Unprecedented temporal analysis of the γ-ray blazar 1ES 1215+303: *Fermi*-LAT and VERITAS light curves spanning ten years

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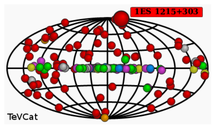
Summary:
We present here the results of the analysis of the gamma-ray blazar, 1ES 1215+303, over a 10-year period, from 2008 to 2017, measured at high energies (HE; 200 MeV < E < 100 GeV) by the Fermi Large Area Telescope (LAT) and at very high energies (VHE; E > 100 GeV) by Fermi-LAT and VERITAS. This is the longest temporal study of this high-frequency-peaked BL Lac object (HBL) at gamma-ray energies. The spectrum follows a log-parabola over this time period, and its HE and VHE spectra are well-connected. Its flux is sufficiently strong at HE to allow us to bin the Fermi-LAT data in 3-day intervals, enabling us to investigate the time evolution of the flux in unprecedented detail. Several flaring episodes were detected and evidence for an overall trend of increasing flux over the span of the 10 years was observed. These light curves, in addition to the spectra, are presented. This unique data set will help us to advance our understanding of the underlying physical processes in blazar jets.

1ES 1215+303 ≡ B2 1215+30 ≡ ON 325

- $z = 0.131$ [4]
- R.A.: $12^h17^m48.5^s$
- Dec.: $+30°07'00''6$
- HBL
- Brightest flares:
  - At VHE: 2013 Feb 07 & **2014 Feb 08** [6].
  - At HE: 2008 Oct 10-15 in a weekly LC [5], and **2014 Feb 08** [6].

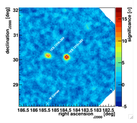


VERITAS

The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is an array of four imaging atmospheric Cherenkov telescopes located at the Fred Lawrence Whipple Observatory in southern Arizona, U.S.A. (31° 40'N, 110° 57'W, 1.3km a.s.l.). Each of the four telescopes comprises a 12-m diameter mirror, of the Davies Cotton design, and an imaging camera with 499 high-quantum-efficiency photomultiplier tubes. The four telescopes operate in stereo mode to cover a field of view of approximately 3.5° with an angular resolution of 0.08° at 1 TeV (68% containment radius). The energy range of VERITAS goes from 85 GeV to above 30 TeV (spectral reconstruction possible from 100 GeV) with an energy resolution of 15-25% and an effective collection area for a 1 TeV photon on the order of $10^5 m^2$. A source with a flux of 1% that of the Crab Nebula, the standard candle at these energies, is detectable at 5 standard deviations above background in approximately 25 hours [2]. The data were analysed using the two standard VERITAS analysis software packages [3],and produced results that were in excellent agreement with each other.

(Credit: http://veritas.sao.arizona.edu/)

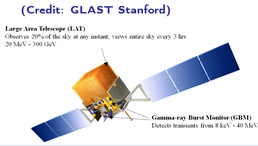
OurVERITAS 2015



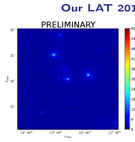
Fermi-LAT

The Large Area Telescope (LAT), on board the Fermi Gamma-ray Space Telescope, is a pair conversion detector that covers the energy range from 20 MeV to more than 500 GeV with a field of view of approximately 2.4 sr [1]. The main observation mode of the *Fermi*-LAT is survey mode during which the LAT scans the entire sky every 3 hrs. We analyzed the *Fermi*-LAT data for 1ES 1215+303 since 2008-08-04, the start of the mission, up until to 2017-09-04. The data analysis was performed using the Fermi Science Tools package, version v10r0p5, and the latest P8R2_SOURCE_V6 instrument response functions. We have considered a maximum zenith angle of 90° in order to reduce contributions from the Earth limb; and photons with energies greater than 100 MeV. For each data sample, we considered photons in a 10° region of interest centered at the position of 1ES 1215+303; and contributions from sources from the 3FGL within a 16.2° region were included. The residual maps obtained in our analysis did not show evidence of excesses. For the modeling of 1ES 1215+303, we considered both a power-law (PL) and a log-parabola (LP) spectral model.

