Exploring Extremely Bright Gamma-Ray Flashes from BL Lacertae

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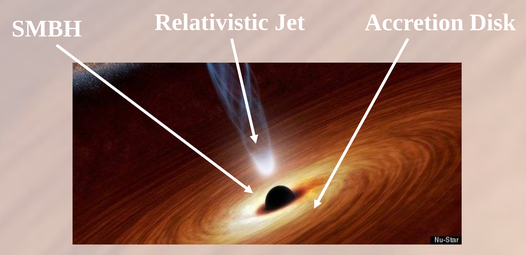
I: Abstract

Ever since the revolutionary discovery by the Fermi mission that active galactic nuclei (AGN) produce copious amounts of high-energy emission, its origin has remained elusive. Extremely bright flashes in the high-energy gamma-ray regime (GeV-TeV) at minutes to hours timescales in blazars (jetted AGN pointed towards our line-of-sight) have attracted the astronomical community's attention as they suggest that particles can be accelerated with impressive efficiency in tiny magnetized regions within extended sources. Using Fermi Large Area Telescope (LAT) data, we investigate the gamma-ray flux variations in the nearby blazar BL Lacertae (BL Lac). This process involves analyzing and filtering the Fermi data using the software package ScienceTools and developing Python code for automatic analysis procedure. We found that the source exhibits multiple modes of flaring activity. Faster flares are superimposed on top of broad outbursts. We detected a significant correlation between photon flux and photon index variations, which suggests that the gamma-ray variations in the source are mostly produced by radiative processes.

II: Active Galactic Nuclei

- AGN—the most powerful objects in the universe—are powered by supermassive black holes (**SMBH**s) accreting surrounding matter. Radio-loud AGN launch a **relativistic jet** perpendicular to the **accretion disk**, which give way to radio lobes extended up to megaparsecs in size.
- Blazars (jetted AGN aligned close to our line-of-sight) constitute a unique laboratory to probe the inner jet emanating from the central engine. They are characterized by powerful, non-thermal emission ranging from radio to gamma-ray bands and exhibit strong variability over minute to month timescales. Radio components detected in VLBI observations often exhibit superluminal motion.

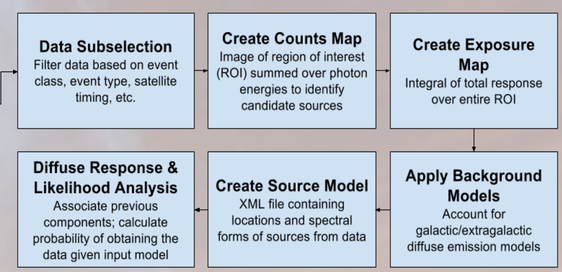


AGN (image courtesy Earth Changes Company, LLC)

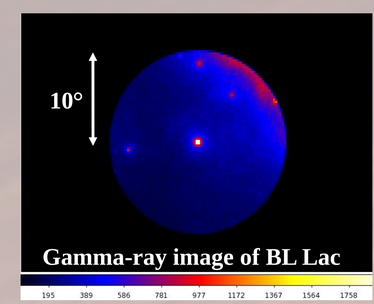
III: Methods

- Used data from 2008-2017 to investigate photon flux and index variations in BL Lac
- Divided data into two week intervals
- Conducted an unbinned likelihood analysis
- Source spectrum modeled using a simple power law defined as $N(E) = N_0 E^{-\Gamma}$ (N_0 is the prefactor and Γ is the power law index)

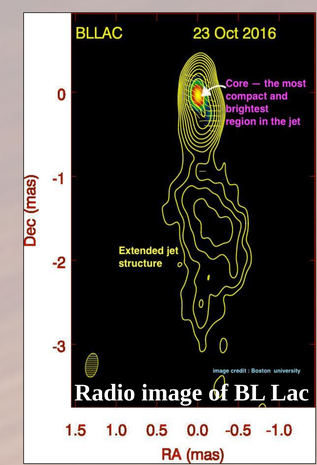
Data was taken using Fermi-LAT.



Flowchart of the data analysis procedure.

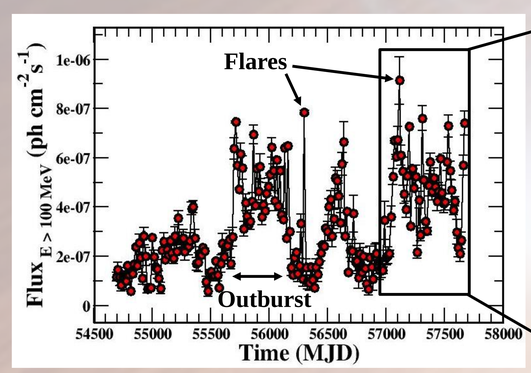


Gamma-ray events centered on BL Lac (image radius 10°) at E > 100 MeV measured by Fermi-LAT. The brightness scale represents the number of photons detected.

