PROCEEDINGS OF SCIENCE
ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

PoS(ICRC2021)636

Building a robust sample of Fermi-LAT blazars that exhibit periodic γ-ray emission

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Blazars can show variability on a wide range of timescales. However, the search for periodicity in the γ-ray emission of blazars remains an on-going challenge. This contribution will show the results obtained when a systematic pipeline is used to implement ten well-established methods to search for periodicity. We analyze the most promising candidates selected from our previous work, extending the *Fermi*-LAT light curves over three more years, for a total telescope time of twelve years. These improvements have allowed us to build the first sample of blazars that display a periodicity detected at a significance $> 5\sigma$. Finally, we will discuss the potential origins for the periodic behavior observed in blazars.

37th International Cosmic Ray Conference (ICRC 2021)
July 12th – 23rd, 2021
Online – Berlin, Germany

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[*] Presenter

1. Introduction

The wealth of multiwavelength observations collected over the past decades has to lead to the idea that supermassive black holes (SMBHs, $M_{BH} > 10^6 M_{\odot}$) lurk at the centers of most galaxies [e.g., 14]. In about 10% of these active galactic nuclei (AGNs), a pair of highly collimated, relativistic jets originate from the accretion disk/SMBH plane in opposite directions [12]. An AGN is referred to as blazar when one of the jets points towards our line of sight. In blazars, the observed emission is dominated by the jet, and is highly variable at different time scales, from minutes to years, and at all wavelengths, ranging from radio to γ rays.

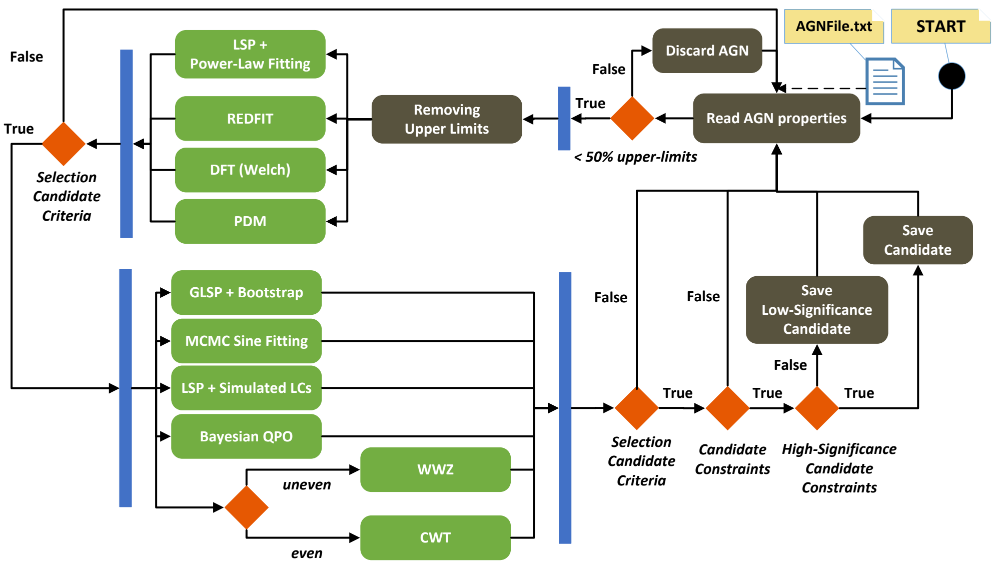

Figure 1: Periodicity search pipeline developed by [10].

The typical approach to search for periodicity at γ-ray energies in blazars is to analyze a limited sample of a few blazars and apply two or three time-series algorithms [e.g., 3, 21]. In [10], we developed a pipeline to perform a search for periodicities in hundreds of blazars. As a result, we discovered 24 blazars with a tentative periodicity (with significance $< 5\sigma$).

2. Blazar sample

In this contribution, we re-analyze the 24 periodicity candidates that were presented in [10]. In [10], this sample was analyzed using nine years of *Fermi*-Large Area Telescope (LAT) observations [2]. Now, we employ twelve years of *Fermi*-LAT telescope time, from August 2008 until December 2020. We use 28-day binned γ-ray light curves (LCs) to be consistent with our previous work. Finally, we extend the lower energy bound from > 1 GeV to > 0.1 GeV; thus, reducing the number of upper limits in the LCs drastically relative to [10].