(Credit: GLAST Stanford)



Our LAT 2015



Our preliminary results

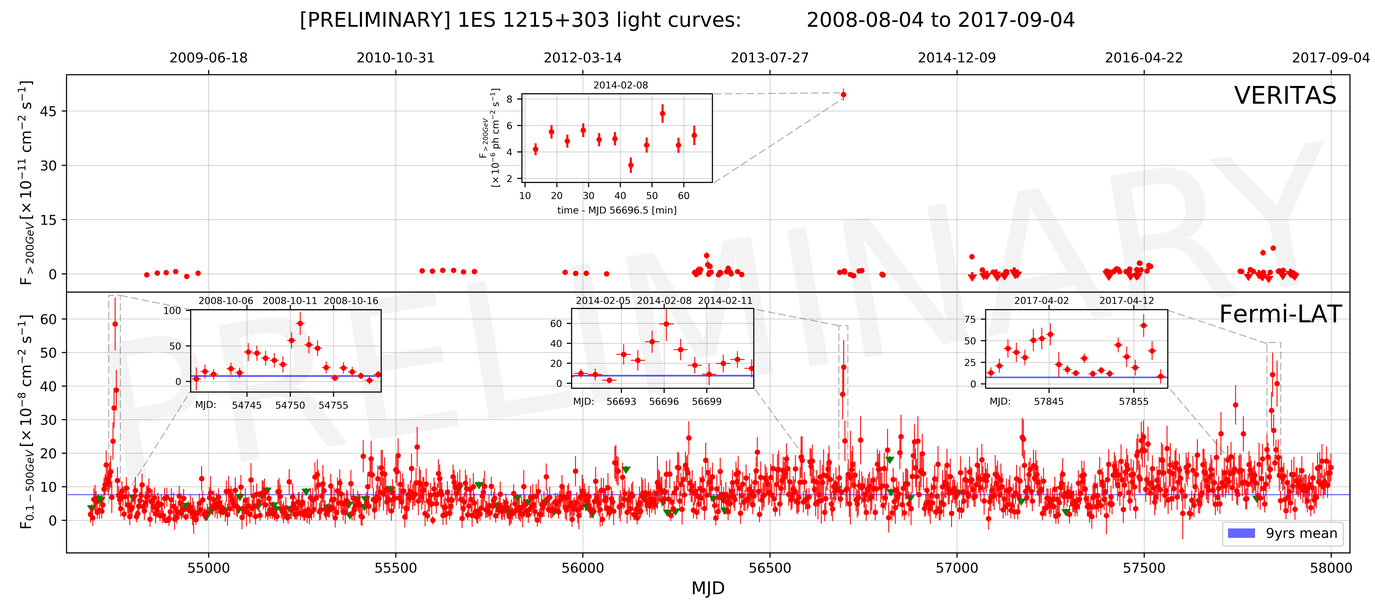


Figure 1: *Long-term light curves: VERITAS 1-day data points on the top and 3-day LAT data on the bottom. Zooms of 1-day light curves are shown for the brightest flares of 1ES 1215+303 for the LAT data, and 5 min bins for the brightest VERITAS flare. The VERITAS light curve includes archival data up to 2014; the 2015-2017 data were not previously published. We detected a coincidental GeV-TeV flare on 2017-04-01, the SED of this flare can be observed in fig. 3 together with the SED of the whole 2017-01-01 to 2017-06-30 season and the SED of the season without the flaring epochs. Upper limits are shown as green downward triangles for the LAT data.*

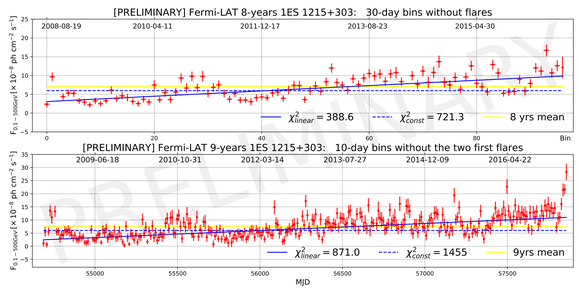


Figure 2: *Top: 30-day binned light curve. Bottom: 10-day binned light curve. Both of them exclude the brightest flares. We observe a preference for a linear increase of the flux over a constant average in both data sets.*

Table 1: Summary of our preliminary results*.

