PROCEEDINGS OF SCIENCE

Characterizing the long-term γ-ray variability of the BL Lac object 1ES 1215+303 with *Fermi*-LAT

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We report on the recent flaring activities from the BL Lac source 1ES 1215+303 detected by the *Fermi*-Large Area Telescope (LAT; 100 MeV < E < 500 GeV). Since its first detection at energies above 100 MeV, several increments on the γ-ray flux have been reported, where the latest ones from 2015 to 2017 are presented in this study. Additionally, we use all the data set accumulated by *Fermi*-LAT spanning more than nine years, along with the improved analysis techniques to perform spectral studies and characterize the long term variability. The results obtained are presented in this contribution.

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1. Introduction

The object 1ES 1215+303, also known as ON 325 and B2 1515+30, is a BL Lac Blazar type located at a redshift of z = 0.13 [1]. It was listed as a γ-ray emitter in the first *Fermi*-LAT bright catalog in 2009 and was first detected at TeV energies by the MAGIC experiment in 2011 after triggering an optical high flux state [2] [3]. Since its first detection at very-high-energies (VHE), other high-flux states from this object have been reported in this energy range. Observations from *Fermi*-LAT covering the flares reported at VHE by VERITAS and MAGIC experiments resulted in only one simultaneous detection of a bright flare seen by VERITAS in 2014 February 14 [4]. A Doppler factor of $\delta < 10$ is required to explain the extreme flare detected at VHE in 2014.

Blazars are Active Galactic Nuclei, whose relativistic jets are aligned closely to the observer's line-of-sight. They are known to undergo extreme and high-amplitude variable emission across the electromagnetic spectrum [5]. The spectral energy distribution (SED) is characterized by a double-hump structure with one peak located in the radio-to-UV/X-ray range and a second one in the X-to-γ-ray range. The first peak is attributed to the synchrotron radiation from the relativistic electrons moving in the jet's magnetic field. The origin of the second component is still under debate where two different scenarios of hadronic or leptonic origin exist. In the leptonic scenarios it is commonly believed that the second component arises from electrons that suffer Inverse Compton (IC) scattering with low energy photons. The origin of the low-energy photons responsible for the IC is still unclear. The so-called Synchrotron-Self-Compton (SSC) and the External Compton (EC) are considered as possible origin of photons. In the hadronic scenarios pion decays and hadronic synchrotron emission are the processes responsible for the high-energy emission if protons are accelerated to sufficiently high energies [6].

Blazars are classified as FSRQ or BL Lac (Flat Spectrum Radio Quasars) based on the strength of the emission lines where the latest are characterized by featureless emission lines. Based on the peak of the SED, 1ES 1215+303 is classified as an intermediate (IBL) or high frequency peaked BL Lac (HBL) [7] [8].

In this contribution, we present the long-term lightcurve derived using almost nine years of data accumulated by the *Fermi*-LAT satellite. This study resulted also in the detection of new flaring activities occurring on the time interval from 2015 and 2017.

This proceeding is organized as follows: Section 2 describes the *Fermi*-LAT detector and observations. Section 3 and 4 describe data analysis techniques and analysis results respectively. Section 5 contains a short summary and the conclusions. In this work all the errors quoted are purely statistical.

2. *Fermi*-LAT

The *Fermi* Gamma Ray Space Telescope mission was launched on 2008 June 11, with two instruments on board; the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM). The *Fermi*-LAT satellite is studying the high-energy (HE; E > $\mathcal{O}(MeV)$) sky by converting γ-rays into electron/positron pairs in one of the thin tungsten foils of the detector [9]. The LAT instrument covers the energy range from $\sim$ 20 MeV up to few hundreds of GeV and celebrated its 9^{th} successful operational year in June 2017.

The data accumulated by *Fermi*-LAT is publicly available, released in the form of event (PH) and spacecraft (SC) files containing the lifetime information and spacecraft pointing positions.

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Since the launch of *Fermi*-LAT, the data is continuously updated by the LAT team using more sophisticated reconstruction techniques and Instrument Response Functions (IRFs). The latest reconstruction technique (Pass 8) leads to a substantial increase of γ-ray acceptance, i.e. high photon detection probability. This allows a better reconstruction up to 500 GeV compared to the previous one (Pass 7).

3. Data Analysis

For this study we used almost nine years of data taken on survey mode on 1ES 1215+303 since the start of *Fermi*-LAT. The data analysis is conducted with the likelihood framework provided in the *Fermi* ScienceTools software package, version `v10r0p5`. We selected events with energies 100 MeV $<$ E $<$ 500 GeV from a 15° region of interest (RoI) centered on the position of 1ES 1215+303 (R.A. = $12^{h}17^{m}52^{s}$, decl. = $+30°07'00''$, J2000).

