Tools for period searching in AGN in the era of "Big Data"

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Introduction

- AGN emission is dominated by stochastic, aperiodic variability that overwhelms any potential periodic/quasi-periodic signal (QPO) that can be present due to e.g; jet emission from blazars, similar accretion mechanisms with BHXBs, SMBH binary mechanisms etc.
- While using different statistical tools to search for QPOs one needs to account for this red noise, since it can spuriously mimic few-cycle sinusoid-like periods and impact statistical significances of detection of periods and calibration of the false alarm probability (FAP).
- Moreover, we have entered the era of "Big Data," wherein current and near-future large-area monitoring programmes facilitate data trawls for period searches; developing the proper know-how for period searching is thus essential.
- In our project we examine several statistical tools — the autocorrelation function (ACF), phase dispersion minimization (PDM), wavelets, and CARMA modeling — to assess how QPO detection and the FAP depend on broadband continuum PSD shape when a mixture of red noise and a QPO is present and provide guidelines on the proper use of these statistical tools to the community. We determine how QPO detection sensitivity depends on QPO strength and broadband red noise shape for evenly-sampled and for realistically-sampled data (e.g., with data gaps).
- We present here the results from analysis using the ACF and PDM. We apply the results to realistic systems, namely gravitational lensing from highly-inclined binary supermassive black hole systems, to check the conditions under which a periodic flux signal can be robustly separated from the red noise using these statistical tools.

Simulation Setup

We simulate AGN light curves using the algorithm developed by Timmer & Koenig 1995 and perform monte carlo simulations for broadband rednoise of unbroken power law PSD model and different strengths of QPO signal for baseline & realistic sampling patterns (sun gaps/LSST; uneven sampling/OVRO).

Results

Effect of pure random stochastic red noise process:

- In the ACF, causes bumps and wiggles e.g, Fig.1(left), green line; similar to what expected from a quasi-periodic signal can possibly misinterpreted as an intrinsic periodic signal. The rate of false positives are greater than 3% in the ACF at all the tested values of the spectral index slope.
- In the PDM, we note that towards the lower frequency bins, red noise can produce the PDM statistic θ value to go lesser than 0.59 at timescales greater than one-third of the duration of the light curve especially towards the steeper spectral index slopes at $\beta \gtrsim 1.6$ causing high false positive rates.