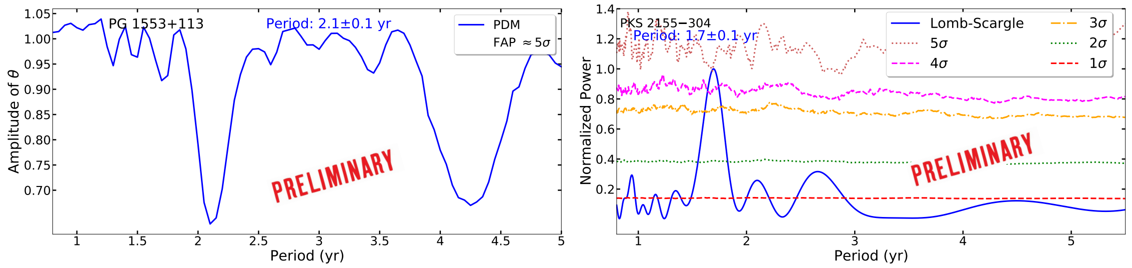

Figure 2: Example of periodicity analysis. Left: PDM analysis for PG 1553+113. The periodogram shows a clear peak at ~2.1 years. The figure also shows the FAP (false alarm probability) of the period, obtained with the Fisher's randomization technique [8]. Right: GLSP analysis for PKS 2155-304 denoting a peak at ~1.7 years. The significance is obtained by simulating artificial LCs, based on the technique of [5].

3. Methodology

To detect periodicity in blazars, we developed a systematic pipeline introduced in [10]. The periodicity-search pipeline consists of more than ten different methods to detect periodicity and the significance associated with such detection, organized in different stages (that is schematically shown in Figure 1). Examples of these methods are the Generalized Lomb-Scargle periodogram [GLSP, 20], and the phase dispersion minimization [PDM, 15] (see Figure 2). The reader is referred to [10] for details about all of the methods.

4. Blazars with $\geqslant 5\,\sigma$ Periodicity

The sample comprises a number of the blazars, including PG 1553+113, and PKS 2155−304, which are discussed in detail here (see Table 1). In [10], the significance of the periods were $>4\sigma$, and $>3\sigma$, respectively.

Table 1: List of $\geqslant 5\,\sigma$ periodicity Candidates. The blazars are characterized by their *Fermi*-LAT name, coordinates, AGN type (BL Lac, bll), redshift, association name, and period (in years) obtained in this work.

Name	RAJ2000	DecJ2000	Type	Redshift	Association Name	Period (yr)
J1555.7+1111	238.93169	11.18768	bll	-	PG 1553+113	2.1±0.2($>5\sigma$)
J2158.8−3013	329.71409	−30.22556	bll	0.116	PKS 2155−304	1.7±0.1($\approx 5\sigma$)

Regarding PG 1553+113 and PKS 2155−304 (see Figure 3), we confirm our previous period detection [e.g., compatible with 17, 21, respectively]. The authors of [19] analyzed most of the blazars included in [10], reporting no evidence of periodicity in the sample candidates, except for PG 1553+113, obtaining a compatible period.

4.1 Flux emission prediction

We propose to predict the low-high emission states of the periodicity candidates [e.g., 1]. Using the results of the MCMC sine fitting method [10], we estimate the future oscillations of the blazars in Table 1. Our predictions are presented in Table 2. Figure 4 shows the predictions for PG

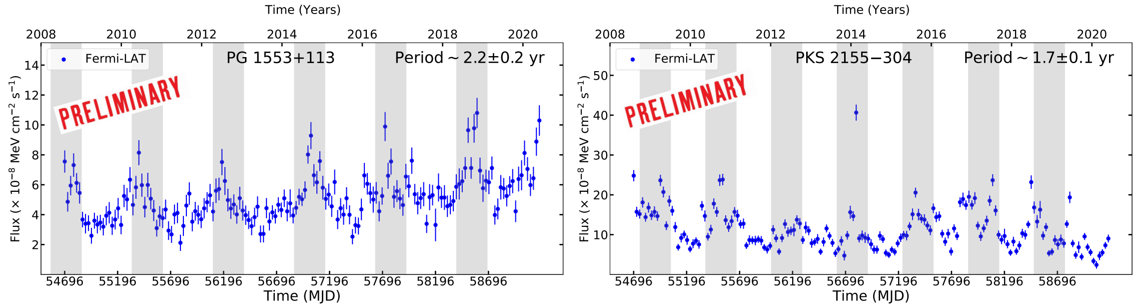

Figure 3: Example of light curves of the 5σ periodicity candidates. Left: PG 1553+113. Right: PKS 2155−234.

