A systematic search for extreme gamma-ray blazars using *Fermi*-Large Area Telescope

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Abstract

Blazars are active galactic nuclei (AGNs) with relativistic jets pointing towards our line of sight. These sources are the most powerful persistent gamma-ray emitters in the Universe. The spectral energy distribution (SED) of blazars has two broad peaks, the lower energy one that lies in the IR-X-ray band, known as synchrotron peak and in the higher energy MeV-TeV band known as inverse-Compton peak. These sources can be classified by the position of their synchrotron peak, which goes from low synchrotron-peaked blazars to extreme synchrotron-peaked blazars with the peak lying at frequencies greater than 10^{17} Hz (around 4 keV). Finding these extreme blazars is challenging due to limits of current instrumentation. Nonetheless, understanding these sources is fundamental for building a complete picture of blazar evolution. In this study, we systematically look for the most extreme of these blazars, by searching for a spectral hardening feature that could lie at the GeV energy range, where NASA's Large Area Telescope is most sensitive. We identify 4 sources with this spectral hardening feature in the gamma-ray energy band with a significance greater than 3 σ. Our results will allow us to understand the recurrence, time-scales, and energetics of these intriguing sources.

1. Introduction

The SED of blazars has a distinctive double peaked shape in the ν vs $\nu L\nu$ diagram, where $\nu L\nu$ is the flux density and ν is the frequency. Based on the location of the synchrotron peak, blazars are further classified into:

- Low synchrotron peaked ($\nu_s \leq 10^{14}$Hz/4 eV)
- Intermediate synchrotron peaked (10^{14}Hz $< \nu_s \leq 10^{15}$ Hz/40 eV)
- High synchrotron peaked ($\nu_s > 10^{15}$ Hz).

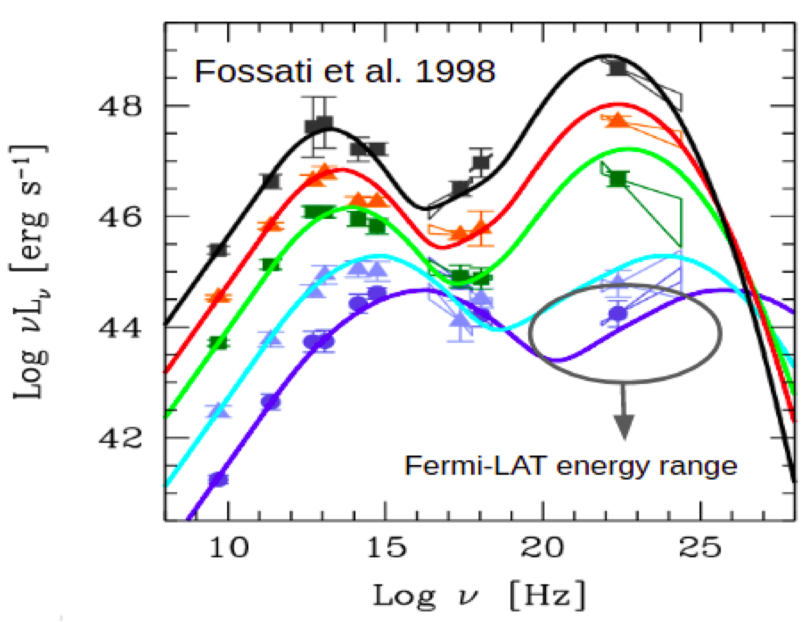

Figure 1: SEDs of different blazars (image from Fossati et al. 1998). The circular region marks the energy range of the Fermi-LAT telescope.

There are also blazars with synchrotron peaks at higher frequencies (above 10^{17} Hz/4 keV) known as extreme gamma-ray blazars.

2. Aim

In this project, we aim to find the most extreme blazars in the universe. The approach involves searching for a spectral hardening feature in the γ-ray SED of blazars in the GeV energy range using Large Area Telescope onboard NASA's *Fermi Gamma-ray Space Telescope.*

Figure 2: *Fermi Gamma-ray Space Telescope* (Credit: SLAC National Accelerator Laboratory).

5. Conclusion

In this project, we attempt to identify the most extreme γ-ray blazars by searching for a distinctive spectral hardening feature within the GeV energy range, using data from Fermi-LAT. Our analysis has found four blazars that exhibit this intriguing feature. In the future, we intend to utilize multiwavelength data to further the understanding of these sources.

3. Methodology

We selected 365 high-latitude blazars from the 4FGL-DR2 catalogue (Ballet et al. 2020), choosing those with synchrotron peak value greater than 10^{16} Hz (i.e, 0.4 keV).

- We fit a Powerlaw (PL) model to the SED of each source and then change to Broken Powerlaw (BPL) model by iterating over the break energy, covering a range from 100 MeV to 10 GeV.
- In each iteration, we calculate twice the difference between the likelihoods of PL and BPL model: $\mathbf{TS_{hardening}=2(BPL\ likelihood\text{-}PL\ likelihood)}$;

We apply this method to the entire telescope time (August 2008-April 2021) and to the flares identified using an algorithm described in Wagner et al. 2022 for each source.