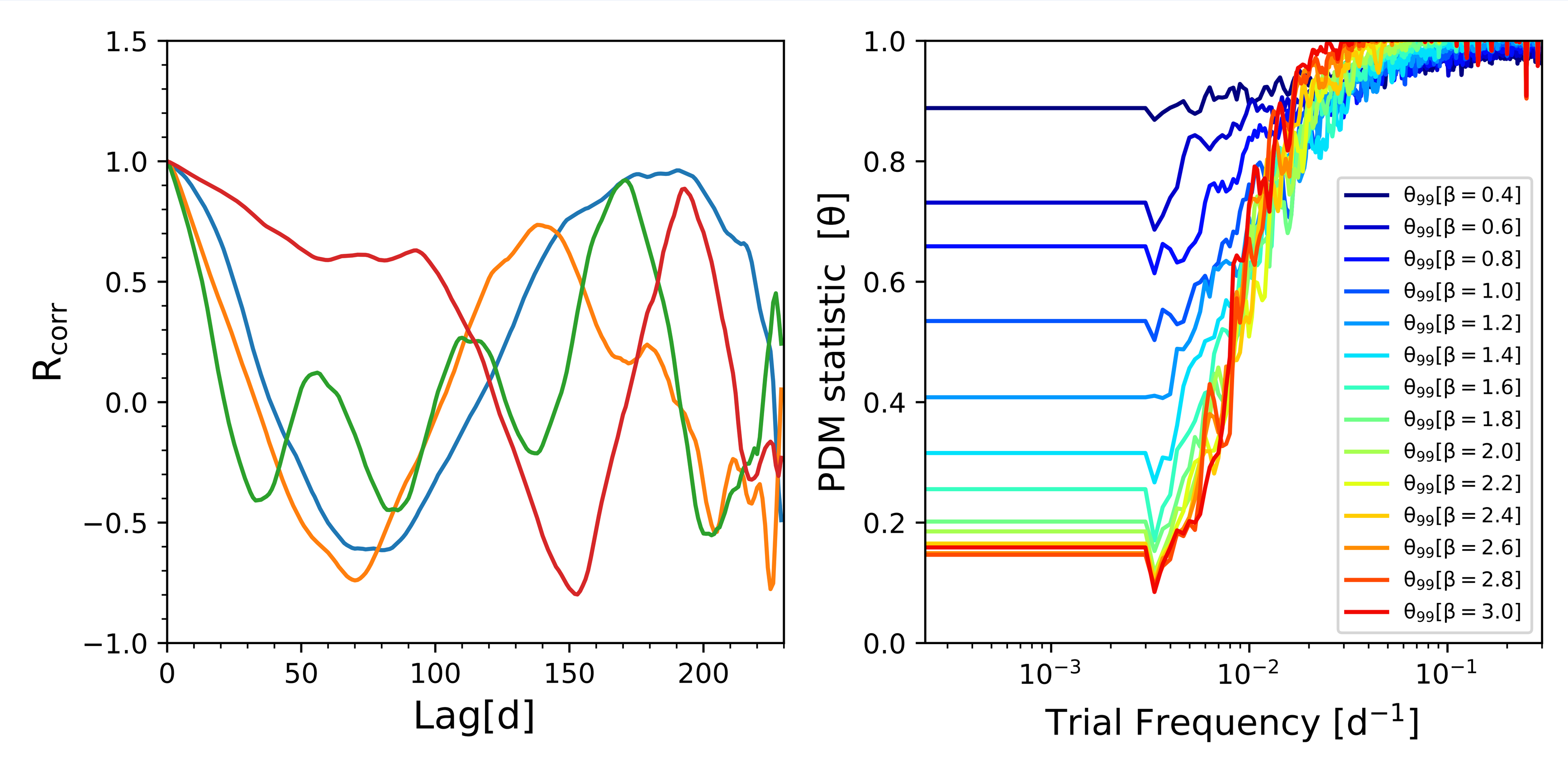

Figure 1: Left: The ACF of pure red noise light curves of unbroken power-law model of $\beta = 2.2$ **Right:** The distribution of the 99% lower limit of the PDM statistic value θ at each test frequency for pure red noise light curves having baseline sampling for the broad band spectral index slope β

Detection rate of QPO mixed with red noise:

- Detection rate increases with increasing strength of the QPO against the unbroken power law PSD slope (P_{rat}) and with decreasing steepness of the spectral slope (β)
- On using the **ACF & PDM:** True positive detection (99.7% significance) requires the relative strength of the QPO against the red noise (logPR) to be extremely large. e.g; log(PR) $\gtrsim$ 4–5 for evenly sampled data.

Realistic sampling

We do Monte carlo simulations of 10 year long light curves similar to LSST AGN monitoring : different yearly sun gaps and/or irregular sampling patterns for pure red noise and QPO mixed with red noise.

