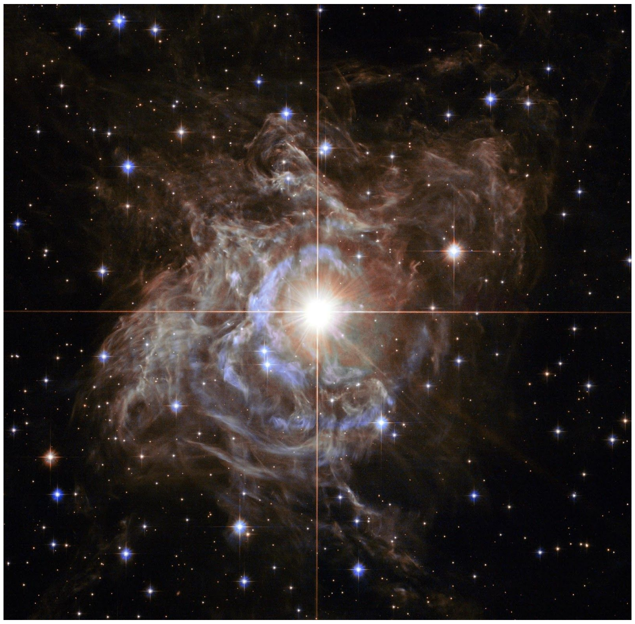
Cepheid Variability and Standard Candles



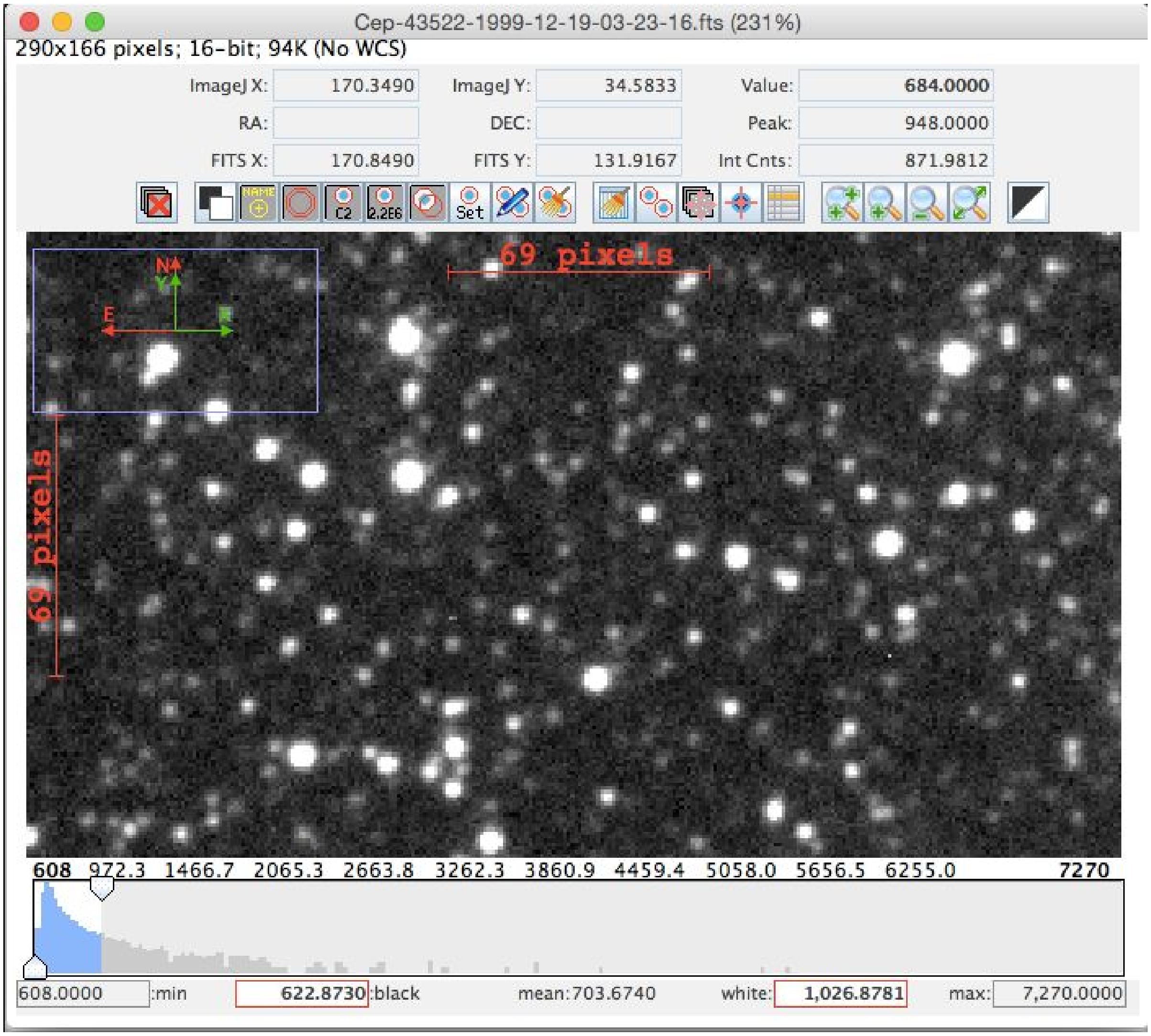
As you've discussed in class, determining distance to celestial objects is one of the most difficult tasks in astronomy. Often, astronomers use *standard candles* to estimate distances. *Standard candles* are objects whose intrinsic brightness is known. Since the observed brightness of an object declines with distance squared, we can compare the known intrinsic brightness to the observed brightness to determine the object's distance.

