Boletim da Sociedade Astronômica Brasileira, **34**, no. 1, 155-156

Study of Active Galactic Nuclei Flares

A brightening analysis from Fermi-LAT data and target sources for the Cherenkov Telescope Array

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Abstract. We intend to perform statistical studies of the newest release of the Fermi-LAT catalog (4LAC), based on the brightness of AGN sources, using their photon flux and energy in order to extrapolate and estimate what the Cherenkov Telescope Array (CTA) will be able to detect, with which probability and how variability affects the size of the population we identify. This for a sample of about 1500 sources selected from the catalog that we will later use to identify target sources for detecting flares across the CTA's gamma-ray spectral range, which goes well above the 100 GeV that Fermi-LAT can observe, extending to 100 TeV.

Resumo. Pretendemos realizar estudos estatísticos da mais nova versão do catálogo Fermi-LAT (4LAC), com base no brilho de fontes AGN, usando seu fluxo de fótons e energia, a fim de extrapolar e estimar o que o Cherenkov Telescope Array (CTA) será capaz de detectar, com que probabilidade e como a variabilidade afeta o tamanho da população que identificamos. Isso para uma amostra de cerca de 1.500 fontes selecionadas deste catálogo, que usaremos posteriormente para identificar fontes-alvo para detectar "flares" na faixa espectral de raios gama do CTA, acima dos 100 GeV que o Fermi-LAT pode observar, estendendo-se a 100 TeV.

Keywords. Galaxies: active – Galaxies: nuclei – Galaxies: jets – Gamma rays: galaxies

1. Introduction

Blazars are one of the main sources of ultra-high-energy gamma-ray emissions and were chosen as the main focus of this study. Our interest is in exploring patterns on the sources seen by Fermi-LAT, if their variability has a specific proportion compared to its average integrated flux from the SED, which we will later use to identify target sources for detecting flares across the CTA's gamma-ray spectral range using a Fractional Variability Parameter from Vaughan et al. (2003). This analysis is rather important for 2 different branches in the CTA Collaboration, the AGN Population Task Force that focuses mainly on an statistical sopulation analysis and the AGN Variability Task Force which focuses on the Variability of the AGNs and flaring episodes by doing simulations.

2. Objectives

The main goal of this project is to perform statistical analysis upon the data from 4LAC Catalog (The Fourth Catalog of Active Galactic Nuclei detected by the Fermi Large Area Telescope, NASA's Fermi-LAT Repository (2022) and NASA's Fermi-LAT Data Access (2022)), by reproducing the spectrum and light curve for 4LAC sources and evaluating "variability trends" in different detected AGNs (Active Galactic Nuclei).

3. Methodology and Numerical Setup

Using a Python notebook developed by the CTA collaboration members, that generates a modified 4LAC catalog, selecting only those sources with a valid redshift and that are bright enough, we first reproduced the lightcurve of many sources from this catalog and compared it to the catalog references (NASA's Fermi-LAT Repository 2022). As an example, see Figure 1 for one of these sources.

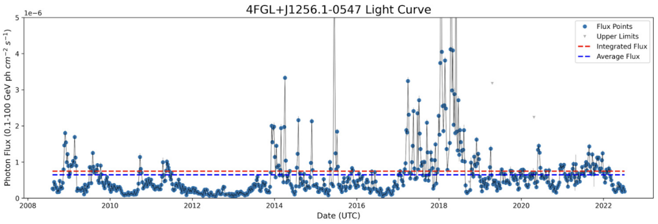

Figure 1. Reconstructed Light Curve of the source 4FGL+J1256.1-0547, made by a Python notebook using the data from the newest 4LAC catalog from Fermi-LAT collaboration. The dashed lines in blue and red represent the average of the flux points and the integrated flux from the Spectrum, respectively. See text for more details.

Then, we reproduced the Spectrum Energy Distribution of those same sources, by using the parameters in the catalog, which were acquired by the Fermi-LAT collaboration within a 10 year average of the observations of each source, and also compared it to the reference ones NASA's Fermi-LAT Repository (2022). See Figure 2 for the same source of Figure 1.

The SED parameters are the Pivot Energy E_0, Flux Density K, spectral slope α and curvature β, both for the LogParabola Spectrum Type, as well as for the PowerLaw Spectrum Type, the only difference is that for a PowerLaw Spectra, $\beta = 0$, and the Equation 1 is defined as the Energy flux for both cases (Abdollahi et al. (2020) & Ajello et al. (2020)). We obtain the Energy Flux νF_ν, in erg cm^{-2} s^{-1} by

$$\nu F_\nu = E^2 \frac{dN}{dE} = E^2\, K \left(\frac{E}{E_0}\right)^{-\alpha\ -\beta\ \log(E/E_0)} \tag{1}$$