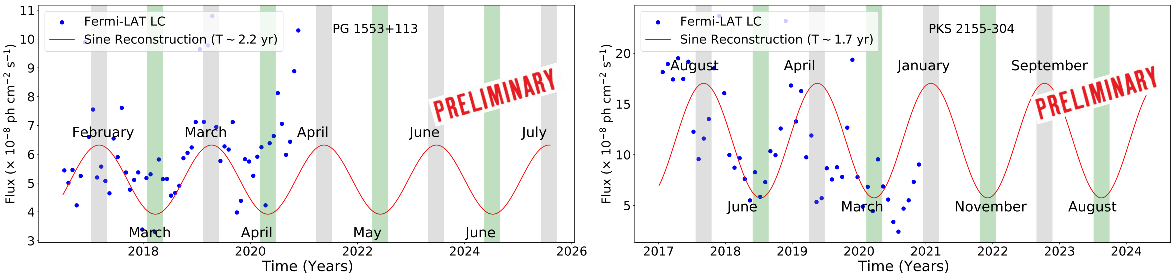

Figure 4: Examples of predictions of γ-ray emission for PG 1553+113 (left) and PKS 2155−304 (right). The grey vertical lines denote the high-flux emissions, and the green lines, the low-flux emissions.

1553+113 and PKS 2155-304. Specifically, the prediction for PG 1553+113 (a high-flux emission in the spring of 2021) was confirmed by the MAGIC observatory[1].

Table 2: List of predictions for the flux states of the periodicity candidates. The predictions are implemented organizing the year in four slices, according to the seasons in the Northern Hemisphere.

Association Name	Peak	Valley	Peak	Valley
PG 1553+113	spring 2021	spring 2022	spring 2023	spring 2024
PKS 2155−304	winter 2021	fall 2021	summer 2022	summer 2024

5. Discussion on the origin of periodicities

Various theoretical models have been proposed to explain the physical mechanisms responsible for the periodic γ-ray emission in blazars. In general, these models can be divided according to whether they describe a single or binary SMBH system. Regarding the first scenario, [9] propose a model based on orbiting blobs, inhomogeneities of plasma coming from the accretion disk and flowing in the magnetic fields of the jet. In [6] the periodicity is explained due to the modulation in the accretion flows, as suggested for the case of PKS 2155−304 [7].

Regarding the binary system, most of the proposed models have been developed to explain the periodic emissions of PG 1553+113. Specifically, according to the model of [11], the secondary

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[1] https://www.astronomerstelegram.org/?read=14520

SMBH destabilizes the accretion flow of the primary SMBH, modulating the accretion rate and, as a consequence, the γ-ray emission. The alternative model of [17] explains the periodicity as being due to the precession of the jet related to the orbiting SMBHs.

Major galaxies mergers are found more frequently at a moderate redshift of about z ~ 1 [e.g., 16]. In turn, the number of binary SMBHs should increase with increasing redshift [18]. Radio−loud galaxies almost always reside in environments where mergers are ongoing or have recently happened [4]. For instance, radio−loud objects located at moderate redshift are powered by a heavy SMBHs [$\sim 10^8 - 10^9$ $M_\odot$, 13], a common property of LAT blazars.

6. Summary

We have identified two blazars with periodic γ-ray emissions detected at a significance of $>5\sigma$, using 12 years of *Fermi*-LAT observations. Specifically, these blazars are PG 1553+113, and PKS 2155−304. This may be the first $\geqslant 5\,\sigma$ sample of periodic γ-ray blazars.

Acknowledgements

The *Fermi* LAT Collaboration acknowledges generous ongoing support from a number of agencies and institutes that have supported both the development and the operation of the LAT as well as scientific data analysis. These include the National Aeronautics and Space Administration and the Department of Energy in the United States, the Commissariat à l'Energie Atomique and the Centre National de la Recherche Scientifique / Institut National de Physique Nucléaire et de Physique des Particules in France, the Agenzia Spaziale Italiana and the Istituto Nazionale di Fisica Nucleare in Italy, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), High Energy Accelerator Research Organization (KEK) and Japan Aerospace Exploration Agency (JAXA) in Japan, and the K. A. Wallenberg Foundation, the Swedish Research Council and the Swedish National Space Board in Sweden.

Additional support for science analysis during the operations phase is gratefully acknowledged from the Istituto Nazionale di Astrofisica in Italy and the Centre National d'Études Spatiales in France. This work performed in part under DOE Contract DE-AC02-76SF00515.

S.B. acknowledges financial support by the European Research Council for the ERC Starting grant MessMapp, under contract no. 949555.

A.D. acknowledge the support of the FPA2017-85668-P of the Agencia Estatal de Investigación del Miniserio de Ciencias, Innovación y Universidades. A.D. is also thankful for the support of the Ramón y Cajal program from the Spanish MINECO.

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