# Enhancing Periodicity Analysis Accuracy through Phase Fold Amplitude Minimization (PFAM) Technique

Sagar Adhikari

Department of Physics and Astronomy, Clemson University, Kinard Lab of Physics, Clemson, SC 29634-0978, USA

**Abstract**

In time-series astronomy, periodicity study is one of the most useful tools to understand an astrophysical system. Research papers on periodicity study often show phase-folded plots to emphasize the presence of periodicity. Depending on the quality of the data points, we can use the phase-folded light curves (LCs) to enhance the accuracy of the observed period further. I discuss an amplitude minimization of the phase-folded LC, which can enhance the accuracy of observed periods in astrophysical LCs.

## 1 Introduction

In time-series astronomy, periodicity study is one of the most useful tools to understand an astrophysical system. The presence of a periodic emission tells us about the possible physical activity in the system and enables us to predict future emissions to guide observation projects. There are multiple ways to do a periodicity analysis in a signal, and all have some uncertainty associated with the method. I aim to make the periodicity analysis more accurate by using phase folding.

## 2 Periodicity analysis of a simulated periodic light curve

I simulate a periodic signal with some Gaussian noise and random sampling to represent a light curve (LC) of an astrophysical source with a periodic emission. The time and amplitude axes have arbitrary units (see Figure 1, top panel). One of the most popular methods for periodicity analysis is the Lomb-Scargle Periodogram (LSP). LSP gives the periodogram of the given signal, from which we can extract the peak period and its uncertainty. The peak period is the period at which the periodogram power is maximum, and the uncertainty is the width at half the relative height of the peak (FWHM). Figure 1 bottom panel shows the LCs periodogram. The detected peak is centered at 2.00 with an uncertainty of 0.38. The reported peak period matches the period of the LC.

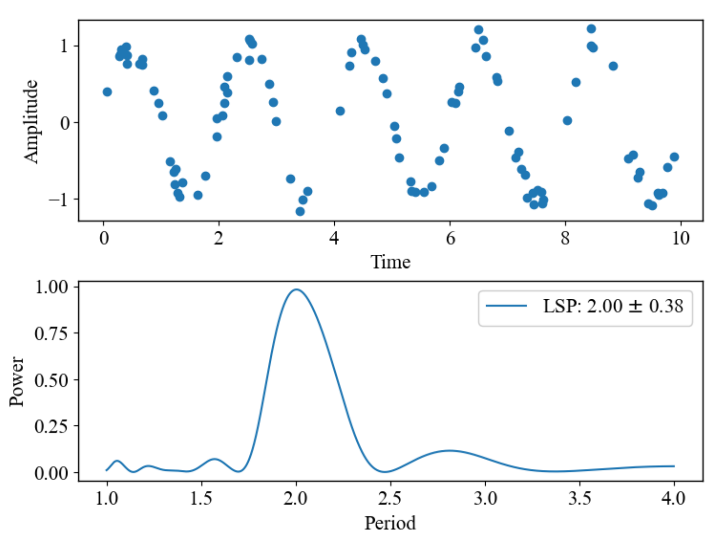



Figure 1: *Top*: Noisy periodic LC with random sampling. *Bottom*: Lomb-Scargle periodogram of the LC.

The unit of time and period can be internalized with an example. If we are talking about long-term periodicities in blazars, the period would be in the units of years

(PG 1553+113 shows ∼2-yr periodicity in its $\gamma$-ray LC. e.g., [1]). The uncertainty in the case of this example would be equivalent to 4.56 months. If we are trying to predict future emission patterns and/or propose telescope time, it would be difficult to convince people to let us use their telescope for five months straight. A smaller uncertainty would undoubtedly be helpful.

After getting the period and uncertainty from a periodicity study method (it does not have to be LSP), one can fold the LC with that period. This is usually seen in periodicity papers to emphasize the existence of the detected period. I am extending this further by folding the LC with a range of period values instead of just the reported peak period, ranging from peak-uncertainty (2.00 - 0.38) to peak+uncertainty (2.00 + 0.38), and fitting a sinusoidal model function to each of the phase-folded LCs.

In this example, the LC in the top panel is folded with periods from 1.62 to 2.38. Naturally, the value of 2.00 would be the best fit. To show this, in Figure 2 top panel, I have plotted the sinusoidal fit variance for different folding period values. Here, I have taken the negative logarithm of the variance to emphasize the peak. This plot is then used to narrow down the uncertainty. The FWHM is reduced to 0.17 from 0.38. This ∼55% reduction in uncertainty is quite significant.