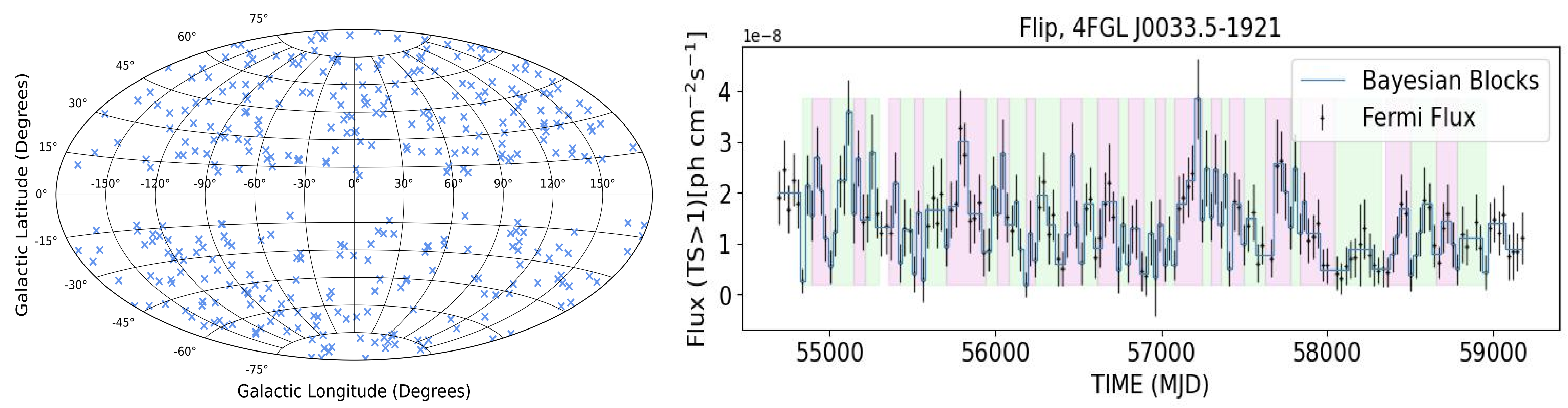

Figure 3: (Left) Distribution of our sources in the sky in Hammer-Aitoff projection system and Galactic coordinates (blue cross-marks). (Right) Lightcurve of a source 4FGL J0033.5-1921 with flares identified highlighted as alternating shaded regions.

4. Results

We identified 20 blazars with spectral hardening feature with significance approximately 3 sigma. However, in few cases, the BPL was not constrained properly and some sources were in a crowded region of X-ray sources which could contaminate the lower energies of the SED. After eliminating such cases, we have **four** robust cases of spectral hardening. Below is an example of one such source.

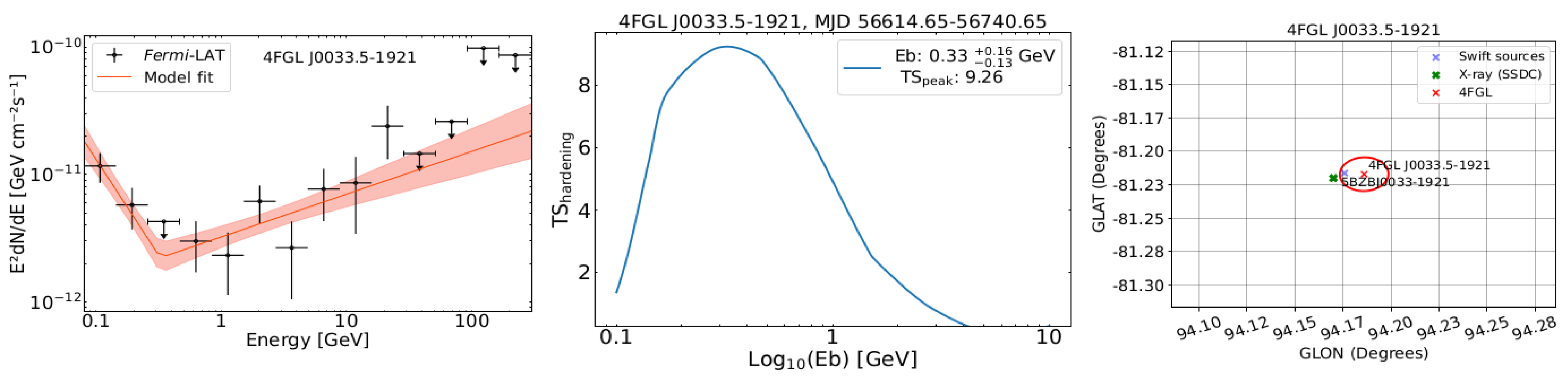

Figure 4: a) Fermi-LAT γ-ray SED of the source 4FGL J0033.5-1921 with a BPL fit. b)$TS_{hardening}$ vs break energy. TS_{peak} is the peak value of $TS_{hardening}$ and Eb is the break energy. c) Nearby gamma ray, X-ray sources and a 95 % confidence error ellipse. The X-ray sources are obtained from SSDC database and our own Swift telescope data analysis. There are no nearby X-ray sources in this case.

6. References

References

Ballet, J et al. (2020). "Fermi large area telescope fourth source catalog data release 2". In: *arXiv preprint arXiv:2005.11208*.

Fossati, G al et al. (1998). "A unifying view of the spectral energy distributions of blazars". In: *Monthly Notices of the Royal Astronomical Society* 299.2, pp. 433–448.

Wagner, S. M. et al. (Mar. 2022). "Statistical properties of flux variations in blazar light curves at GeV and TeV energies". In: *37th International Cosmic Ray Conference*, 868, p. 868.

7. Fermi-LAT Shifts

Fermi-LAT flare advocate shifts are undertaken to monitor the γ-ray sky and notify the astronomy community of any potential flares. I have participated in 5 such shifts spanning one week. When relevant flares are observed during these shifts, the findings are published in Astronomers Telegram (ATel). These are two such communications led by myself:

- *Fermi-LAT detection of enhanced γ-ray activity from the Radio source S5 0532+82.*
- *Fermi-LAT detection of enhanced gamma-ray activity from the FSRQ PKS 0227-369.*