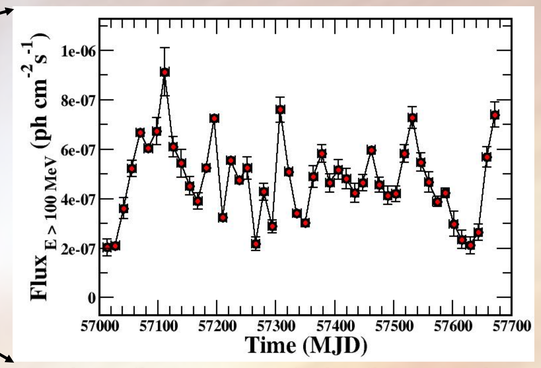


Parsec-scale (< 5 parsec) radio image of BL Lac at 43 GHz radio frequency.

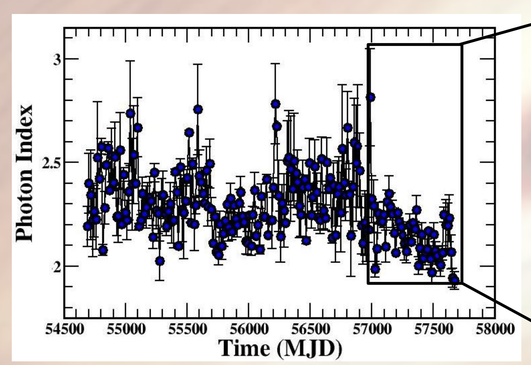
IV: Results



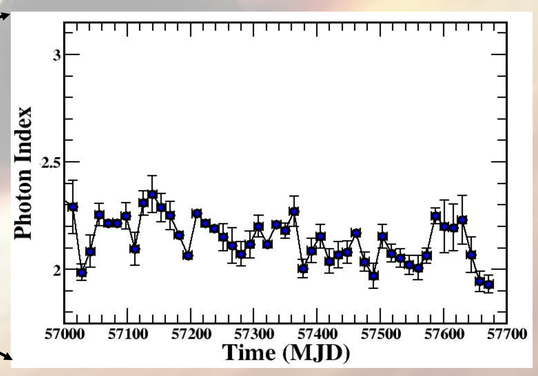
Photon flux variations observed in BL Lac. We detected multiple modes of flaring activity—faster flares are superimposed on broad outbursts.



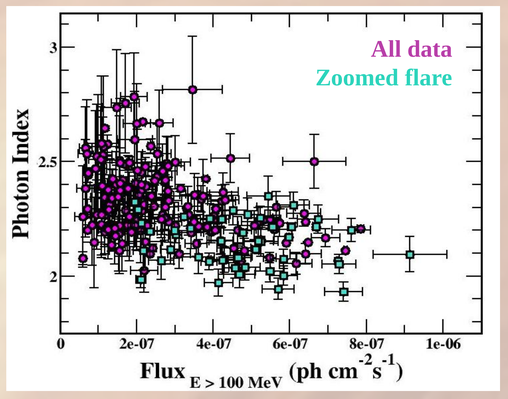
Photon flux versus time for last flare zoomed in.



Photon index variations observed in BL Lac.



Photon index versus time for last flare zoomed in.



Photon index versus photon flux variations.

- Photon index vs. flux correlation tested via linear Pearson correlation analysis.
- We obtained r_p (linear Pearson correlation coefficient) = -0.46 at p-value = 1.2e-12, which indicates a significant anti-correlation.
- Harder-when-brighter trend—hardening (flattening) of spectrum during bright flares indicates that the variations are driven by radiative processes.

VI: Acknowledgements and References

Special thanks to my mentor Dr. Bindu Rani, Dr. Sara Buson, Dr. Elisabetta Cavazzuti, and the entire Fermi group for their help and encouragement. Data from Fermi-LAT. Details of data analysis can be found at https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/likelihood_tutorial.html.

V: Summary

- Multiple modes of flaring activity—faster flares superimposed on broad outbursts—are observed in BL Lacerate.
- Gamma-ray flux variations significantly correlate with photon index variations such that the spectrum gets harder (flatter) when the source gets brighter.
- Harder-when-brighter trend indicates that the gamma-rays variations are driven by radiation processes.