J. Astrophys. Astr. (2014) **35,** 373–378

Fermi LAT View of a Sample of Flaring γ-Ray AGNs

S. Buson[1,*], D. Bastieri[1], F. D'Ammando[2] & G. Tosti[2]
on behalf of Fermi LAT Collaboration
[1]*Università degli Studi di Padova & INFN Padova, via Marzolo 8, I-35131 Padova, Italy.*
[2]*Dipartimento di Fisica & INFN Perugia, Via A. Pascoli I-06123, Perugia, Italy.*
**e-mail: buson@pd.infn.it*

Abstract. In the first 3.5 years of operations, Fermi detected several sources whose flaring activity brought them to exceed daily fluxes brighter than $F(E > 100\,\text{MeV}) > 10^{-6}$ ph cm^{-2} s^{-1}. These episodes were promptly reported to the scientific community by the Fermi collaboration by means of astronomer telegrams (ATels). We focus our attention on the sample composed by these flaring sources, most of which are blazars, known to be extremely variable over the whole electromagnetic spectrum, from radio to γ-ray energies. We study properties of the selected sample and compare them to general characteristics of the Fermi source catalogue.

Key words. Galaxies: active—γ rays: observations.

1. Introduction

Since the beginning of its operations, the Large Area Telescope (LAT) on-board the Fermi satellite has demonstrated to be an ideal γ-ray flares and transients detector. Besides guaranteeing a continuous monitoring of the MeV–GeV sky, the usual LAT operation mode, the scanning sky-survey mode allows the coverage of the full sky every two orbits (about 3 hours), so that rapid flare detections and follow-up observations are performed almost continuously.

Invaluable complement to this all-sky monitoring capability is offered by the effort of the Flare Advocate duty activity (also known as Gamma-ray Sky Watcher, FA–GSW). This scientific service, operated on a voluntary basis by Fermi members, aims to provide a first quick-look review and daily check of the gamma-ray sky observed by LAT, and is carried out with continuity through weekly shifts. Sources that exceed the pre-defined daily flux of $F(E > 100\,\text{MeV}) > 10^{-6}$ ph cm^{-2} s^{-1} (which is a typical value used for defining a source in a flare at γ rays) are promptly reported to the scientific community, e.g., by means of Astronomer's Telegrams (ATels).

Between August 4, 2008 and February 4, 2012, 91 sources satisfied ATel criterion as they presented at least one high state overcoming the pre-defined flux threshold. We investigated all these flaring events and we noted that among them, the overwhelming of flaring objects is represented by blazars. This relative rare sub-class of

Active Galactic Nuclei (AGNs, 10% of the entire AGN population), characterized by its strong non-thermal continuum emission attributed to a jet oriented at a small angle with respect to the observer, constitute the largest known population of gamma-ray sources as well as the great majority of sources detected by the Fermi LAT. We focus on the general characteristic of AGNs pointed out by the FA–GSW activity and provide a comparison with AGNs seen in flaring state by the previous gamma-ray instrument, the energetic γ-ray experiment telescope (EGRET), on-board the Compton gamma-ray observatory (Thompson *et al.* 1993).

2. Flare advocate activity

Through a day-by-day inspection of the collected all-sky photon count maps and the results of a quick-look science analysis pipeline, FA–GSW service delivers a daily bulletin of the activity of the gamma-ray sky which can be of interest to Fermi science groups and communities. Relevant information like detection of new sources, transients, brightness trends, flaring and variable sources are released to the scientific community using the LAT-multiwavelength mailing-list[1], posting ATels, automatic burst GCNs, and special GCNs for blazar flares and other (non-GRB type) transients[2]. Weekly summary reports are also published in the 'Fermi Sky Blog'[3]. In addition, the FA–GSW on duty is in charge of triggering Target of Opportunity (ToO) follow-up observations of Fermi LAT transients. Swift is normally the satellite of choice and this shows nice cooperation between these two missions. They also involve the astrophysical community organizing joint observing programmes and multiwavelength observing campaigns targeted on single blazars and galactic sources.

ATels are one of the main products of FA–GSW activity: during the first 3.5 years 181 ATels have been published on behalf of the Fermi LAT collaboration, with an average rate of about one per week.