One of the most important types of *standard candles* is cepheid variables. The brightness for these stars oscillates sinusoidally around an average value. The period of oscillation is directly related to the star's average brightness. Thus, if we can estimate the oscillation period for a known cepheid, we can determine the intrinsic brightness and therefrom the distance.

In this lab, you will use real observational data to perform photometric measurements on a cepheid variable to determine the period and distance to the star.

1. Open the image analysis software AstroImageJ - It should either appear in the Application folder in the Finder or as an icon  on the Taskbar. The AstroImageJ toolbar should appear.

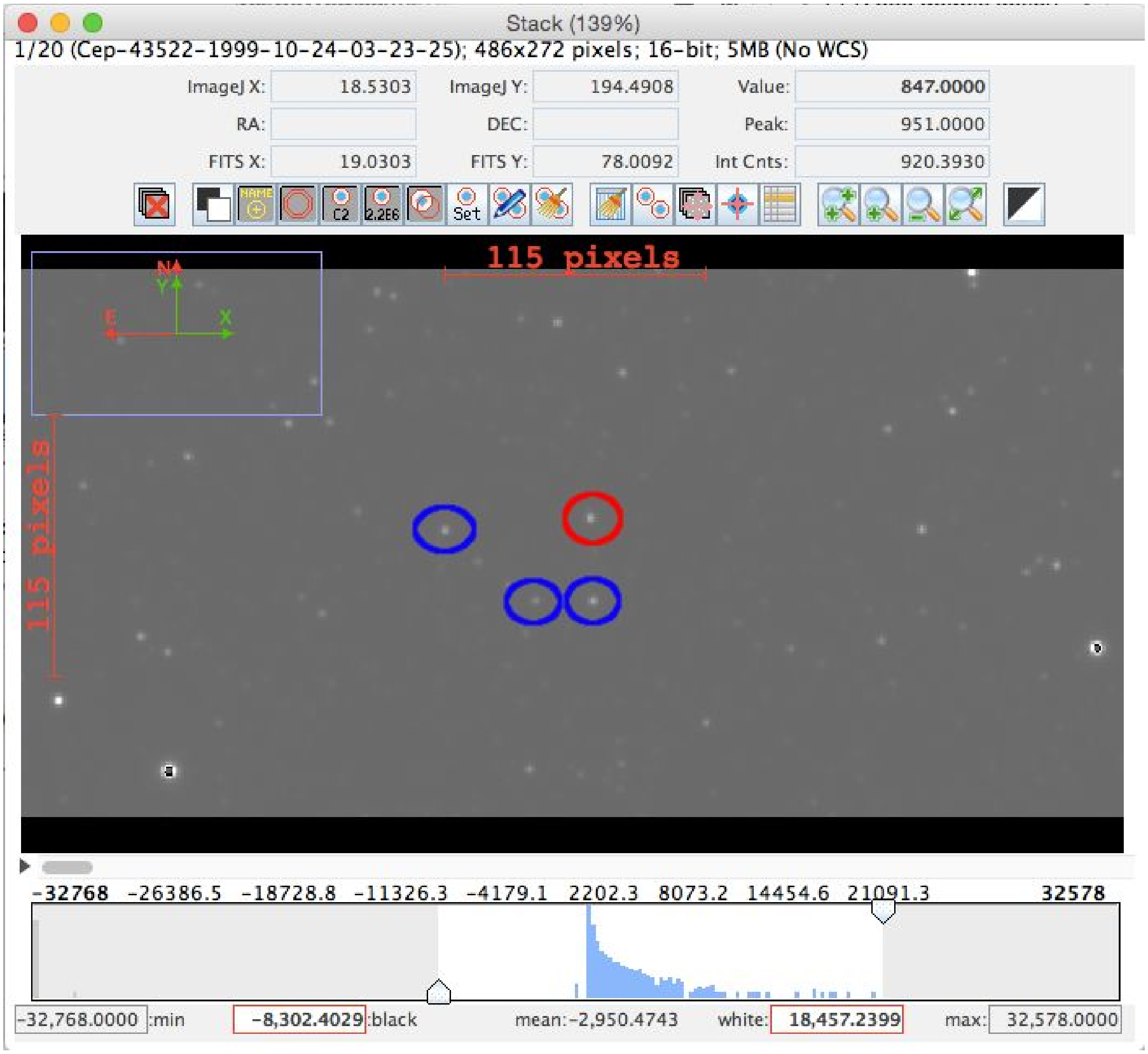
2. You will analyze a series of *.fts files, all named Cep-43522-YY-MM-DD-HH-NN-SS.fts, where YY-MM-DD are the year, month, and day and HH-NN-SS are the hour, minute, and seconds at which the observation was made. Open up these files in AstroImageJ by shift-clicking each file name in the Finder window and dragging them onto the AstroImageJ toolbar. Twenty windows will open up, each showing an image:



