γ 2022
7th Heidelberg International Symposium on
High Energy Gamma-Ray Astronomy
Barcelona, July 4-8 2022

ICCUB

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Quasi-periodic oscillations in the γ-ray light curves of bright active galactic nuclei

Helena X. Ren[1, 2] *, Matteo Cerruti[1, 3] **, and Narek Sahakyan[4] ***

[1]Universitat de Barcelona, ICCUB, IEEC-UB, E-08028 Barcelona, Spain; [2] Max-Planck-Institut für Kernphysik, P.O. Box 103980, D 69029, Heidelberg, Germany;
[3] Université Paris Cité, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France; [4] ICRANet-Armenia, at NAS RA, 0019 Yerevan, Armenia

Introduction

The detection of quasi-periodic oscillations (QPOs) in the light curves of active galactic nuclei (AGNs) can provide insights on the physics of the super-massive black-holes (SMBHs) powering these systems. And could also represent a signature of the existence of SMBH binaries.

Identification of long term QPOs (with periods ~months to years) is particularly challenging and can only be achieved via all-sky monitoring instruments, like the *Fermi*-LAT satellite.

In this work, we systematically study the light curves of bright AGNs using the continuous wavelet transform (CWT) in order to get access to transient QPO candidates.

Sources & Fermi-LAT data

- We limit the analysis to the 35 brightest sources in the 4LAC catalogue.
- The only exception in our source selection due to brightness is PKS 2247-131, which is manually added due to the high significance QPO detected by [1].
- The γ-ray data spans from August 8, 2008 to April 4, 2021 (from MJD 54686 to MJD 59308).
- We produced the light curves binned into weekly and monthly intervals, with an energy range of 0.1 – 300 GeV.

Continuous Wavelet Transform Maps

The CWTs are performed using the Morlet wavelet. Here we show the result for three sources showing the most significant QPOs, with post-trial significances. The best candidate in our results is the one found in S5 1044+71.

Source	Period(d) 30 d LC	Significance (σ)	Period(d) 7 d LC	Significance (σ)
S5 1044+71	1134±225	>4	1127±223	>4
	392±108	>5	401±108	>5
PKS 2247-131	217±43	>5	214±43	>5
			35±13	>5
	176±48	>5	180±46	>5
B2 1520+31			71±16	>5

Table 1: QPOs candidates identified by the CWT of the Fermi-LAT light-curves in time bins of 30 days and 7 days.