3. Fermi LAT data analysis

Fermi LAT is a pair conversion telescope with large effective area ($\sim$ 8000 cm^2 on the axis for $E > 1$ GeV) and large field-of-view ($\sim$ 2.4 sr at 1 GeV). It is optimized for gamma rays in the energy range from 20 MeV up to energies beyond 300 GeV. Full details of the instrument and descriptions of the on-board and ground data processing are given by Atwood *et al.* (2009), and information regarding on-orbit calibration procedures are given by Ackermann *et al.* (2012). Thanks to its high sensitivity and almost uniform sky coverage, it is an ideal tool for multiwavelength monitoring, gamma-ray flares detection and follow-up observations.

For our analysis we selected the time intervals of the flares as reported in the ATels (one day interval) and analysed all source class events located within 10° of each source of interest. When a time interval longer than a day was indicated in ATel, we

[1] More information regarding the 'gammamw' mailing list are available at: http://fermi.gsfc.nasa.gov/ssc/library/newsletter/

[2] http://gcn.gsfc.nasa.gov/gcn/gcn3_archive.html

[3] http://fermisky.blogspot.com

looked at the daily Automated Science Processing (ASP, Ciprini *et al.* 2012) light curve and studied data related to the first daily high flux showed by ASP-light curve. We restricted the data to a maximal zenith angle of 100° and time periods when the spacecraft rocking angle exceeded 52° are excluded. In this way we limited the contamination from Earth-limb gamma rays produced by the cosmic-rays interaction with the upper atmosphere.

For each flaring episode the best estimation on the position of the flaring source is determined using the point-like tool (Kerr 2011). Subsequently, the analysis is performed with the standard analysis tool *gtlike*, part of the Fermi ScienceTools software package (version 09-27-01) available from the Fermi Science Support Centre (FSSC[4]). Applying an unbinned maximum likelihood technique (Mattox 1996) to events in the energy range from 100 MeV to 300 GeV in combination with the post-launch instrument response functions (IRFs) P7SOURCE_V6, we derived the spectral parameters for each target source in each flaring interval.

The model for each Region of Interest (RoI) includes the diffuse galactic foreground emission and isotropic diffuse emission: the former by means of the template gal_2yearp7v6_v0_trim.fits and the latter, which accounts for both photons and residual charged particle background, by means of the template iso_p7v6source.txt[5]. Sources listed in the 2FGL catalogue and located within 15° of the target sources are incorporated in the model of RoI as well. For these individual LAT sources and the sources of interest themselves we assumed a power-law model.

In the fit parameters of sources located within 10° radius centred on the source of interest are left free, while parameters of sources located within the 10–15° annulus are fixed along with the isotropic background normalization. We performed a first fit to estimate reliable starting values for the parameters in the RoI and removed from the model, sources with too low significance. For this aim, we used the Test Statistic (TS) which provides an estimate of the significance of the detection for each gamma-ray source in RoI. The TS value is defined as twice the difference between the log-likelihood function maximized by adjusting all the parameters of the model, with and without the source. Sources with $TS < 5$ are removed from the RoI model. A subsequent minimization procedure is applied to the data to derive the final values for the fluxes and spectral indices. When the target source is not significantly detected, i.e. TS value is <25[6], flux upper limits at 95% confidence level are calculated.

4. Sample general characteristics

The objects that exceeded the fixed flux threshold that have been reported in Fermi ATels belong to different source classes. Following the classification that has been used in the second *Fermi* catalogue of AGNs (2LAC, Ackermann *et al.* 2011), the

[4]http://fermi.gsfc.nasa.gov/ssc/

[5]These templates are publicly available and can be found at the web address: http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html

[6]The square root of TS in the case of two degree of freedom is distributed as χ^2, therefore $TS = 25$ roughly corresponds to 4.6 sigma.

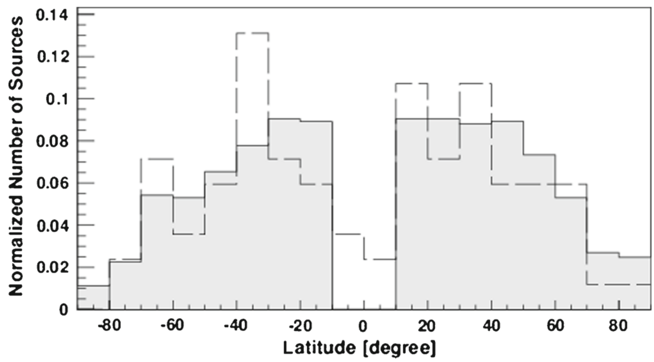

Figure 1. Distribution of galactic latitude: solid line (gray area) represents the overall distribution corresponding to 2LAC sample, dashed line represents this sample (normalized counts on vertical axis).

objects of this sample divide into: 68 flat spectrum radio quasars (FSRQs), 14 BL Lacs, 2 AGN, 4 AGU[7], 2 Narrow Line Seyfert I (NLSyI) and one radio galaxy.