Next, we need to convert the series of images into a Stack so that AstroImageJ can automatically measure the pixel brightnesses. Unfortunately, the images are not all the same size or all pointing at exactly the same part of the sky, so we need to shift and align the images.

3. Click on the AstroImageJ toolbar (if you don't do that, you won't get the options you need). Then go to the Menu bar and select "Image > Stacks > Images to Stack".

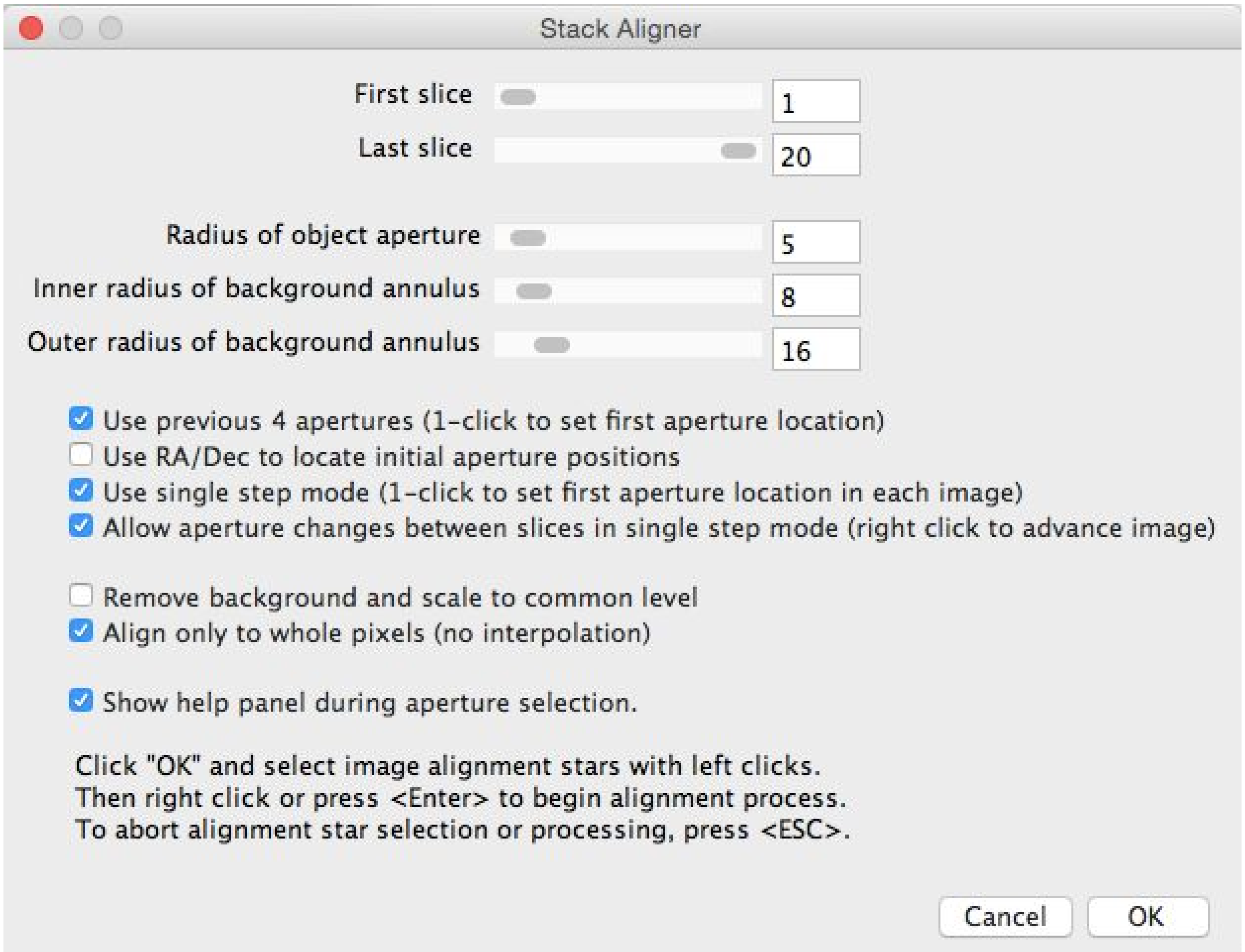
4. This selection will construct an image stack out of all the images. The images are different sizes, so AstroImageJ needs you to choose a technique for how to stack the images. Choose "Center" as the stacking scheme. Click "OK", and AstroImageJ should pass quickly through the images and open a new window showing the Stack:



