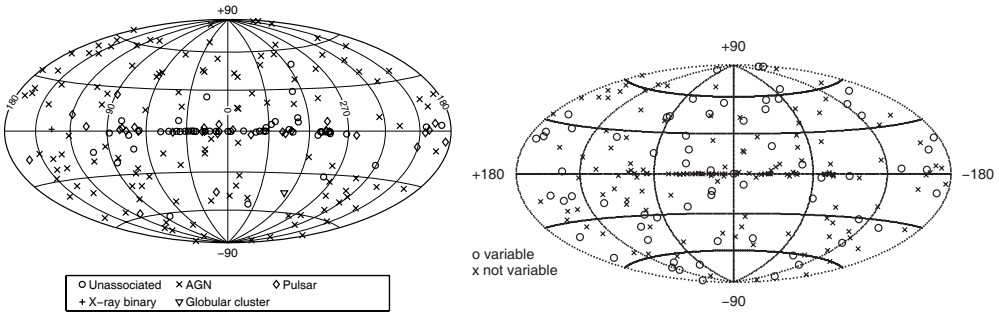

Fig. 1. – Left: the LAT Bright Source List, showing the locations on the sky coded according to the legend. Right: locations of variable (circles) and not-variable (crosses) sources [4].

2. – The Fermi Large Area Telescope Bright Gamma-ray Source List

During the first three months of scientific activity (from August 4 to October 30, 2008), the LAT has produced a deeper and better-resolved map of the gamma-ray sky than any previous space mission. The Fermi LAT Bright Gamma-ray Source List [4] includes the 205 most significant (statistical significance greater than 10σ) gamma-ray sources detected above 100 MeV. For the construction of this list, only photons belonging to the so-called Diffuse class, with energies above 100 MeV were retained. These photons provide the purest gamma-ray dataset, with the minor background contamination [1]. Moreover, in order to avoid background contamination from the bright Earth limb, time intervals where the Earth entered the LAT Field-of-View (FoV) were excluded from the analysis. It is worth to underline that the source list is not a catalog (the first official LAT catalog is planned for release after the first year of operations): in fact it does not include all the sources seen by the LAT in the first three months of operations and it does not give detailed information about the energy spectra. Finally, all sources included in the bright source list cannot be defined as "identified" sources, but only as "associated" sources. In fact, a firm identification of a source is based on a timing characteristic such as periodicity for a pulsar, or variability in the case of a blazar and not only on a simple location [4]. Figure 1 left shows the locations of the 205 bright sources, in galactic coordinates: 73 sources are found within 10° of the Galactic plane, while 132 sources are seen at higher Galactic latitudes (b). The AGN group, composed by 121 associated sources, is the largest in the bright source list. Also pulsars (including young radio pulsars, millisecond pulsars and radio-quiet pulsars), form another large group composed by 30 sources. As shown in fig. 1 right, 66 of the Bright LAT sources have shown evidence of variability on weekly time scales during the three months interval analyzed. This level of variability is not surprising as blazars, a particular sub-class of AGNs, are known to be strongly variable on timescales from days to weeks. It is worth to underline that sources not flagged as variable, might also show variability at lower amplitude or different timescale.

3. – Active Galactic Nuclei results

As underlined in sect. **2**, the first LAT Bright Gamma-ray Source list includes 132 sources with $|b| > 10°$, including 7 pulsars. For the remaining 125 sources, in order to

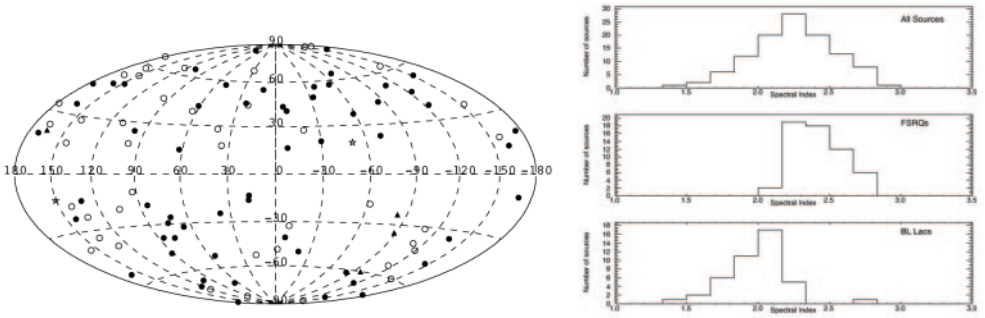

Fig. 2. – Left: location of the LBAS sources. FSRQs: closed circles, BLLacs: open circles, Uncertain type: closed triangles, RG: open stars [5]. Right: photon index distributions for the LBAS blazars. Top: all sources. Middle: FSRQs. Bottom: BLLacs [5].