Among them, 83 have a measured redshift and 7 have not been detected in the second Fermi source catalogue (2FGL, Nolan *et al*. 2012). Considering the usual BL Lac classification based on the position of the SED peak, 14 sources are divided into 6 ISP, 6 LSP and 2 HSP (as defined in Ackermann *et al*. 2011). It is worth mentioning that 9 sources of this sample are detected at TeV energies: Ap Lib, S5 0716+74, BL Lacertae, 3C 66A, PKS 2155−304, 3C 279, 4C +21.35, PKS 1510−089 and NGC 1275.

We analysed the sources of interest for the periods reported in the correspondent ATels and recorded the main spectral parameters (e.g., flux, index) along with other derived quantities (e.g., TS, luminosity). All the recalculated values and the complete outcomes resulting from this analysis will be presented in an upcoming publication. In the following, we briefly report the general characteristics of the sample. In particular we consider the properties of our sample with respect to those of the whole source samples detected by Fermi, i.e. 2FGL and 2LAC catalogues.

Figure 1 shows histogram of the galactic latitude distribution for the objects of this study (dashed line) and the ones reported in the 2LAC clean catalogue (solid line, gray area). The sources of this sample appear to be equally distributed in the northern and southern hemispheres, the only difference with respect to 2LAC distribution is found at low latitudes ($|b| < 10°$), due to the fact that the 2LAC clean sample is based on *a priori* criterion to select only sources at high galactic latitude, i.e. $|b| > 10°$. The redshift distribution of our sample (dashed line) is presented in Fig. 2 and follows well with the redshift distribution of the 2LAC clean sample (solid line, gray area). Figure 3 displays the flux distribution of our sample as the ratio between the flux calculated for the time interval reported in the ATel and the average value reported in

[7] AGU refers to sources without a good optical spectrum or without an optical spectrum at all, whereas AGN refers to sources that are neither confirmed blazars nor blazar candidates. For more details, we address the reader to Ackermann *et al.* (2011).

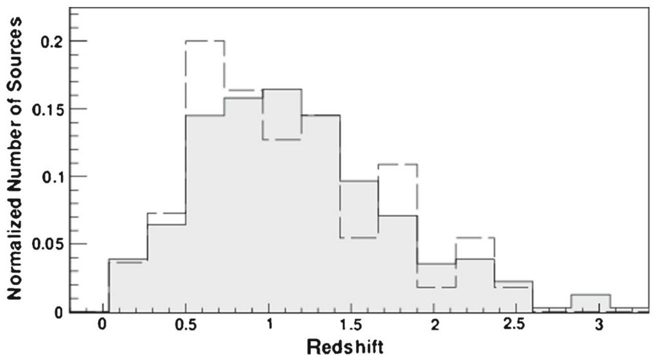

Figure 2. Redshift distribution: solid line (gray area) represents the overall distribution corresponding to FSRQ 2LAC clean sample, and dashed line represents the FSRQ of this sample (normalized counts on vertical axis).

2LAC. It results that on an average the sources of this sample have fluxes, a factor 11 higher than their 2LAC averages, although we note that there are some exceptional cases for which we measure a flaring flux >40 times its average value (as in the case of 2FGL J0532.0−4826, 2FGL J1153.2+4935 and 2FGL J1848.6+3241). We search for possible differences in the flux distributions of the two main classes that make up our sample: FSRQs and BL Lacs. In the inset of Fig. 3, the former are represented by a solid line while the latter by a dashed line. This plot shows that there are no particular discrepancies between the distributions of the two classes, but the largest flares belong only to the FSRQ class. The distribution of the photon index