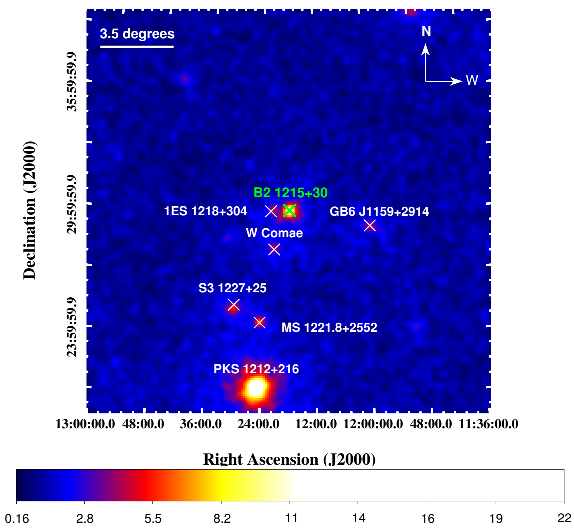

Figure 1: Counts map produced with *Fermi*-LAT data in a 20° $\times$ 20° region of sky. The map is centerd at the position of 1ES 1215+303 (marked as B2 1215+30) which is indicated a cyan cross in the map. All the other bright sources in this region are marked with a white cross.

In this analysis, the background model includes the all known γ-ray sources from the third *Fermi*-LAT catalog (3FGL) within the RoI and the sources located up to 5° outside the RoI edges. The galactic and isotropic diffuse emissions were modeled with `gll_iem_v06` and `iso_P8R2_SOURCE_V6_v06` respectively from the *Fermi* ScienceTools and a set of instrument response functions `P8R2_SOURCE_V6`[1] were used. The contamination from γ-ray Earth's limb is taken into account by excluding events with zenith angles $<$ 90°.

4. Analysis Results

Figure 1 shows the counts map produced using 6 months of data from 2016. It shows an RoI of 20° centered on 1ES 1215+303 (marked as B2 1215+30). This sky region is interesting

[1]http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/

since it is a sky region populated with TeV sources. Only the bright sources appearing in this region are marked with a cross. All of them are BL Lac type objects and TeV emitters, except the GB6 J1159+2914 which is a quasar and no TeV emission has been detected from it so far. One can distinguish the nearby source, 1ES 1218+304 (z=0.182), a bright TeV emitter located (R.A. = $12^{h}21^{m}26.3^{s}$, decl. = $+30^{\circ}11'29''$, J2000). These two nearby sources exhibit opposite emission behaviour, in terms of brightness, in the GeV and TeV energy bands. For instance, 1ES 1215+303 apperas brighter in the GeV energy range and faint in TeV, whereas 1ES 1218+304 exhibits the opposite behaviour in this regard [10].

4.1 Long-term Lightcurve

The lightcurve was derived using the *gtlike* algorithm from ScienceTools to calculate the integral flux in different time bins. The spectrum of 1ES 1215+303 was modeled using a simple power law:

$$\frac{\mathrm{dN}}{\mathrm{dE}} = \mathrm{N}_0 \left(\frac{\mathrm{E}}{\mathrm{E}_0}\right)^{-\Gamma} \tag{4.1}$$

where N_0 is the normalization factor at a chosen reference energy E_0, and Γ is the photon index. The spectral index and integral flux of 1ES 1215+303 were let free during the global fit. Other known sources located within RoI but detected with TS > 9 ($\sigma \simeq \sqrt{TS}$), were kept in the model with fixed parameters to their catalog values. While calculating the integral flux in short time bins, only the integral flux was left free while the spectral index was fixed to the value obtained during the fitting procedure for the entire time range. For the other sources inside the RoI, detected with a TS < 9, all the parameters were frozen to the values obtained during the fitting procedure over the whole time period.

The long term-light curve, derived with data from September 2008 1st to 2017 June 30, corresponding to MJD (54710-57934) is shown in Figure 4. The flux's evolution of 1ES 1215+303 is studied by calculating the integral flux, from 100 MeV-500 GeV in one week time bins. Three major flaring episodes, with weekly averaged flux $\mathrm{I} > 3.0 \times 10^{-07}$ $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, are detected during October 2008, February 2014 and April 2017.

Fermi-LAT (0.1-500 GeV)	Dates	Signal	Flux [$\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$]
	2008 Oct 12 – 2008 Oct 13	15.5σ	$(9.2 \pm 0.15) \times 10^{-7}$
	2014 Feb 08 – 2014 Feb 09	12.2σ	$(9.2 \pm 0.18) \times 10^{-7}$
	2017 Apr 12 – 2017 Apr 13	14.0σ	$(8.0 \pm 0.15) \times 10^{-7}$

Table 1: The major flares of 1ES 1215+303 detected using nine years of *Fermi*-LAT observations

The strength of the signal during these flares allows to derive the lightcurve in one day time bins. The corresponding lightcurves in one day time bin around these flares are shown in the bottom part of Figure 4. These flares are investigated by deriving one day time bin lightcurves for a longer time period, centered around the highest flux value. The corresponding details are summarized in Table 4.1. The strength of these flares allows to investigate the variability on short-time scales and it is possible to go down to 4.6 hours time bins.

