AS5001 (SUPAAAA) Advanced (Astronomical) Data Analysis
Project 1 —— Due Wed 09 Nov 2022.

Rapid Oscillations in an HST Lightcurve of the Dwarf Nova OY Car

A cataclysmic variable star is a close binary system with a white dwarf primary and a late-type main-sequence secondary star. The binary separation is so small (the orbit period is only a few hours) that the companion star fills its Roche lobe and transfers gas to an accretion disk around the white dwarf. If the system is viewed at high inclination (close to the orbit plane), an eclipse is seen at binary phase 0 as the companion star passes in front of the white dwarf and accretion disk. Cataclysmic variables sometimes exhibit "quasi-periodic" oscillations (QPOs) in their brightness. The QPO periods are of order 10 seconds, close to the Kepler period of the white dwarf. An ultraviolet lightcurve obtained with the Hubble Space Telescope records an eclipse of the accretion disk around a white dwarf star in the cataclysmic variable star OY Car. The goal of the project is to use the data analysis techniques learned in the lecture course to search for QPOs in the lightcurve. Suggested steps of analysis:

1. Plot the lightcurve. Note the deep eclipse. Are any QPOs visible in the lightcurve ? [10]
2. High-pass filter the lightcurve to eliminate the eclipse. This may be accomplished by for example fitting a loose spline curve and subtracting that from the lightcurve. Alternatively, a running boxcar or gaussian filter may be used to construct a "smoothed" lightcurve, and that may be subtracted. Use graphics to illustrate your results. [10]
3. Considering the time intervals between successive data points, the total number of data points, and the total duration of the light curve, determine the Nyquist frequency, and the range, total number, and spacing of trial frequencies that need to be searched. [10]
4. Perform a periodogram analysis, i.e. for each trial frequency f, fit the function

   $$F(t) = B + C\,\cos\left(2\,\pi\,f\,t\right) + S\,\sin\left(2\,\pi\,f\,t\right)$$

   to the data points, and plot the χ^2 of this fit as a function of the trial frequency f. The χ^2 should decrease to minima near the frequencies of QPOs that are strong enough to be detected in the data. Sample densely enough to adequately resolve the χ^2 minima. Is it appropriate to scale error bars to make $\chi^2/N = 1$? If not, why not? Extend your periodogram to twice the Nyquist frequency, and note the aliasing that occurs. [10]
5. Use the results of your fit to estimate the period P of the strongest QPO and its 1-sigma uncertainty. Describe your algorithms carefully to avoid ambiguity, and present enough evidence to convince readers that your results are correct. [20]
6. Use the results of your fit to estimate the amplitude A of the strongest QPO, and its 1-sigma uncertainty. Express the QPO amplitude both in flux units and as a percentage of the out-of-eclipse light. Make your algorithms clear and results convincing. [15]
7. Are QPOs detected at just 1 period, or at several periods ? If more than 1, estimate the frequency, period and amplitude of each QPO, all with 1-sigma uncertainties. Present results in a table. Are any QPOs affected by aliasing? [5]
8. Are the QPO amplitudes and phases constant over the entire lightcurve, or do they change during the eclipse? Describe how would you could measure changes in amplitude and phase of a QPO as a function of time before, during, and after the eclipse. [5]
9. Carry out the procedure you described, and make a plot showing the amplitude and phase (with error bars) of the strongest QPO as a function of time. What happens during the eclipse? From your results, try to identify which part of the system (e.g. white dwarf, accretion disk, donor star) is the source of the QPOs. [5]
10. Prepare a report presenting your results. Be concise, but make your algorithms clear and provide sufficient evidence to convince readers that your results are reliable. [10]