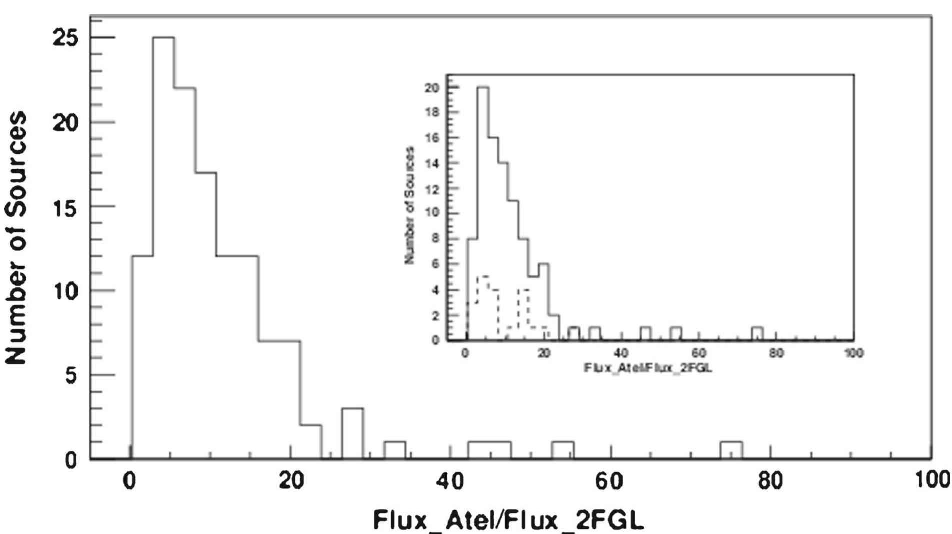

Figure 3. Ratio between the flux ($E > 100\,\text{MeV}$) measured in the time interval reported in the ATel and the mean 2FGL flux; in the inset are shown the two main different classes: solid line represents FSRQ and dashed line represents BL Lacs.

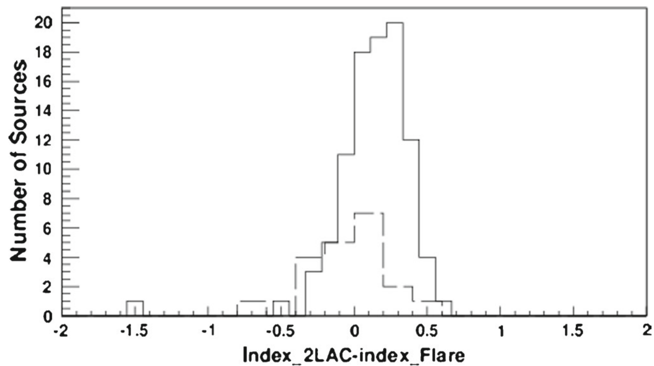

Figure 4. Difference between the mean 2LAC index and the index measured in the time interval reported in ATel. Solid line represents FSRQ and dashed line represents BL Lacs; here only sources belonging to the 2LAC clean sample are considered.

derived for the flaring state is presented in Fig. 4, distinguishing the two classes of blazars: BL Lacs are plotted by a dashed line, and FSRQs by a solid line. The histogram represents the difference between the average 2LAC index and the index measured during the flare. While BL Lac indices remain almost constant, FSRQs show a hint of hardening their spectra during the flaring state.

Acknowledgements

Fermi LAT Collaboration acknowledges support from a number of agencies and institutes for both development and operation of the LAT as well as scientific data analysis. These include NASA and DOE in United States, CEA/Irfu and IN2P3/CNRS in France, ASI and INFN in Italy, MEXT, KEK and JAXA in Japan, and K. A. Wallenberg Foundation, the Swedish Research Council and the National Space Board in Sweden. Additional support from INAF in Italy and CNES in France, for science analysis during the operations phase is also gratefully acknowledged.

References

Ackermann, M. *et al.* 2012, *Astrophys. J. Suppl.*, **203**, 4.
Ackermann, M. *et al.* 2011, *Astrophys. J.*, **743**, 171.
Atwood, W. B. *et al.* 2009, *Astrophys. J.*, **697**, 1071.
Ciprini, S. and the Fermi-LAT Collaboration, 2012, *American Inst. Phys. Conf. Ser.*, **1595**, 697.
Kerr, M. 2011, Ph.D. in physics (New York: University of Washington).
Mattox, J. R. 1996, *Astrophys. J.*, **461**, 396.
Nolan, P. L. *et al.* 2012, *Astrophys. J. Suppl.*, **199**, 31.
Thompson, D. J. *et al.* 1993, *Astrophys. J. Suppl.*, **86**, 629.