Characterising the accuracy of time-scale recovery from "gappy" and noisy AGN light curves

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INTRODUCTION

The Atacama Cosmology Telescope (ACT) was a ground-based CMB experiment in the Atacama desert in Chile, that observed the millimeter sky at frequencies ranging from 90 GHz to 220 GHz. Accurate measurements of the flux for different point sources (AGN) can be obtained from daily observations of the instrument, thus providing us with lightcurves for these point sources.

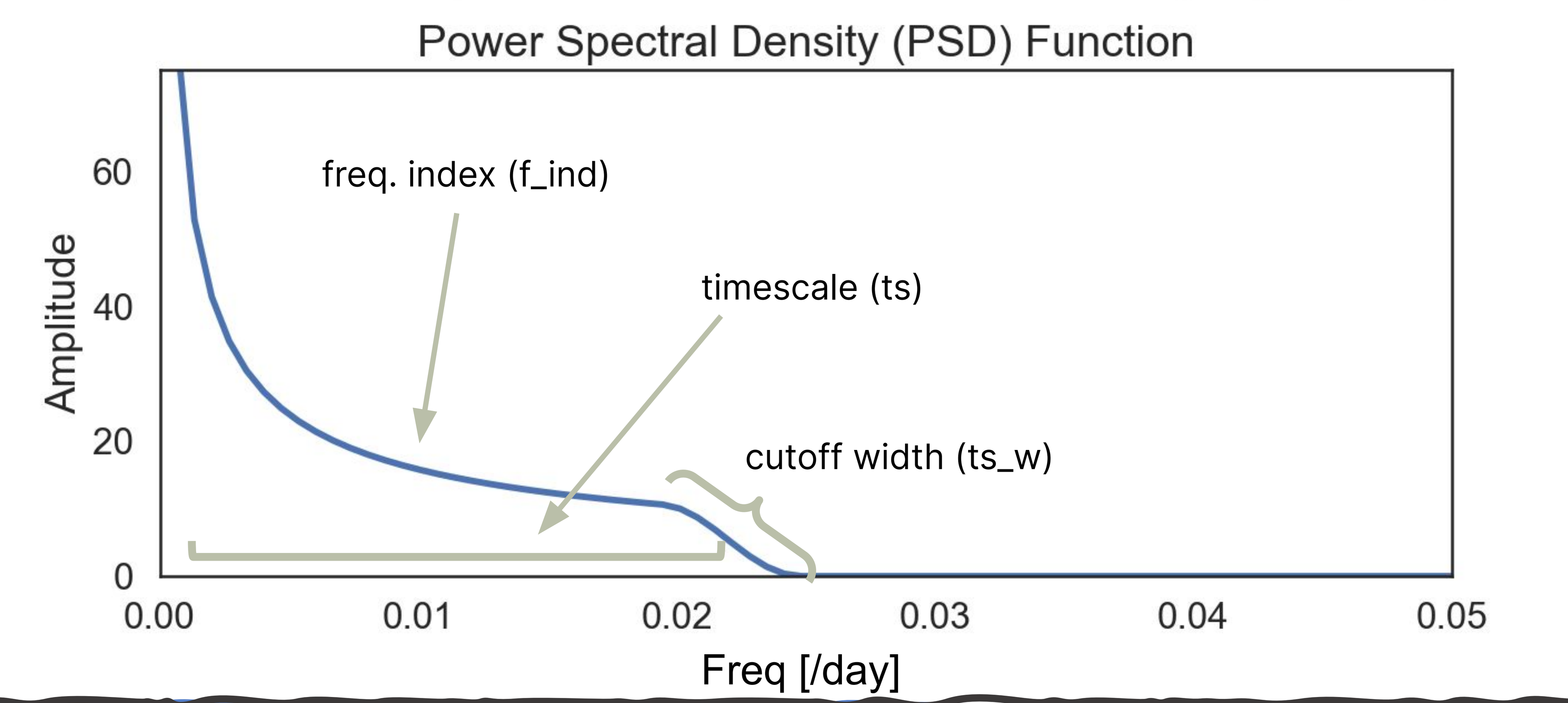
Active galactic nuclei (AGN) can display variability on timescales ranging from months to years. These variations are essential in our pursuit to understand their morphology. Efforts have been made to quantify AGN variability, including efforts to directly model light curves. A model that works generally well is the damped random walk (DRW) model which has a broken power law structure function, and which is consistent with what is observed for AGN (Kozlowski 2016). The structure function (SF) characterizes the variance between points at different timescales and is defined as