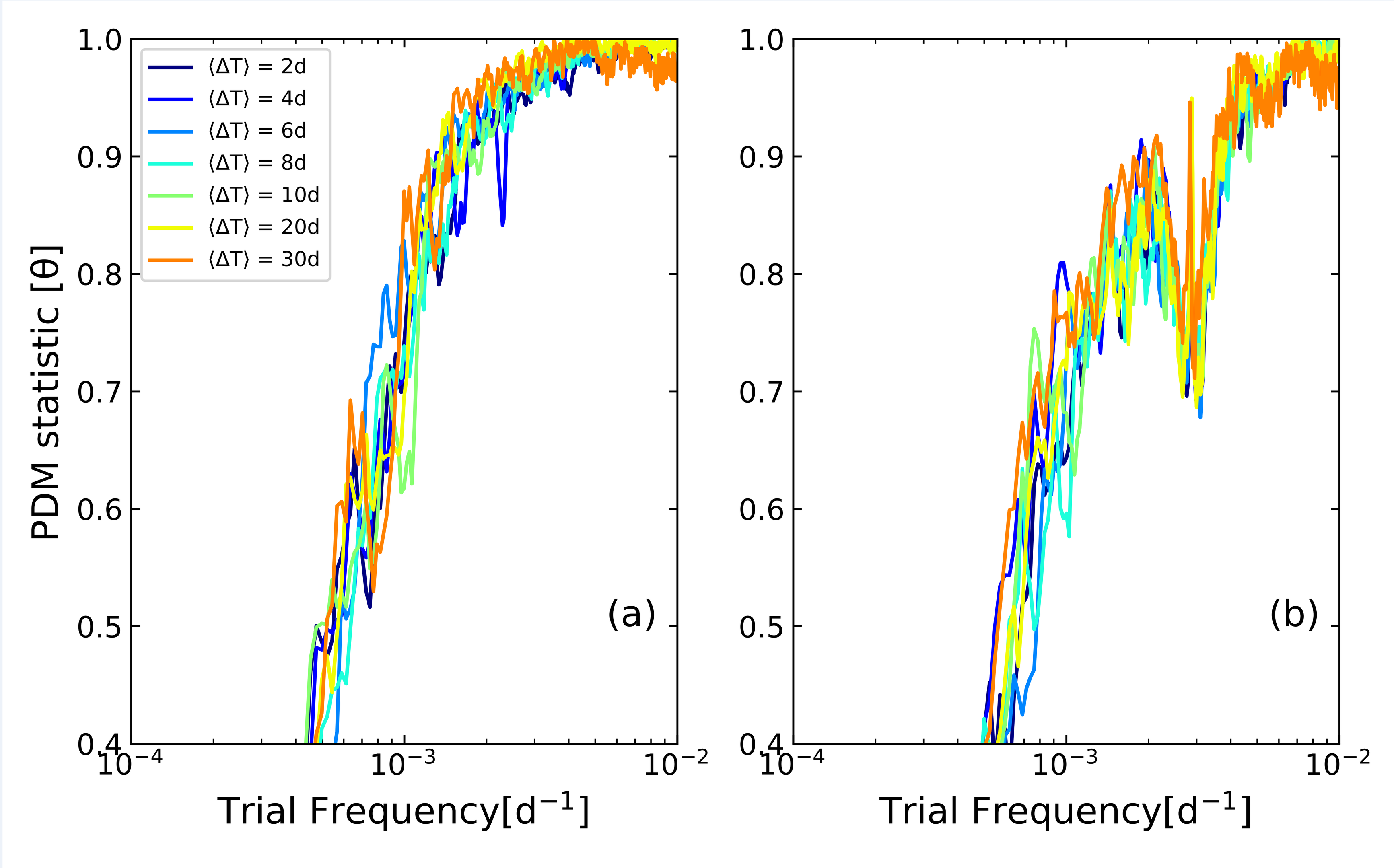

Figure 2: The distribution of the 99.9% lower limit of the PDM statistic value θ at each test frequency for a randomly sampled pure red noise light curve having spectral index slope $\beta \sim 2.0$ with (a) 10% yearly gap and (b) 45% yearly gap for different average sampling rates.

- Pure red noise light curves with sun gaps can cause deep minimum in PDM at timescales ~ 1/3-1/4th of duration.
- uneven sampling doesn't affect the PDM much in terms of the detection probability of the signal.

Conclusions

- The pure red noise process having unbroken power-law PSD model for evenly sampled data can produce false positives at significantly high rate (>0.3%) at all the tested values spectral index slope both for ACF & PDM.
- To obtain statistically significant detection with low false positive rates, we consider one-third of the duration of the observed light curve for ACF & PDM. Additionally we recommend to look for signals in ACF to have $r_{corr} > 0.45$ and in the case of PDM to check if the signal produces $\theta_{min} < 0.65$ for atleast 40% of the iterations.
- Any claim of detection of a QPO using ACF or PDM implies claiming a detection of a strong QPO signal of power $\sim \log(P_{rat}) \gtrsim 4$ - 5 against underlying red noise.
- Applications to Gravitationally lensed accreting BHs in highly inclined binary systems detection for LSST type monitoring over 10 years: likely only when the number of Einstein radius is $N_E \sim 0.05$–0.1; q=0.05,0.5

Acknowledgements

S.K., A.M., and A.S.-C. all acknowledge support from NCN grant 2016/23/B/ST9/03123 & the BEETHOVEN NCN grant 2018/31/G/ST9/03224.