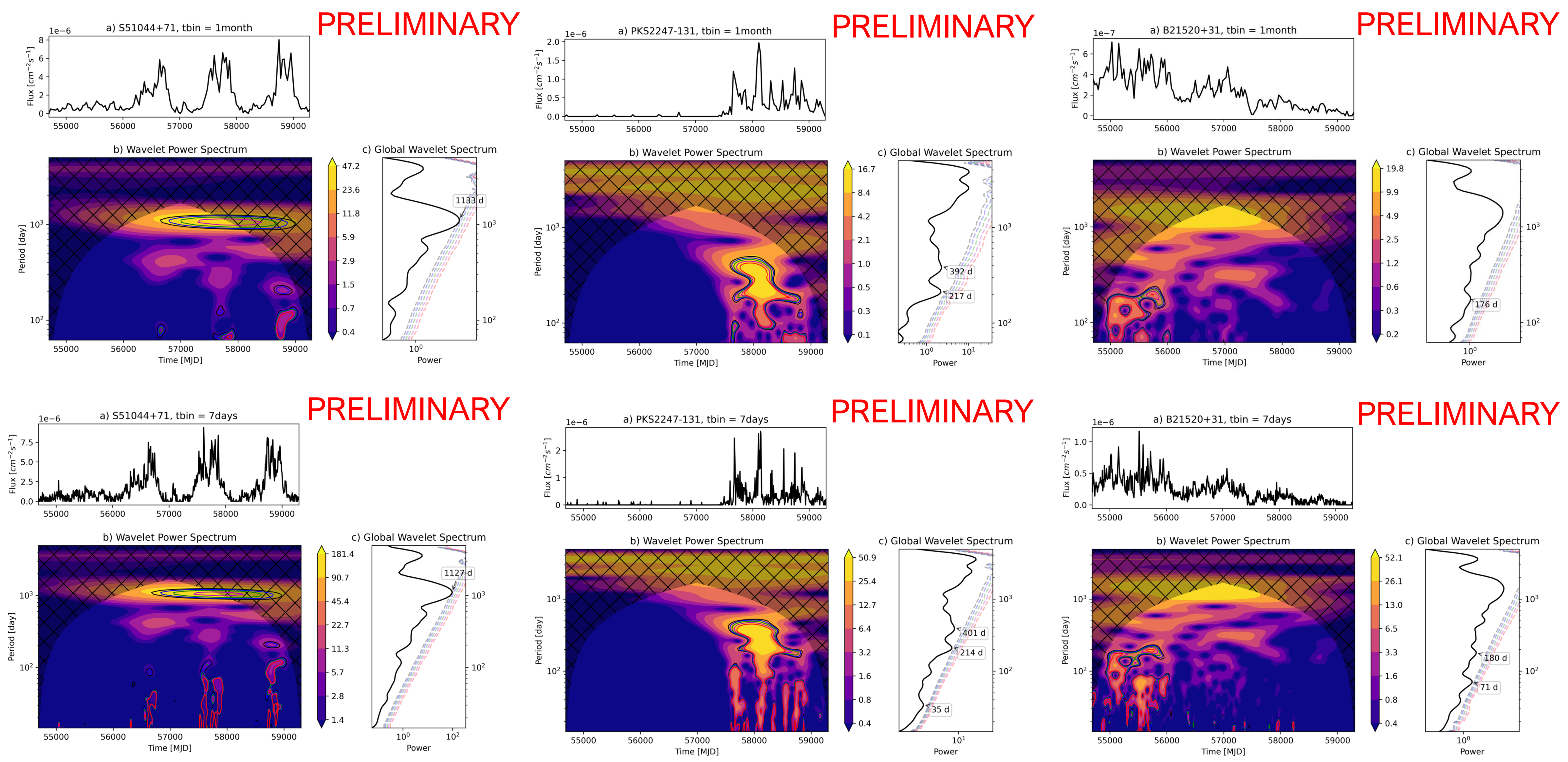

Figure 1: CWT map for monthly binned light curve (upper) and weekly binned light curve (bottom) for S5 1044+71, PKS 2247-131 and B2 1520+31 . In each subplot, the panels represent a) *Fermi*-LAT light curve, b) wavelet power spectrum and c) global wavelet power spectrum. The solid coloured contours in b) and the dashed coloured lines in c) are the confidence levels (1 to 5 in black, blue, green, violet, and red).

Contacts: *helena.ren@mpi-hd.mpg.de; **cerruti@apc.in2p3.fr; ***narek@icra.it

Method

- The search for QPOs is performed using the PyCWT code provided by [2].
- Significance is tested via Monte Carlo simulations with the same PSD and PDF as the original light curves thanks to the algorithm of [3].
- We build a histogram of the global wavelet spectrum computed for each simulation at every period. Then the histograms are fitted with a χ^2 distribution.
- Post-trial confidence levels are estimated following [4].

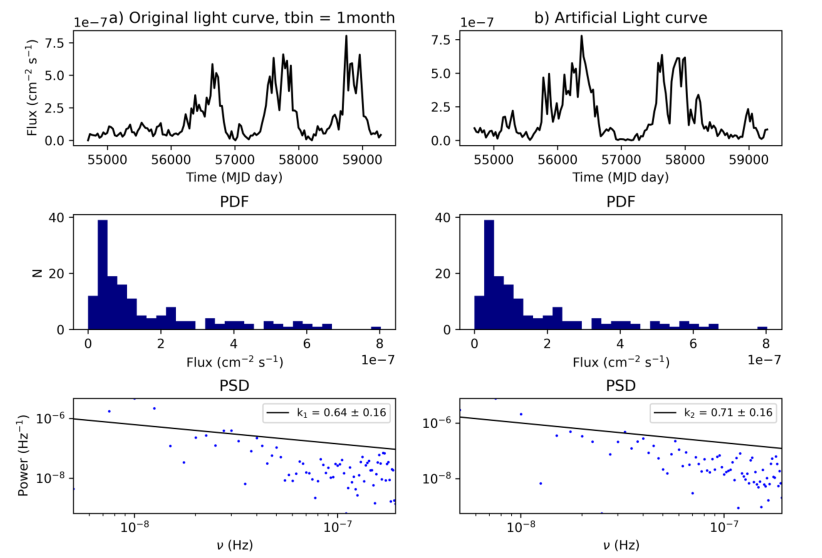

Figure 2: PDF and PSD of the original light curve of S5 1044+71 compared to those of a simulated light curve. The solid line in the PSD is the power law fit.

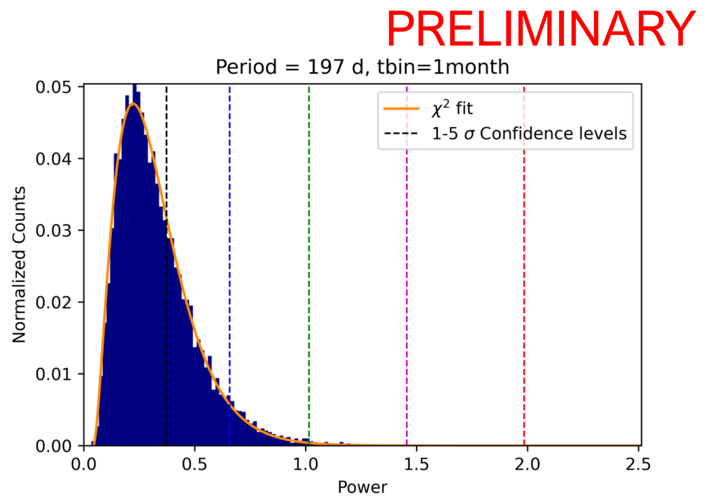

Figure 3: Global wavelet spectrum histogram fitted with a χ^2 function, for S5 1044+71. Pre-trial confidence Levels are shown in dashed lines.

Conclusions & Next Steps

- CWT is very powerful identifying QPOs and highly sensitive to transient and/or period-shifting QPOs.
- However, it is influenced notably by flares and border effects (require visual inspection).
- Trials are not negligible due to the bins in the time-period map and the total number of light curves considered.

A future study would be a multiwavelength analysis to boost the significance or to identify false positives.

References

[1] Zhou, J., Wang, Z., Chen, L., et al. 2018, Nature Communications, 9, 4599.
[2] Torrence, C. & Compo, G. P. 1998, Bulletin of the American Meteorological Society, 79, 61.
[3] Emmanoulopoulos, D., McHardy, I. M., & Papadakis, I. E. 2013, MNRAS, 433, 907.
[4] Auchère, F., Froment, C., Bocchialini, et al. 2016, ApJ, vol. 825, no. 2.