Search for High-Redshift Blazars with *Fermi*/LAT

Michael Kreter[1,2], Matthias Kadler[2], Roopesh Ojha[4], Sara Buson[2], for the *Fermi*/LAT Collaboration
Joern Wilms[5], Markus Böttcher[1]

[1]Centre for Space Research, North-West University, Private Bag X6001, Potchefstroom 2520, South Africa
[2]Lehrstuhl für Astronomie, Universität Würzburg, Emil-Fischer-Strasse 31, 97074 Würzburg, Germany
[3]ECAP, Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany
[4]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[5]Dr. Remeis Sternwarte & ECAP,Universität Erlangen-Nürnberg, Sternwartstrasse 7, 96049 Bamberg, Germany.

Email: michael@kreter.org

Abstract

High-redshift blazars are difficult to study with *Fermi*/LAT, as their emission peaks are often downshifted to energies below the GeV band and at their large distances, only the very brightest objects are detectable. On the other hand, high-redshift blazars are disproportionately important targets, because they serve as cosmological probes and represent the most powerful class of γ-ray emitting sources in the Universe. Unfortunately, only a small number of high-redshift blazars could be detected with *Fermi*/LAT so far. We developed a strategy to increase the detection statistic at redshift $z \geq 2.5$ via a search for flaring events in high-redshift γ-ray blazars which long-term flux is just below the sensitivity limit of *Fermi*/LAT.

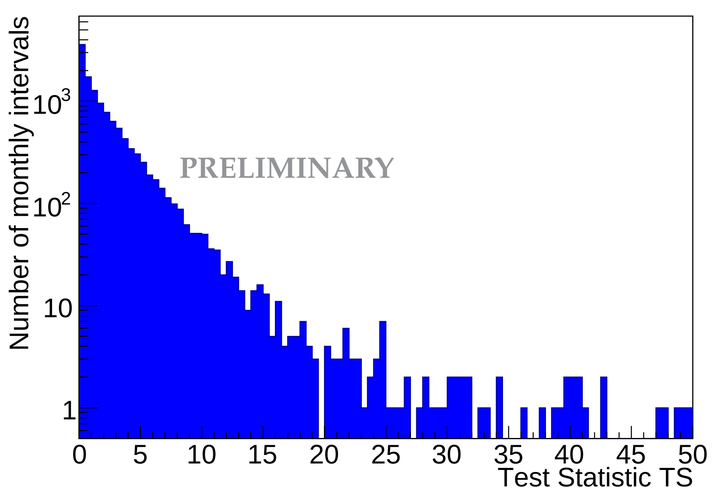
Motivation & Sample Selection

High-redshift blazars are of particular interest in the filed of γ-ray Astronomy, as they account for one of the most powerful (non-transient) astrophysical sources ever detected by *Fermi*/LAT. These sources possess the highest jet powers and accretion luminosities and have black-hole masses often in excess of $10^9\,M_\odot$. They are important as cosmological probes and serve as test objects for blazar evolution models, which directly implies, that the detection of new high-redshift blazars would test the hypotheses of blazar evolution. In fact, only a small number of high-redshift blazars has been detected by *Fermi*/LAT, some of them only because of bright flaring states.

A systematic search for γ-ray undetected high-redshift blazars is performed by targeting a sample of 176 blazars with a redshift of $z \geq 2.5$ and a radio flux density of more than 50 mJy, taken from the Roma BZCAT[a] Multifrequency Catalogue of Blazars and the SHAO[b] list of high-redshift radio- loud quasars. The total sample consists of 169 BZCAT blazars, as well as 7 SHAO sources, fitting the selection criteria mentioned before. Monthly binned *Fermi*/LAT γ-ray light curves are calculated for the entire sample to keep the computing effort at a reasonable level.

[a] http://www.asdc.asi.it/bzcat/
[b] http://202.127.29.4/CRATIV/en/high_z.html

Detected Monthly Intervals

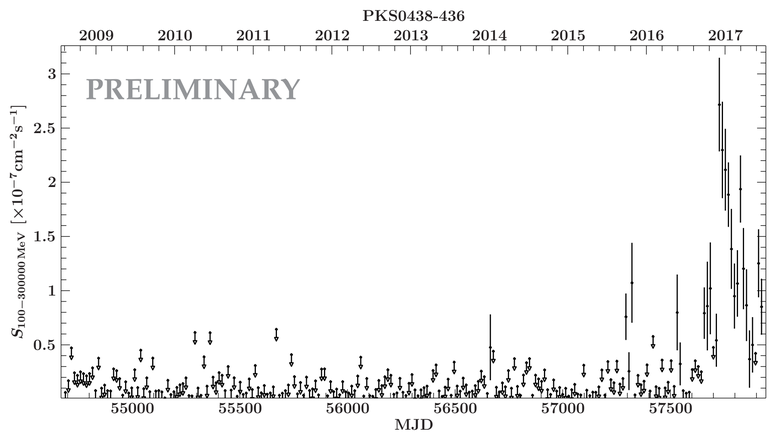


Test Statistic (TS) distribution of the total $\sim$ 20000 monthly time intervals. 30 monthly intervals are identified with a significance of TS $\geq$ 25, while at a TS $\geq$ 9 level 411 months are detected. While the majority of intervals is well below TS $\leq$ 9 and thus likely just of accidental nature, these TS $\geq$ 25 intervals can be considered as a significant source identification caused by 7 different blazars.