Instrument	Dates	Live time [min.]	Sign.	Γ
VERITAS	2015-01-17 to 2015-05-19	979.4	17.1σ	-3.31±0.18
	2016-01-12 to 2016-05-09	1324	26.4σ	-3.13±0.12
	2017-01-03 to 2017-05-29	1473.95	33.0σ	-3.62±0.10
	2015-01-17	114.3	17.1σ	-2.96±0.18
	2017-04-01	150.1	28.9σ	-3.56±0.13
Fermi-LAT	2015-01-01 to 2015-06-30		37.4σ	-1.91±0.04
	2016-01-01 to 2015-06-30		44.4σ	-1.88±0.03
	2017-01-01 to 2017-06-30		54.7σ	-1.85±0.02
	2008-08-04 to 2017-09-04		139σ	-1.92±0.01
	2017-04-01		11.2σ	-1.75±0.15

* Refer to the paper in preparation for the the final numbers.

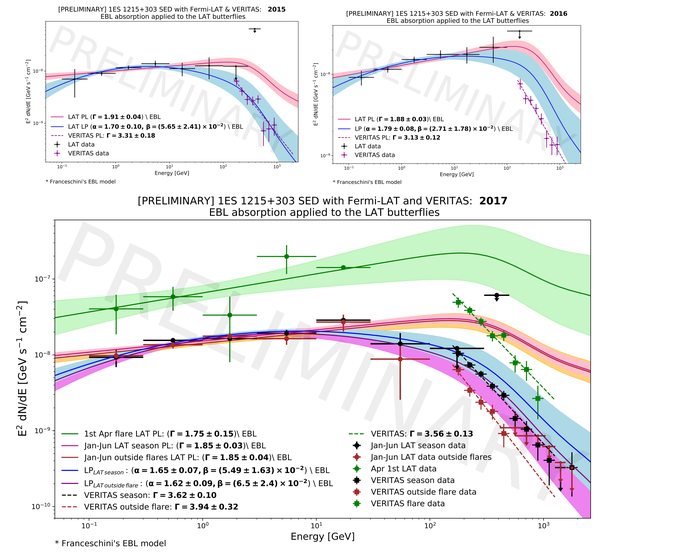


Figure 3: *The GeV-TeV data is observed to be well connected in all these SEDs. The EBL-absorbed LAT spectra were extrapolated to the VERITAS energy range. We observe that the LP SED is more compatible than the PL model with the TeV observations. We additionally show the flaring and quiescent state SEDs for the 2017 season, which displays compatibility as well.*

Discussions

Our studies of the long-term LAT/VERITAS data from 1ES 1215+303 have allowed us to derive detailed light curves and simultaneous spectral energy distributions. The LAT data have demonstrated a preference for a log-parabola fit to the GeV spectrum (a power-law fit was rejected at the 5.26σ level with the first 8 years of LAT data). This indicates that the gamma-ray spectrum of this blazar begins to turn over in the LAT energy range, i.e., at energies below those that can be attributed purely to absorption by the EBL thus indicating curvature intrinsic to the source itself. The EBL-absorbed LAT log-parabola spectrum is consistent with the spectrum measured by VERITAS at higher energies, and therefore already subjected to the effects of EBL absorption. Unlike what has been observed for other blazars at TeV [9][10] and GeV energies [7], the spectral index of this blazar does not show significant evidence for hardening when it enters a higher flux state (fig. 3). This relationship will be investigated further in our ongoing more detailed analyses as this relationship has been shown to be complex when shorter-term spectra were derived - e.g. for the case of Mrk 421 [8].

The fact that we were able to measure the GeV flux of this blazar in such unprecedented detail over a ten-year span has allowed us to evaluate the evolution of the flux with time. An interesting feature that we have already found is an apparent increasing trend in its flux over the duration of the observations (fig. 2). We find that, for the GeV gamma-ray flux, an increasing-flux model is preferred to a constant flux at more than 15σ level. Additionally, a preliminary yearly study of the complete LAT data set has shown some indication of a spectral-hardening trend of 1ES 1215+303 as a function of time. We are investigating this potential trend in the flux and spectral index, excluding the flaring epochs, and will present a more in-depth study in a subsequent publication that is in preparation between the *Fermi*-LAT and VERITAS Collaborations.

In conclusion, this unique data set will help us to advance our understanding of the underlying physical processes in blazar jets through the investigation of the variability, the search for periodicity and the cross-correlation studies between different wavelengths. Additionally, further investigation of the trend of long-term increasing flux and potential spectral hardening is ongoing.

References

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