ASTR 5490 Homework #2

Due Sep. 23 (14th class day)

Learning goals: Gain a feel for Fourier analysis used to describe variability in light curves or velocity curves, explore time series radial velocity data, using standard tools to find periods, characterize limits of variability, create folded velocity curves, and fit velocity curves to data to obtain system parameters.

1. Period finding is a fundamental tool in many areas of astrophysics, especially in the growing area of time-domain astroiphysics. The idea of Fourier analysis is to decompose a complex periodic signal S(t) with period P into a linear combination of cosine or sine functions with different frequencies and amplitudes, C_n., called the *Fourier coefficients*. Note that the constant factor in each term below, $2\pi t_0/P$, can be thought of as a phase, angle, ϕ, which merely shifts the plot left or right. A phase shift of $\pi/2$ (¼ of the Period) is equivalent to turning all of the cos() functions into sin() functions, so for some shapes below, feel free to substitute sin() for cos(). C_0 is an arbitrary zero point which merely shifts the plot up or down. (Note that a negative coefficient is the same as performing a phase shift of π.)

$$S(t)=C_0+C_1\cos\left(1\frac{2\pi(t-t_0)}{P}\right)+C_2\cos\left(2\frac{2\pi(t-t_0)}{P}\right)+C_3\cos\left(3\frac{2\pi(t-t_0)}{P}\right)+C_4\cos\left(4\frac{2\pi(t-t_0)}{P}\right)+\ldots$$

Write a `python` code to plot S(t) with C_1=1 and the other coefficients 0 (i.e., the first odd Fourier component is the only one that matters). Let t_0=0. Plot the curve from -P/2 to P+P/2 so that you can see two full cycles. Overplot a curve when C_2=1 and the other terms are zero (i.e., the first even Fourier component is the only one that matters). Do the same for C_3=1 and C_4=1 to see the form of each Fourier component individually.

A) Now let C_1=C_2=1 and $C_{>2}$=0. Describe the effect of this summation of the first odd and the first even component. Here and subsequently for visualization purposes, renormalize the plot so that the plotted maximum amplitude is 1.0. This lets you avoid the need to rescale the Y axis each time. The renormalization factor R is the sum over all coefficients, $R=\Sigma_i C_i$. Dividing your final function by R is mathematically the same as dividing all of your coefficients by R.

B) Next, plot only the first four even components (i.e., odd coefficients are zero; even coefficients =1) and describe the effect of adding increasingly more even components all having equal power.

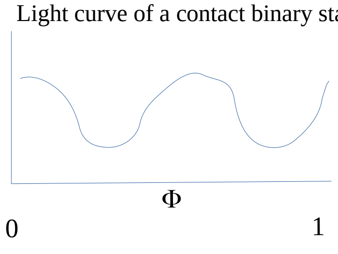
C) Repeat part C but assign each successive component <u>half</u> the power of the preceding component.

D) Plot only the first four odd terms with equal power. Describe the effect of adding even more odd terms of equal power.

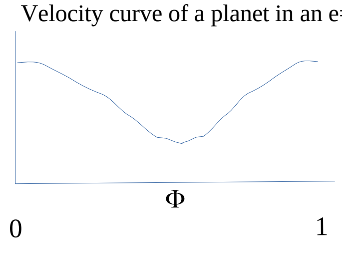
E) By adding some combination of even or odd Fourier components and letting the individual coefficients vary, try to reproduce qualitatively the following astronomical periodic phenomena and report your recommendations. Use as many Fourier components as seem needed. Most shapes can be reproduced to first order by the first 2-5 Fourier components.

F) For the case of the transiting planet, make a plot of the magnitude of C_n versus n in a histogram manner. There, you've just done a Fourier transform that shows you the power in various components!

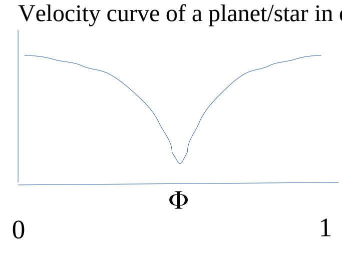
Light curve of a contact binary star



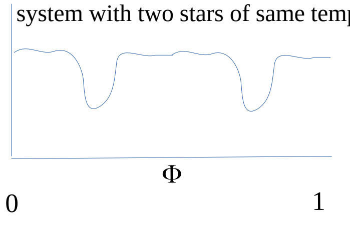
Velocity curve of a planet in an e=0 orbit



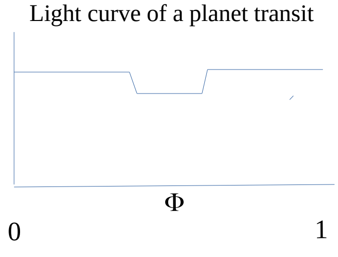
Velocity curve of a planet/star in e>>0 orbit



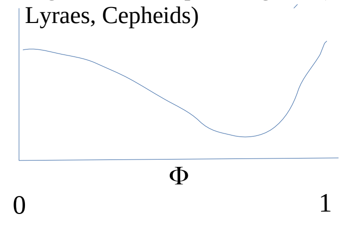
Light curve of an eclipsing binary star system with two stars of same temp.