$$SF(\Delta t) = \sqrt{(N(\Delta t)_{pairs})^{-1} \sum_{i=1}^{N(\Delta t)_{pairs}} (y(t) - y(t+\Delta t))^2}.$$

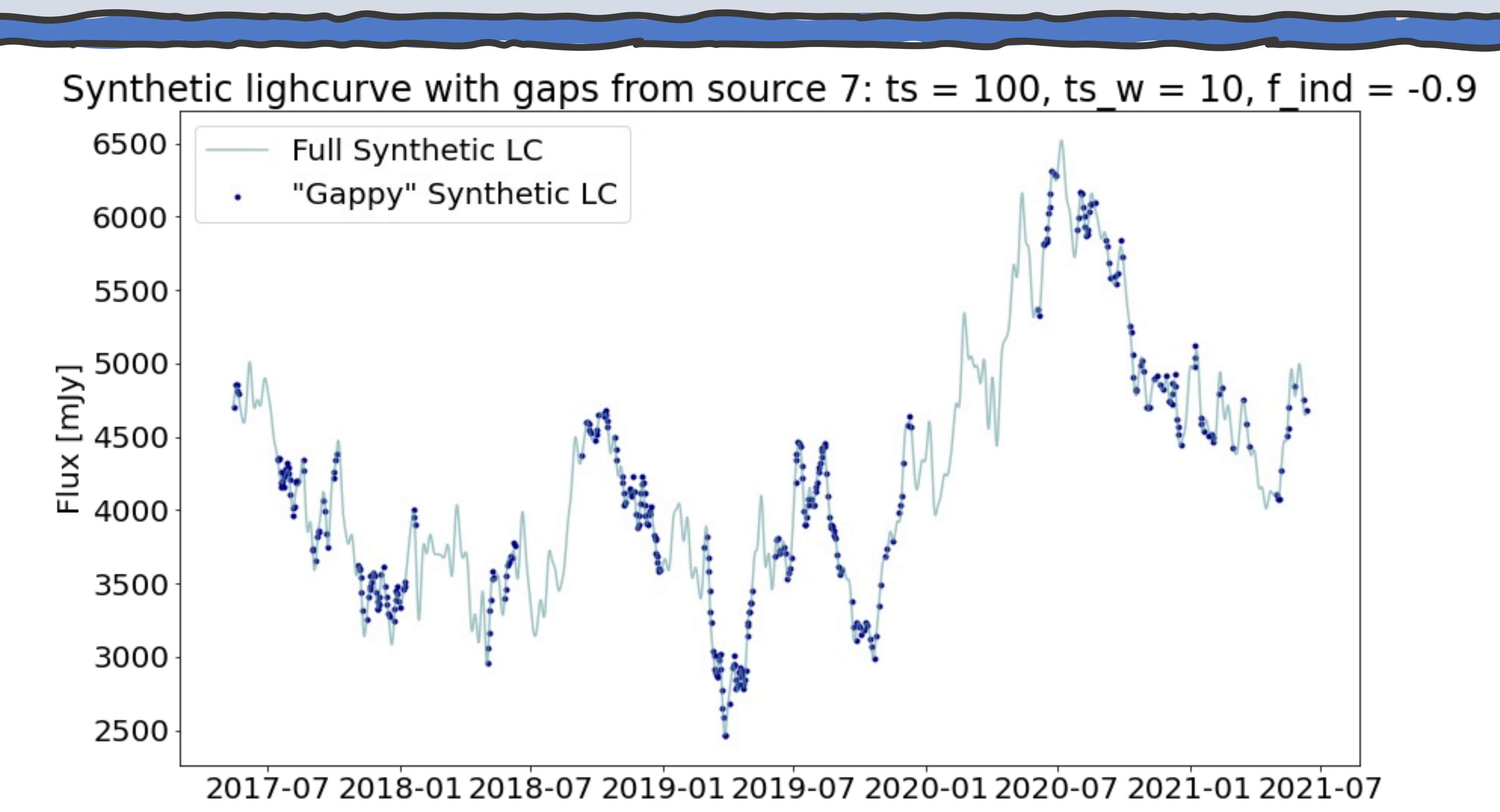
Currently we are analyzing the ~ 200 brightest lightcurves in our sample, which can be useful for studying the variability of AGN in the millimeter. However, due to the details of instrument operation, lightcurves measured with ACT display significant gaps, which can introduce features in the SF. It is thus important to understand how the gaps in our data affect the reliability of the conclusions we can draw from the SFs of these lightcurves. The aim of this project is to quantify how well the SF from a "gappy" lightcurve replicates that from a full lightcurve.