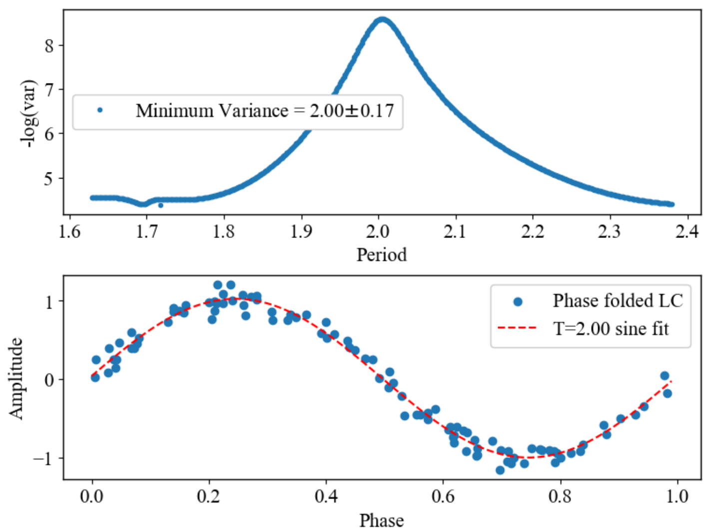
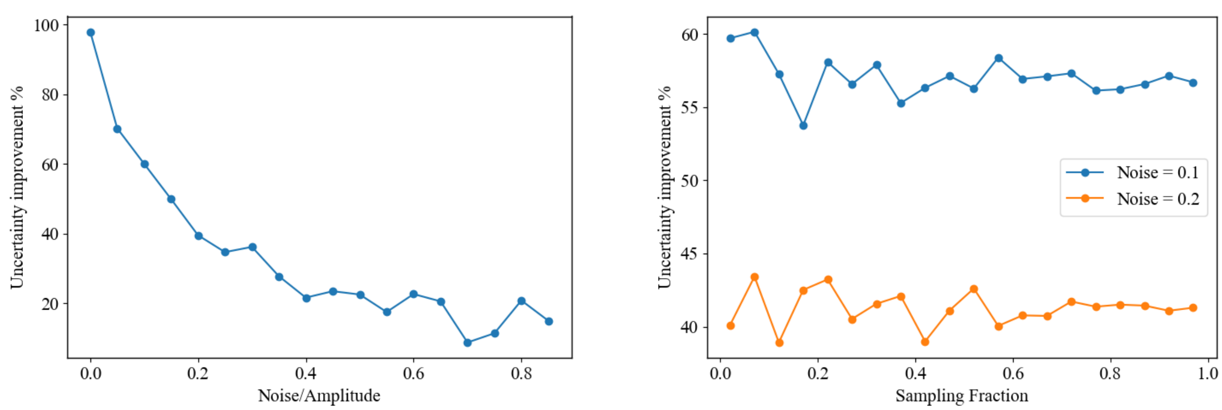



Figure 2: *Top*: Negative logarithm of the variance of sinusoidal fit vs the periods on which the LCs are folded. *Bottom*: Phase-folded LC folded with the best fit period and the best period sine overlaid on top.

Returning to the blazar example, the uncertainty reduces to ∼2 months. The bottom panel of Figure 2 shows the LC from Figure 1 (Top panel) folded with a period of 2.00. The best-fit sine curve is overplotted on the folded LC.




(a) Improvement percentage of the uncertainty from LSP to PFAM for various noise levels in the periodic random-sampled signal.

(b) Improvement percentage of the uncertainty from LSP to PFAM for various random-sampling fractions in the periodic signal shown for two different noise levels.

Figure 3: Limitation study of PFAM.

I analyzed this reduction in uncertainty for various noise levels and data sampling rates by simulating multiple periodic signals and performing the PFAM analysis on them. Figure 3a shows as the noise level increases, the improvement in uncertainty decreases sharply. So this method is not very useful if the signal is too noisy but is extremely valuable if the signal has low noise. On the other hand, the data sampling rate has virtually no effect on the improvement of the uncertainty, as seen in Figure 3b, which is an excellent quality for periodicity analyses as, usually astrophysical LCs have gaps due to sampling limitations.

Overall, PFAM method to improve the accuracy due to its independence on the sampling rate should be useful for astronomical time-series analyses as long as the signal has a relatively low noise or high signal-to-noise ratio.

## References

[1] P Peñil, M Ajello, S Buson, A Domínguez, JR Westernacher-Schneider, and J Zrake. Evidence of periodic variability in gamma-ray emitting blazars with fermi-lat. *arXiv preprint arXiv:2211.01894*, 2022.