Pressing ">" and "<" or dragging the scrollbar underneath the image will scroll back and forth through the stack, showing you all the images.

Next, we need to align the images, and we'll use the positions of the four stars in the center of the above image. The star in the red ellipse is our cepheid, and the other stars are the comparison stars. For this next step, we'll draw circles (apertures) over each of these stars, and AstroImageJ will shift the images around until the same four stars sit on top of one another in each image.

5. Click the "Align stack using apertures" button - . The Stack Aligner menu will pop up:

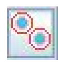


6. Make sure the options in the window match up with what's shown in the image above. These settings will allow you to scroll through the Image Stack, one by one, and lay down an aperture over each of the four stars. Click "OK". That will bring up the Stack Aligner Help window.
7. Click over the cepheid star. That will draw a green circle over the target star. Next, you should click over the three comparison stars, which will draw red circles over the stars. You don't need to click exactly over the center of each star. AstroImageJ will center the apertures for you.
8. Having selected the stars in the first image, press "Enter". That will scroll to the next image in the Stack. Again, select the target star first. AstroImageJ should automatically draw apertures over the three comparison stars. If it doesn't, you can click on the apertures that are wrong to remove them and draw them again. ***Be sure that you always select the comparison stars in exactly the same order.*** If you have trouble seeing the stars, move the sliders at the bottom of the image window around to improve the contrast.

After you've finished, you should be able to scroll through the Stack (using ">" and "<") and see that the same four stars are aligned.

Next, you'll perform the photometric analysis by counting up all the pixels inside of each aperture. The type of photometry you'll do is called *differential photometry*. In other words, you'll measure the relative change in brightness over time, rather than the exact brightness.

One important detail in this kind of analysis is that we need to compare the brightness of our target star to the brightness of comparison stars that are nearby in the sky. That way, if the brightness of the target star changes for some non-astrophysical reason (e.g., a thin cloud rolls in and covered the star), we should see its effect in all the stars, target and comparison, at once, and we can distinguish astrophysical from other changes.

9. With your several apertures still selected, click on the "perform multi-aperture photometry" button - . That will bring up the Multi-Aperture Measurements window. Make sure the aperture settings are the same as before ***EXCEPT be sure to unclick "Allow aperture changes ..." and "Use single step mode..."***. Click the "Place Apertures" button to start placing the aperture.
10. Click on the target star first, and AstroImageJ will select the comparison stars automatically. You should then press "Enter", and AstroImageJ will count up all the pixel values inside of each aperture for each image. An plot showing several blue dots, along with several other windows should pop up.
11. Sift through the windows that have popped up to find the one labeled "Measurements", which shows a table of measurements. From the Menu bar at the top, select "File > Save As" and save the file in a folder where you can find it later.