METHODS

To study how the gaps in our data affect the structure function (SF) we first generate synthetic lightcurves (LCs) with daily measurements, then sample them with the same gaps as those found in our data. To generate a synthetic LC, we begin by creating a power spectral density (PSD) function with selected timescale cutoff, steepness, and witdth of the cutoff.



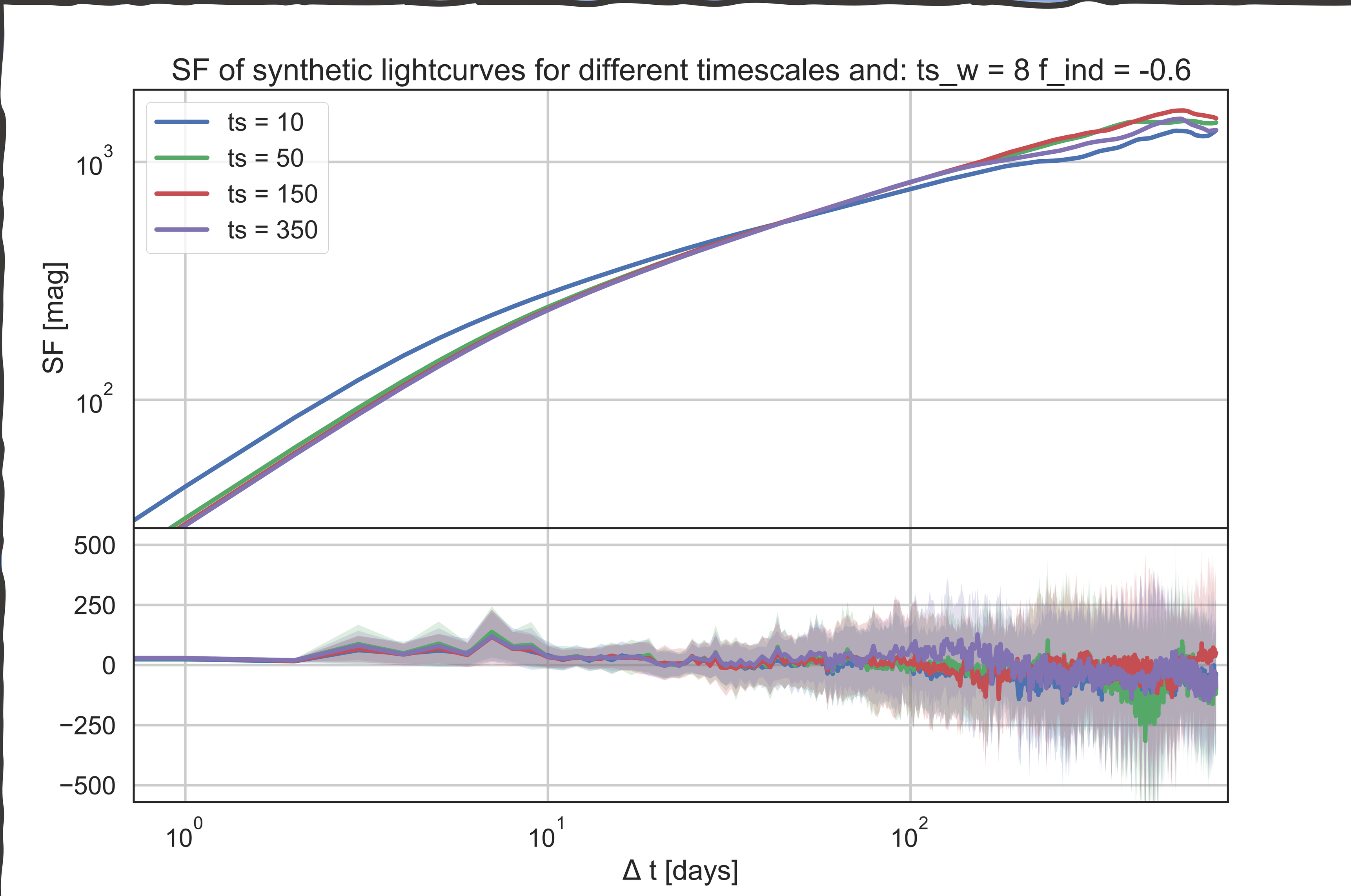
Random points/phases are drawn from the PSD function, the inverse Fourier transform is then taken to obtain the synthetic LC, which is then given the same average flux and amplitude range/variance as a measured LC of our choice. At this point we have a synthetic LC with daily measurements. The full synthetic LC is then sampled with the same gaps as those found in the chosen observed LC, we call this the "gappy" LC.