Light curve of a planet transit



Light curve of a pulsating star (e.g., RR Lyraes, Cepheids)



2. On the course web page under HW#2 find an ascii text normalized light curve file for the Kepler Input Catalog object KIC02141697, a contact binary star.

A) Make a plot of the Flux versus Julian Date (or modified Julian Date MJD=JD-2,400,000, or just pick the date of first observation as time zero and plot days...that'll be easier to read for humans). Describe qualitatively the raw light curve.

B) Use the python `astropy LombScargle` method to calculate and make a plot of the power spectrum (that is, power versus frequency) for the entire Kepler Quarter 2 dataset. Use manual frequency spacing, [e.g., `frequency=np.linspace(minfreq,maxfreq,nintervals)]` as documented in the astropy example pages and try using i=1 Fourier terms (components)

```
power =LombScargle(times,flux,err,nterms=i).power(frequency)
```

From the raw light curve, justify how many Fourier components might be required. Try nintervals=1000 to start and increase it to 10,000 or larger if needed. Set minfreq and maxfreq to values that encompass a reasonable range of periods for things like 0.2 d to 100 days. Show a power spectrum with a peak near the known period for this object which you can look up on simbad. Discuss why might you be off by exactly a factor of two for this object. Then try `nterms=2`.

C) What does your power spectrum look like if the searched frequency range is too large or too small or does not encompass the true frequency of the data? What does your power spectrum look like if the search frequency range is broad and `nintervals` is (too!!) small, like 100 or 1000? Document and discuss some ways you can end up with the <u>wrong</u> period.

D) Try using `nterms=3` or larger….what do the resulting power spectra look like, and discuss how wrong you can be about the period if you adopt one of those peaks from using too many Fourier terms.

E) Make a phased light curve using the best identified period, P. Then try folding the light curve using a period which is ½ P or 2P and see if, on the basis of the phase light curve, you can rule out those periods.

F) Astronomers often find multiple peaks in the periodigram and have to sort out which is the true period and which are aliases. Chop down the input data set to the first 100 days of data, then the first 10 days of data then the first 1 day. Show how the certainty of your period determination declines with reduced time baseline. For this period of this object, what is the minimum time baseline you would want to have in your data to determine the true period?

3. Obtain the Kepler light curve file for the transiting planet Kepler-427 from the class web page.

A) Plot the raw light curve.

B) Perform a LombScargle analysis and show power spectra plots to locate possible periods and compare to the known period. You may need to use `nterms=4` or higher….why??

C) Fold the light curve at the best/known period to obtain and plot the phased light curve. Compare to published light curves to check agreement.

4. Download Table 3 from Wittenmyer et al. (2007) (from the class webpage, or you can get an ascii text file from the *Astronomical Journal* website by clicking on table links) which gives the radial velocity of the planet-hosting star HD3651 = 54 Psc.

A) Make a plot of the observed radial velocity versus Julian Date (or modified Julian Date MJD=JD-2,400,000, or just pick the date of first observation as time zero and plot days...that'll be easier to read for humans).

B) Perform a LombScargle analysis to determine several probable period(s) and make the phased velocity curve for each. Let t_0 be arbitrary for now. Compare your best result to the published accepted period for this object. Describe difficulties in arriving at the accepted period and best practices that you work out by trial and error.

C) Now that you have already determined the period, the remaining variables are e, ω, K, and t_0. Building upon the tools you developed before to plot a radial velocity curve, create a model radial velocity curve by manual trial and error that roughly matches your data. Compare your best fit values to published values. You can also feel free to change the period slightly to see if you can obtain a better fit. Your first guess from the LombScargle will probably be close, but not the very best.

D) Compute the chi-squared and reduced chi-squared for your best-fitting model. You'll have to interpolate the model at the phases of your data to calculate the residuals from the best-fitting model.

E) Finally, implement an automated fitting routine such as `scipy.optimize.curve_fit` or `lmfit` to obtain best parameters and report χ^2_{red}. Use a table of reduced chi-squared probabilities to give a probability of obtaining such a χ^2_{red} by chance and discuss if this model si a good fit to the data.