Measurements

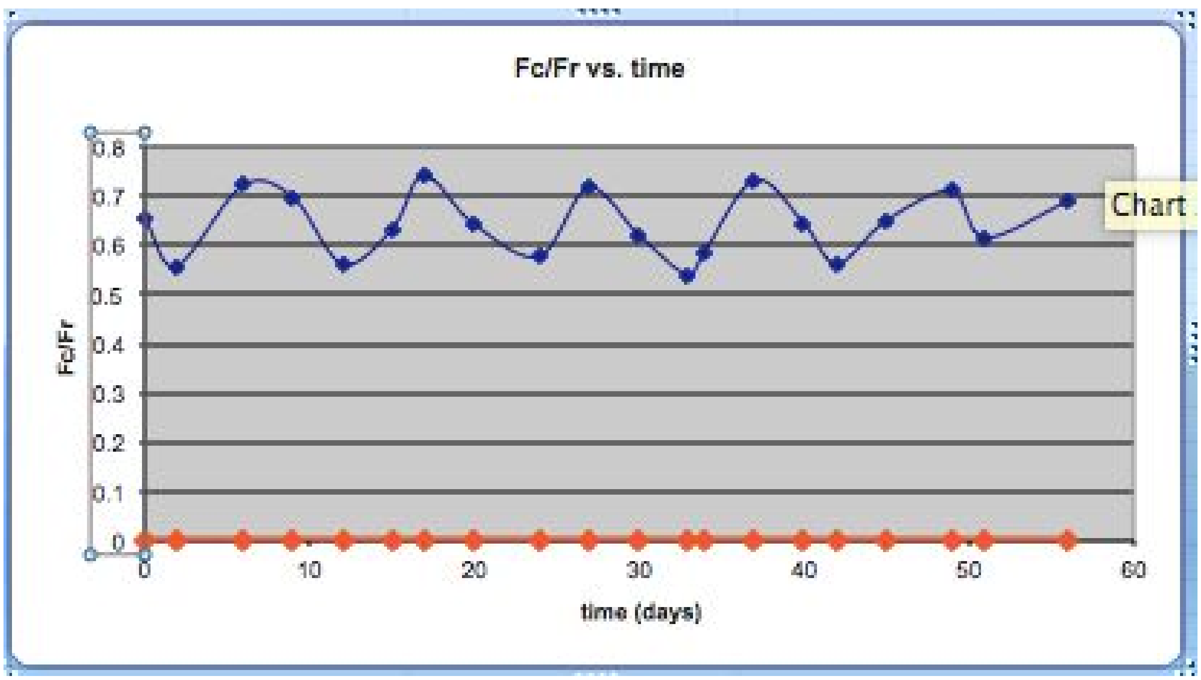
	Label	slice	Saturated	J.D.-2400000	JD_UTC	JD_SOBS	HJD_UTC	BJD_TDB	AIRMASS	ALT_OBJ	CCD-TEMP	EXPTIME
4	Cep-43522-1999-11-02-03-17-50.fts	4.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.410000	NaN	NaN	8192.00000
5	Cep-43522-1999-11-05-03-11-00.fts	5.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.412000	NaN	NaN	8192.00000
6	Cep-43522-1999-11-08-04-07-00.fts	6.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.455000	NaN	NaN	8192.00000
7	Cep-43522-1999-11-10-01-42-37.fts	7.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.413000	NaN	NaN	8192.00000
8	Cep-43522-1999-11-13-00-40-34.fts	8.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.441000	NaN	NaN	8192.00000
9	Cep-43522-1999-11-17-01-22-04.fts	9.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.411000	NaN	NaN	8192.00000
10	Cep-43522-1999-11-20-01-19-30.fts	10.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.409000	NaN	NaN	8192.00000
11	Cep-43522-1999-11-23-02-55-34.fts	11.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.444000	NaN	NaN	8192.00000
12	Cep-43522-1999-11-26-01-22-41.fts	12.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.407000	NaN	NaN	8192.00000
13	Cep-43522-1999-11-27-00-48-33.fts	13.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.409000	NaN	NaN	8192.00000
14	Cep-43522-1999-11-30-03-15-26.fts	14.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.495000	NaN	NaN	8192.00000
15	Cep-43522-1999-12-03-02-39-09.fts	15.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.466000	NaN	NaN	8192.00000
16	Cep-43522-1999-12-05-02-44-18.fts	16.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.480000	NaN	NaN	8192.00000
17	Cep-43522-1999-12-08-02-25-59.fts	17.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.473000	NaN	NaN	8192.00000
18	Cep-43522-1999-12-12-01-10-52.fts	18.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.423000	NaN	NaN	8192.00000
19	Cep-43522-1999-12-14-02-08-45.fts	19.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.480000	NaN	NaN	8192.00000
20	Cep-43522-1999-12-19-03-23-16.fts	20.000000	0.000000	0.000000	NaN	NaN	NaN	NaN	1.646000	NaN	NaN	8192.00000