Contact Information

Michael Kreter
Centre for Space Research
North-West University,
Potchefstroom, South Africa
Email: michael@kreter.org

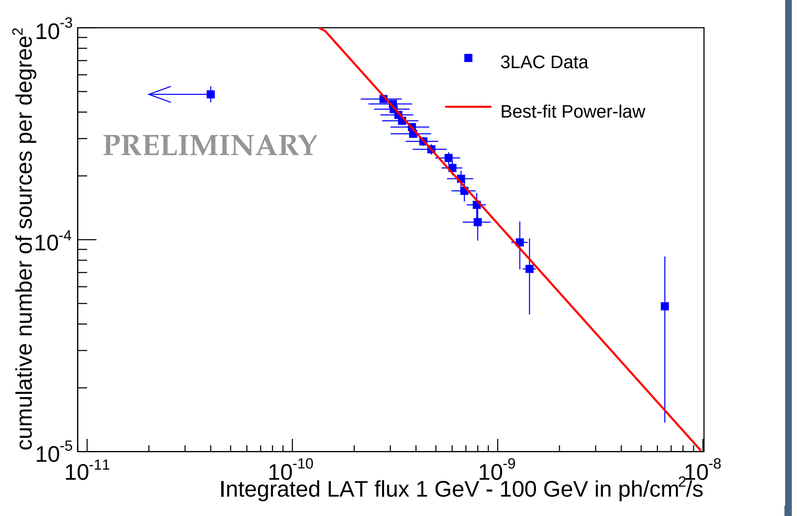
Detection Strategy



14 day binned Pass 8 *Fermi*/LAT γ-ray light curve of PKS 0438−43 over $\sim$ 9 years from 2008 August 4 to 2017 July 1. The light curve is shown for an energy range of 100 MeV to 300 GeV. This source has been unknown to *Fermi*/LAT for $\sim$ 8 years, only identified in December 2016 by the *Fermi* Flare Advocate Service during a massive flaring state. Such periods of enhanced activity typically only last for several days, leading to a significant detection (TS $\geq$ 25) due to a drastic background reduction, compared to long-term averaged fluxes used in catalogs. Still, PKS 0438−43 is unknown to any published *Fermi* catalog.

Recently, 5 new high-redshift blazars have been identified by *Fermi*/LAT, making NVSS J151002+570243 the most distant known γ-ray emitting blazar at $z = 4.31$.
We introduce a new method to search for hitherto undetected high-redshift γ-ray emitting blazars, which are too faint to be detected significantly on long time periods typically considered for *Fermi* catalogs, but can show up as significant sources during shorter ($\sim$ monthly) periods of increased activity.

Detection Potential



$logN - logS_{max}$ digram of blazars taken from the third catalog of active galactic nuclei detected by *Fermi*/LAT (3LAC). The plot shows the cumulative number of sources normalized per square degree with a redshift z $\geq$ 2.5, using statistical uncertainties only. The power-law fit ($N = (1.92 \pm 0.68) \times 10^{-14} \times S^{-1.079\pm0.097}$) is used for parametrization

For PKS 0438−43, which was not detected in the 3LAC, we calculate the corresponding upper limit, which is shown in the $logN - logS_{max}$ diagram at 4×10^{-11} ph /cm^2 /s. Based on the power-law fit, the $logN - logS_{max}$ distribution predicts $\approx$ 140 high-redshift blazars at similar or higher γ-ray flux levels, of which only 19 are known in the 3LAC. Considering the 19 known high-z blazars reported in the 3LAC, 3 out of 19 sources showed bright γ-ray flares in the past 9+ years.
Somewhat fainter flares, which would not led to Astronomer's Telegrams are likely more frequent so that a fraction of 3/19, i.e., about 16 % can be considered a conservative lower limit. **Thus, this approach should be capable to detect about 22 γ-ray flares of hitherto unknown high-redshift blazars in the MeV to GeV regime.**

Newly Identified γ-ray Blazars

Source Name	RA J2000	DEC J2000	z	Detections TS $\geq$ 25
5BZQ J0009+0625	2.32	6.43	2.69	1
5BZQ J0339−0133	54.75	-1.55	3.20	4
5BZQ J0434−4355	68.51	-43.93	2.65	4
5BZQ J1441−1523	220.44	-15.39	2.64	2
5BZQ J1837−5848	279.47	-58.80	3.04	15
5BZQ J2219−2719	334.90	-27.32	3.63	1
5BZQ J2321−0827	350.33	-8.46	3.16	3

We identified 30 γ-ray flares from 7 high-redshift blazars, which were too faint to be detected on long-term time scales of several years, but showed significant γ-ray activity at a $\geq 5\,\sigma$ significance level on monthly time scales. With a redshift of z = 3.63, the source 5BZQ J2219−2719 represents the farthest new γ-ray blazar identified by this analysis. Still, these sources represent only a small fraction of potentially detectable high-redshift blazars. Some studied sources are detected slightly below the $\geq 5\,\sigma$ threshold and thus, are not included in this table. A total of 411 intervals have been detected at a significance level of TS $\geq$ 9, with several sources showing multiple detections. While such an individual detection would not be significant enough to claim the detection of a new γ-ray source, multiple detections from a single source could lead to a robust source identification. However, a detailed understanding of the expected background background fluctuation is required for such an analysis.