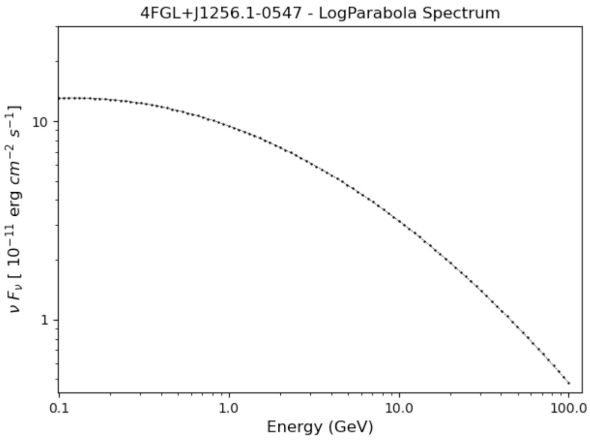

Figure 2. Spectral Energy Distribution of the source 4FGL+J1256.1-0547 within a 10-year average taken between 2012 and 2022 of the observations from Fermi-LAT in Figure 1.

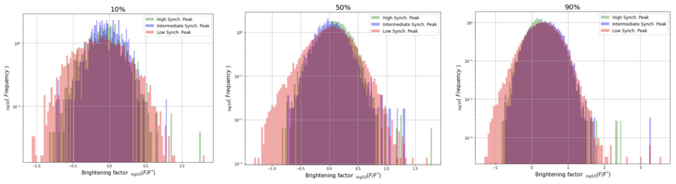

Figure 3. Histograms of the Frequency of the Brightening Factor in a log 10 scale, for selected percentages of 10%, 50% and 90% of the difference between the average flux and the integrated flux.

In order to compare the SED averaging the last 10 years of observation from Fermi-LAT with the Light Curve, the units of the y-axis should be [0.1-100 GeV ph cm^{-2} s^{-1}], by using the Equation 2:

$$\int \frac{dN}{dE} dE \Rightarrow \left[\int \frac{dN}{dE} dE \right] = \frac{ph}{cm^2\ s} [0.1 - 100\ GeV] \tag{2}$$

4. Expected Results and Conclusion

To compare the brightness of each source with its spectrum flux, we divided each flux point from the catalog by its integrated spectrum average flux, that is what we call, the brightening factor, we calculated it for each flux point detected for each source, and made a comparison between Low, Intermediate and High Synchrotron Peak sources.

Within our light curves, sources are always observed during 1-week bins, but they are only detected in the time bins that have flux points instead of upper limits. The blue dotted line in Figure 1 is the average of the flux points, although it does not have any physical meaning in this case, we only use it as a way to separate the sources, we only want to assure that the brightening factor is not unrealistically large due to extremely bright sources.

Therefore, we have selected 3 percentages of the difference between the average flux and the average spectrum flux, 10%, 50% and 90%. Then, we gathered all the brightening factor values to investigate a different time evolution between each of the classified sources, see Figure 3.

In Figure 3, the histograms show how the sources change in flux, it is an average state. Given that in a log 10 scale, the value 0 means 1, to the left we have fainter fluxes and to the right, brighter fluxes. Those histograms are still being analyzed within the collaboration. We can see, for now, that the blazars classified as so called Low Synchrotron Peak sources are more variable, because their sigma is larger, while the so called Intermediate Synchrotron Peak (ISP) and High Synchrotron Peak (HSP) have a similar sigma, which can be understood as they having similar brightening ranges, though Fermi-LAT is sensitive to those variations.

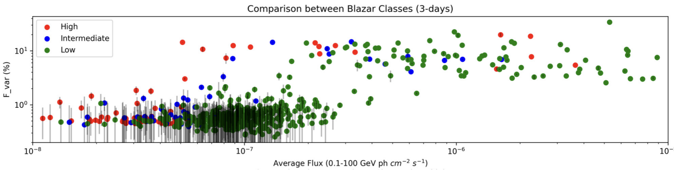

Figure 4. The F_{var} value for each source as a function of the Average Flux for each blazar class type. It shows a comparison between Low (dots in green), Intermediate (dots in blue) and High Synchrotron Peak (dots in red).

We have also calculated the Variability Parameter F_{var} (Acciari et al. (2020), Poutanen et al. (2008) & Vaughan et al. (2003)) and its uncertainty in order to estimate the spectral variation we would expect in a certain period of time. The Variability Parameter F_{var} (Eq. 3) is a linear statistic and can therefore give the rms variability amplitude in percentage terms, in which $< F_\gamma >$ is the average photon flux, S the standard deviation of the N flux measurements and $< \sigma^2_{err} >$ the mean squared error. See Figure 4.

$$F_{var} = \sqrt{\frac{S^2 - < \sigma^2_{err} >}{< F_\gamma >^2}} \tag{3}$$

This investigation can allow to simulate with CTA's machinery and extrapolate what we may observe and how many sources we could detect in a determined range of time as well as target-sources for this new generation of telescopes, by producing a new catalog assuming a reasonable spectral brightening (both in flux and index) per source.

Acknowledgements. This work is funded by the Unified Scholarship Program for Undergraduate Students (PUB) from University of São Paulo and by FAPESP, under the grant number 2013-10559-5.

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