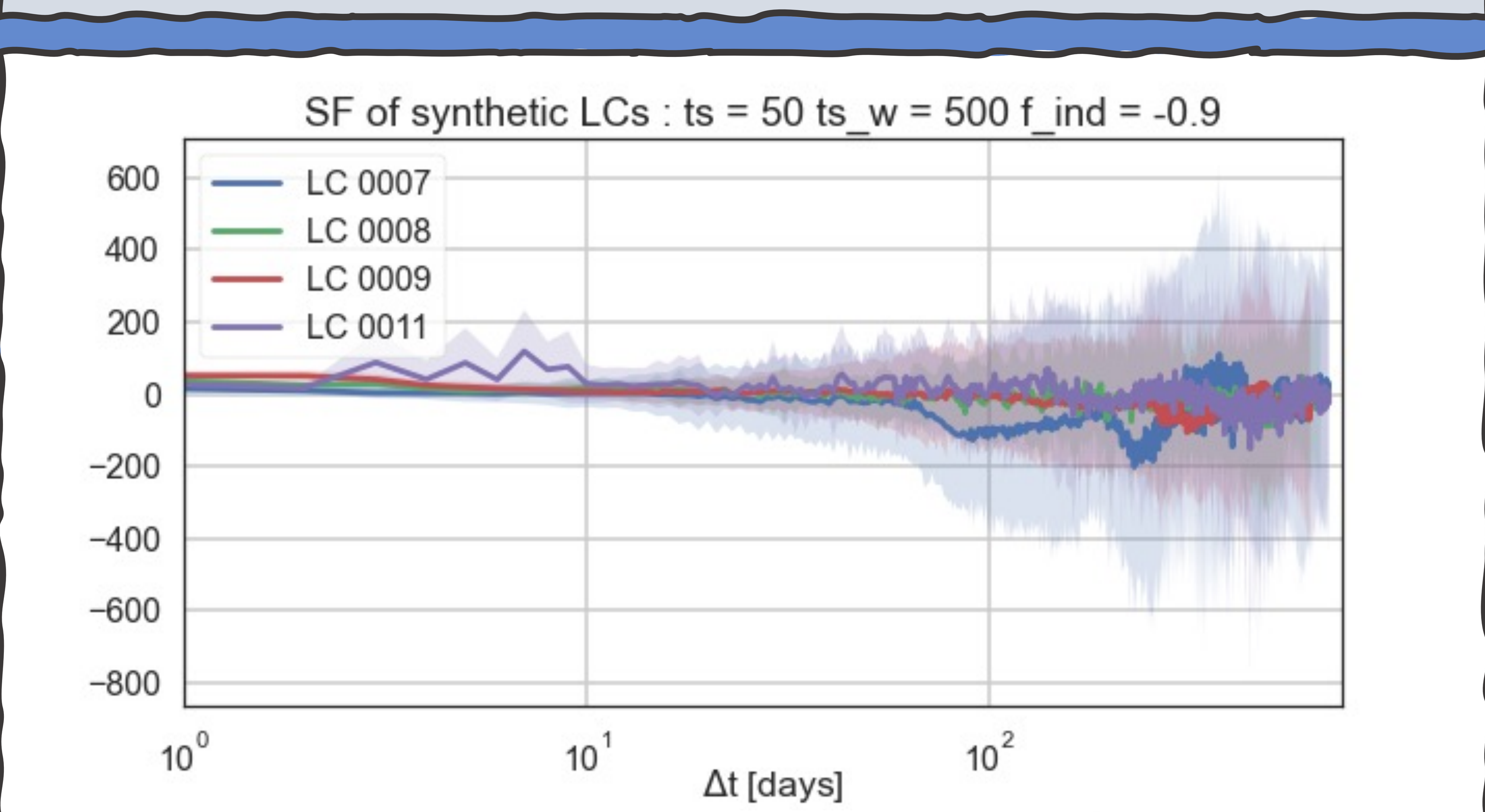
We compute the structure function for both the full and "gappy" synthetic LCs. These structure functions are compared by taking the difference in their magnitudes at each timescale Δt. This process is repeated over multiple iterations with the same parameters for the PSDs of the synthetic lightcurves, and the same sampling (i.e. the same observed lightcurve). The mean and standard deviation of the difference between the full and "gappy" SFs at each Δt over all iterations is computed.

