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Re-Analysis of QPO in 3C 273 Light Curve

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Abstract. We have developed analysis tools to search for quasi periodic oscillations in light curves from active galactic nuclei, using the following time series techniques: Wavelets, periodogram, Lomb–Scargle periodogram, structure function and multi-harmonic analysis of variance.

The analysis tools incorporate different noise models with significant levels for all the techniques that is an improvement over the previous work. By looking for consistently high significance, we make the detection of periodicities more robust. We apply this tool to a previously reported QPO (Espaillat *et al.* 2008) in the X-ray light curve of 3C 273 with a periodicity of ∼3300 s and find that the significance is only 74% in the wavelet and fails to show up above 95% significance in the periodogram and multi-harmonic analysis of variance.

Key words. Galaxies: active—galaxies: quasars: individual: 3C 273—X-rays: galaxies.

1. Introduction

The presence of quasi-periodic oscillations (QPOs) are fairly common in both black hole and neutron star binaries in our galaxy and nearby galaxies (e.g., Remillard & McClintock 2006). Recently there has been a few stronger (statistically significant) claims of QPO detection on diverse time scales ranging from a few tens of minutes to hours to days and even years using X-ray and optical data of various classes of AGNs (Espaillat *et al.* 2008; Gierliński *et al.* 2008; Gupta *et al.* 2009; Lachowicz *et al.* 2009; Rani *et al.* 2009, 2010). The first significant X-ray QPO detection of ∼1 hour time scale has been reported for a narrow line Seyfert 1 galaxy RE J1034+396 (Gierliński *et al.* 2008). Espaillat *et al.* (2008) have reported an X-ray QPO on the time scale of 3.3 ks in 3C 273, which is a flat spectrum radio quasar (FSRQ). Lachowicz *et al.* (2009) have reported a probable detection of an X-ray QPO in the BL Lac PKS 2155−304 on a time scale of ∼4.6 hours. All three QPO detections on IDV time scales (a few tens of minutes to less than a day) were based on observations made with XMM–Newton. On few occasions, optical QPOs on IDV time scales were recently claimed to be present in another BL Lac, S5 0716+714 (Gupta *et al.* 2009; Rani *et al.* 2010). By using All Sky Monitor (ASM) data from the Rossi X-ray Timing

Explorer, Rani *et al.* (2009) have reported a possible QPO from the BL Lac AO 0235+164 on a short term variability (STV) time scale (days to a few weeks) of ∼18 days and a possible QPO from the BL Lac 1ES 2321+419 on a long term variability (LTV) time scale (months to years) of ∼420 days. Statistically sound detections and careful characterizations of QPOs in these and other AGNs may shed new light on the physical processes at the sources and the production of the associated X-ray and optical emission. Therefore the search for their presence in both new and archival light curves (LCs) of AGNs using robust statistical techniques is very important.

2. Analysis techniques

We employed a wide set of statistical techniques, namely, wavelets, periodogram, Lomb Scarlge periodogram (LSP), structure function (SF) and multi-harmonic analysis of variance (MHAoV). We made improvements to the previously followed approaches by including significant tests in all of the techniques except the SF. Since we have developed these tools independently, we have cross-checked the numerics by using an analytic test case of the cosine wave for the wavelet, SF and LSP analyses.

The choice of the noise model is crucial to the significance tests. We have characterized the red noise using a lag 1 auto-regressive process (AR(1)) for the wavelet analysis, while we have used power-law forms for the noise in the periodogram and LSP implementations. For the MHAoV, the significance test is based on the incomplete beta function with parameters being the MHAoV Θ statistic, the number of sampling frequencies and a correlation length. The significance criteria used for the MHAoV statistic is valid for red-noise data. For the wavelet technique, we can directly calculate the significance threshold using AR(1), while for the LSP and periodogram analyses we test the significance by comparing the result against those produced by large numbers of randomly generated red-noise datasets with suitably extracted slopes.

The advantage in using all these techniques with the associated significance tests is that it enables us to make detections of QPOs more reliable, since each approach has different strengths. The number of harmonics in the SF and the duration of a signal is strong in the wavelet picture and is an indication of the number of cycles a periodic signal survives. The LSP and MHAoV do not require even sampling in time. The periodogram offers a natural way of testing the significance of the periodicity against randomly generated power-law noise. Our look out for a consistent detection of nearly the same periodicity across all the techniques makes our approach more robust over previous studies.