Fermi-LAT reported on the detection of a bright flare on 2014 Feb 14, seen simultaneously by VERITAS experiment at TeV energies. We investigated the latest flaring activities, occurring in the GeV range after this date and found the source in several high flux states.

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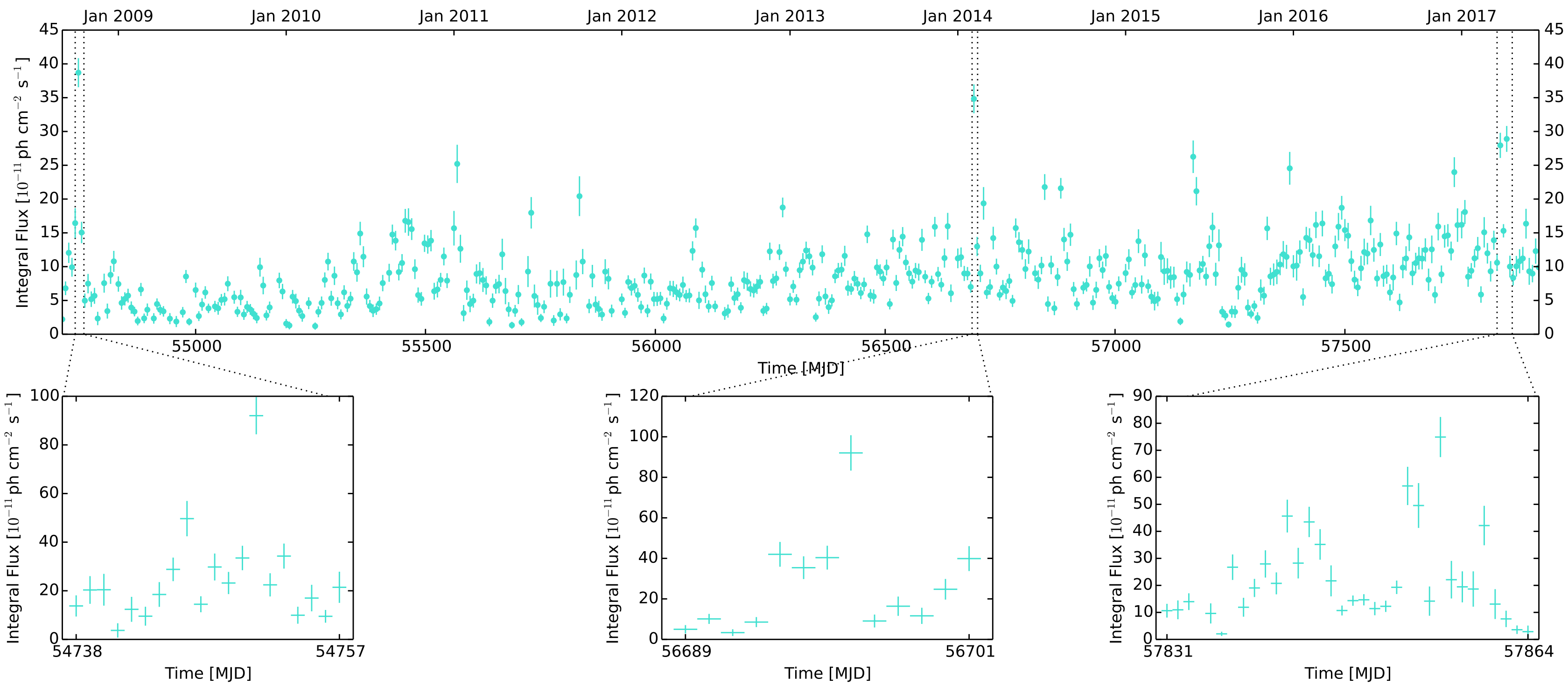

Figure 2: *Top panel:* Long-term lightcurve of 1ES 1215+303, from 2008 September 1st to 2017 June 30. The integral fluxes are calculated in one week time bins. The major flares, with weekly averaged flux $I > 3.0 \times 10^{-07}$ cm^{-2} s^{-1} are indicated by dashed black lines. *Bottom panel:* lightcurve in one day time bins around the major flares detected during October 2008, February 2014 and April 2017.