find associations with known AGNs, two different approaches were pursued. The first method is based on a procedure similar to that developed for associating EGRET blazars with radio counterparts using an observational figure of merit (FoM). The second one is based on the calculation of source association probabilities following a Bayesian approach. Several catalogs were used for the source association, the most important ones being the Combined Radio All-Sky Targeted Eight GHz Survey (CRATES) catalog and the Roma-BZCAT. The CRATES catalog contains precise positions, 8.4 GHz flux densities, and radio spectral indices for more than 11000 flat-spectrum sources over the entire $|b| > 10^\circ$ sky. The Roma-BZCAT is a list of blazars presently including about 2700 sources, all observed at radio and optical frequencies and showing proper characteristics of blazars. Sources are classified as BL Lacertae objects (BZB), flat spectrum radio quasars (BZQ) or blazars of uncertain type (BZU). The combination of the different association methods yields a number of 106 high-confidence ($P \geq 0.90$) associations and 11 low-confidence ($0.40 < P < 0.90$) associations.

The 106 high-confidence associated AGNs costitutes the LAT Bright AGN Sample (LBAS). As shown in fig. 2 left, the LBAS comprises 57 FSRQs, 42 BL Lac objects, 5 blazars of uncertain type, and 2 radio-galaxies (RGs). BL Lacs constitues 40% of the LBAS blazars, a fraction significantly higher than found with EGRET (23%) [5]. Figure 2 right (top panel) shows the photon index distribution for all the LBAS sources: it is roughly symmetric and centered at $\gamma = 2.25$. The corresponding distributions for FSRQs and BL Lacs, shown in fig. 2 right, respectively, in the middle and in the bottom panel, appear clearly distinct: the average photon index is 1.99 ± 0.22 (rms) for BL Lacs and 2.40 ± 0.17 (rms) for FSRQs. A Kolmogorov-Smirnov test has been used to test the null hypothesis that both index samples are drawn from the same distribution and a probability of 2×10^{-12} has been found. Although indications for the existence of two spectrally distinct populations (BL Lacs and FSRQs) in the EGRET blazar sample were mentioned before, this is the first time that the distinction appears so clearly [5].

4. – Pulsar results

Many EGRET unidentified sources are thought to be of Galactic origin, because of their lack of variability and concentration along the Galactic plane. A large fraction of these have been suspected to be pulsars, despite deep radio and X-ray searches have not given positive results.

The radio-quiet pulsars are pulsars that even though they may emit radio waves, they cannot be detected from the Earth. Before the launch of Fermi, Geminga was the only known radio-quiet gamma-ray pulsar. The analysis of LAT data collected from sky survey observations between August, 4 2008 and December 25, 2008, applying the so-called time-difference technique, has led to the detection of 16 new gamma-ray pulsars. Among these, 13 have been associated with unidentified EGRET sources. Five pulsars have been associated with Pulsar Wind Nebulae and/or with Supernova Remnants and an additional one has been associated with a known isolated neutron star [6]. The first radio-quiet pulsar detected by the LAT is located near the center of the compact synchrotron nebula inside the supernova remnant CTA 1 [7].

The LAT has revealed new classes of GeV gamma-ray pulsars, such as the millisecond pulsars (MSPs) that are essentially rapidly rotating neutron stars with small spin periods ($P < 30\,\mathrm{ms}$) and very small period increases ($< 10^{-17}$). They represent roughly 10% of the known pulsars (listed in the ATNF online catalogue). Most of them are in binary systems, and are thought to have been spun-up by the torque due to accretion of mass from their companions. They are 10^8 to 10^{10} years old, compared to ages between 10^3 and 10^5 years for the young gamma-ray pulsars. For the gamma-ray timing analysis, LAT data acquired during the commissioning phase, beginning June 30, 2008, and the science phase of the mission from August, 4 2008 to March 15, 2009 have been used, selecting only events with energy greater than 0.1 GeV that pass the Diffuse gamma-ray selection cuts. At the end of the analysis, eight MSPs showed strong gamma-ray pulsations [8]. The first millisecond pulsar detected by the LAT has been the PSR J0030+0451: this has been the first high-confidence detection of a millisecond pulsar in gamma-rays [9].

5. – Conclusions

Since the start of its scientific activity, the Fermi-LAT has revealed its excellent capability to detect cosmic gamma-rays and it has just begun to give us a new picture of the gamma-ray sky. Here, just some examples of the major results obtained especially in the domain of active galactic nuclei and pulsars have been presented. For a complete and detailed analysis of the Fermi-LAT results, we remind you of the articles that you can find at the web page: `http://www-glast.stanford.edu/cgi-bin/pubpub`.

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