3. Results & conclusions

One way to illustrate the robustness of our new analysis tool is to re-analyze the previously reported QPOs. A QPO was reported by Espaillat *et al.* (2008) for 3C 273 based on XMM–Newton data taken in the 0.75–10 keV, with time bin of 5 s (ObsID 126700301). We applied various time series analyses to the X-ray light curve of this quasar (i.e., 3C 273) as shown in Fig. 1 for both the 5 s binning and a 100 s binning. No statistically significant (>95 %) periodicity was detected by a majority

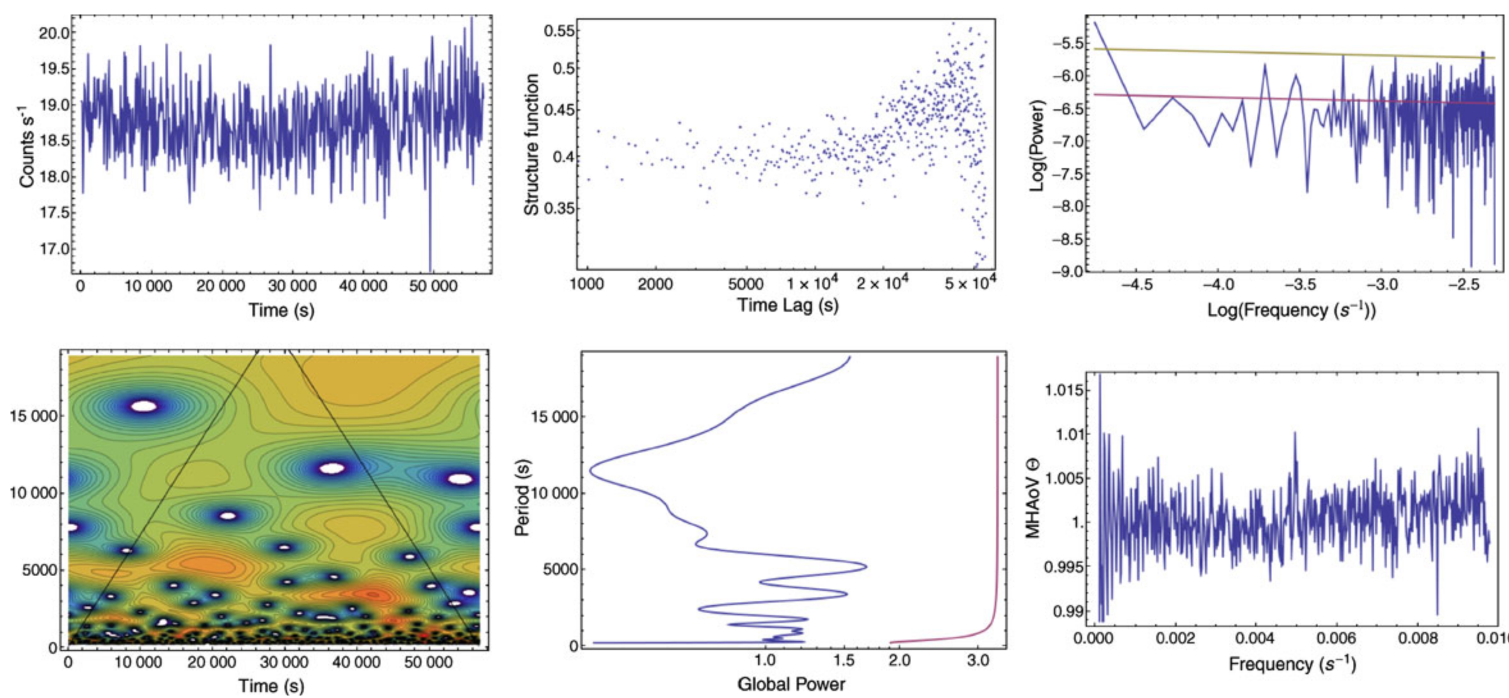

Figure 1. Multiple analysis methods applied to the time series of X-ray data of the quasar 3C 273 (light curve of duration 57000 s – first plot on first row): structure function (second plot on first row), Fourier periodogram (third plot on first row), wavelet contour plot (first plot on second row), global wavelet power spectrum (second plot on second row), multi-harmonic analysis of variance (third plot on second row) – No conclusive result in any of the methods.

Table 1. Results from various analyses applied to X-ray LC of 3C 273.

Observation duration (s)	57000
Time step size for wavelet and SF (s)	100
Lag-1 autocorrelation coeff., α	0.137961
Wavelet periodicity (74% significance) (s)	3329
Wavelet periodicity range (s)	3229−3429
Duration during observation period (s)	14500
No. of cycles	4.35
Periodogram slope, α	−0.282899
Error on slope	± 0.0304489

of the analysis techniques (see Table 1 for results and data properties). The wavelet analysis gives a periodicity of ∼3329 s with a 74% significance that lasts for 14500 s (∼4.4 cycles). In Espaillat *et al.* (2008), a periodicity of ∼3300 s was claimed with a significance of above 99% (wavelet analysis). In our re-analysis, we have used the above set of robust statistical tools and have found a negative result. Considering the statistical results, we rule out the presence of a 3300 s periodicity in this dataset.

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