4.2 Recent flaring activities

This analysis resulted in the detection of several flux increament from 2015 to 2017, where only one flare has been reported by the *Fermi*-LAT on 2017 April 13 (ATel #10270). The corresponding lightcurves for these years are plotted in Figure 3. The flaring episodes where the flux is exceeding the value of $I > 2.4 \times 10^{-8} cm^{-2} s^{-1}$ (weekly average) are summarized in Table 4.2.

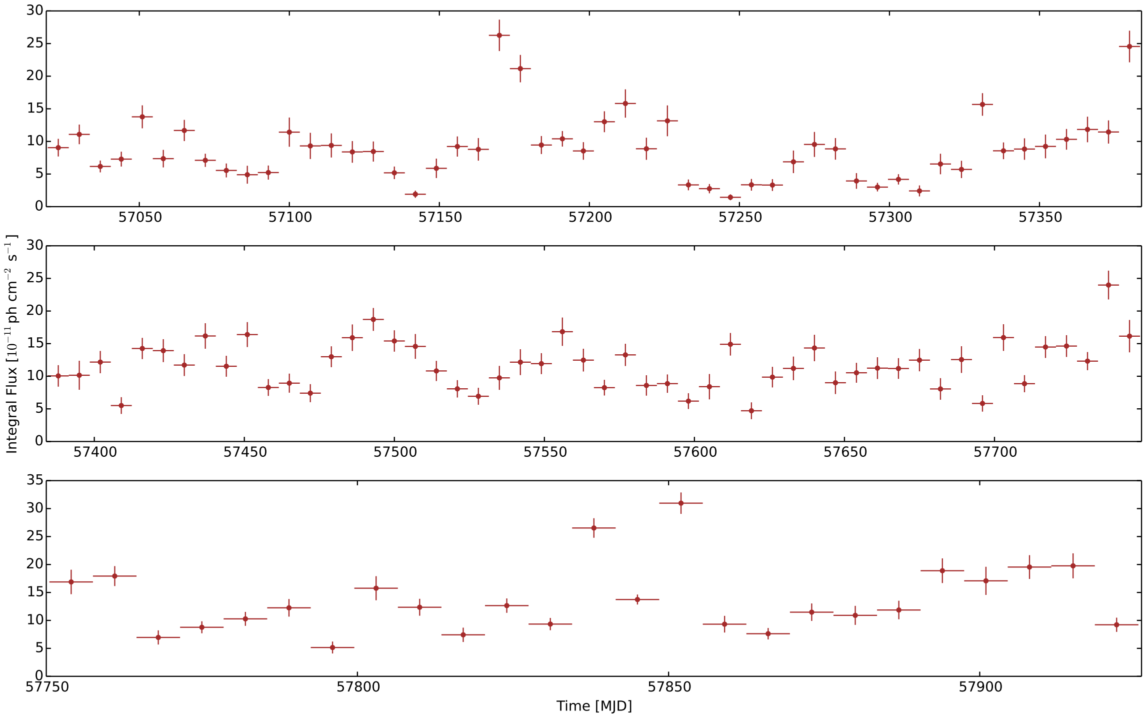

Figure 3: Integral flux I (100 MeV < E < 500 GeV) in one week time bins for all the 2015 (MJD 57023-57387) and 2016 (MJD 57388-57753) sets in top and middle panels. The bottom panel shows six months of data, from 2017 January 1st to 2017 June 30 (MJD 57754-57934).

Fermi-LAT (0.1-500 GeV)	Dates	Signal	Flux [$cm^{-2} s^{-1}$]
	2015 Jan 01 – 2015 Jan08	12.0σ	$(2.6 \pm 0.48) \times 10^{-7}$
	2015 Dec 23 – 2015 Dec 30	9.4σ	$(2.5 \pm 0.48) \times 10^{-7}$
	2016 Dec 16 – 2014 Dec 23	14.2σ	$(2.4 \pm 0.44) \times 10^{-7}$
	2017 Mar 25 – 2017 Apr 01	21.6σ	$(2.7 \pm 0.35) \times 10^{-7}$
	2017 Apr 07 – 2017 Apr 15	20.1σ	$(3.1 \pm 0.38) \times 10^{-7}$

Table 2: The latest flares of 1ES 1215+303 detected from 2015-2017

5. Summary and Conclusions

In this proceeding we have presented the long-term lightcurve of the BL Lac object 1ES 1215+303 in the energy range 100 MeV < E < 500 GeV with *Fermi*-LAT. Several flux increment have been detected from 9 years of *Fermi*-LAT data analysis. The major flares are reported on in this work. The three brightest flares ($I > 8.0 \times 10^{-7}$ $cm^{-2} s^{-1}$) occurred during 2008, 2014 and

2017 respectively. Such events are used to derive the variability time scale and to set limits on the size of the emission region of the source.

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