RESULTS

We repeated this process over 50 iterations for 4 different timescales (ts). Other parameters of the synthetic PSD were left the same, and the sampling for the gaps was consistent throughout (i.e. a single observed lightcurve). The results for the mean and standard deviations of the difference between the full and "gappy" synthetic lightcurves are presented below, as well as examples of the SFs for full (solid) and "gappy" (dotted) lightcurves. There doesn't seem to be a timescale (ts) dependence on the scatter of the "gappy" SF.



We then repeated process again over 50 iterations for 4 different samplings (i.e. 4 different observed lightcurves). All parameters of the synthetic PSD were the same.



The scatter appears to be more inconsistent across different samplings, which supports the idea that the scatter in the SF is introduced at least partly by the sampling. Although LC 0007 introduces more scatter in the SF, upon investigation it was found that the sampling from LC 0007 doesn't contain significantly more (or larger) gaps than the other LCs. However, the amplitude range of LC 0007 is significantly higher than that of other LCs. Recall that the synthetic LCs are generated with the same amplitude range as the observed LC of choice. This effect of the amplitude range on the scatter of the SF can be explained by the simple fact that maxima/minima regions can be lost in certain gaps, and for large enough gaps this will have a significant impact on the value of the structure function.

CONCLUSIONS

We investigated the effects of sampling on the structure function (SF) and found that sampling will have a more significant effect on the scatter of the SF for lightcurves with larger amplitude range. We've also developed a method to obtain errorbars that are tailored to the SF of each individual lightcurve in our catalogue, by taking the standard deviation of the scatter observed for synthetic lightcurves. Future work will aim to quantify how accurately we can determine characteristic time-scales from our lightcurves.

LITERATURE CITED:
1. Kozlowski, S. (2016). Revisiting Stochastic Variability of AGNs with Structure Functions. ApJ, 826, 118

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