Next, we'll transfer these measurements to the spreadsheet where you'll do the analysis.

12. Open the spreadsheets “Measurements.xls” and “answerfile_empty.xls” in Excel.
13. In the “Measurements.xls” spreadsheet, find the column the two columns labeled “rel_flux_T1” and “rel_flux_C2”. These are the relative brightnesses for the target and comparison stars. To calculate the “rel_flux_T1” column, AstroImageJ divided the measured pixel values for the target star by the total of the measured pixel values for all the target stars, reducing the influence of non-astrophysical variability.
14. Copy-paste the “rel_flux_T1” column into the column labeled “Flux of the Cepheid Fc” in the “answerfile_empty.xls” spreadsheet. Also, copy-paste the “rel_flux_C2” column into the column labeled “Flux of the Reference Star Fr”.

That should populate the “Fc / Fr” column and the plot in the bottom left-hand corner of the spreadsheet automatically.

You should probably adjust the y-range on the plot by right-clicking on the numbers and choosing “Format Axis…”. In the window that pops up, click the checkbox next to the word “Minimum”, then click “OK”. That should zoom out the plot and show you the whole oscillation signal from the cepheid.



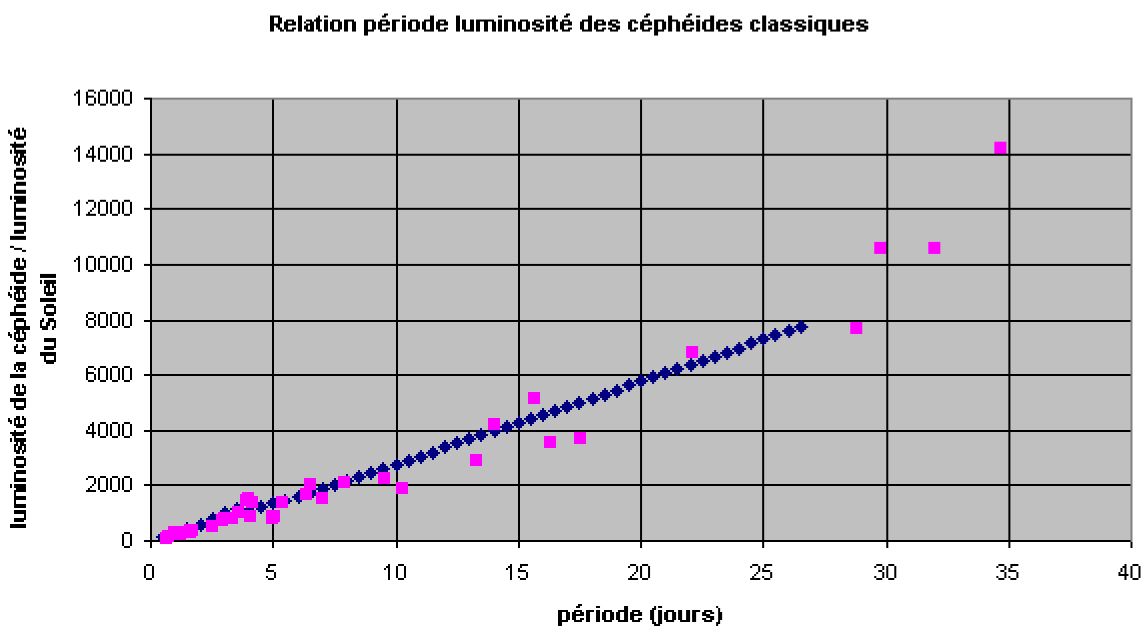
Next, we want to qualitatively fit a sinusoidal model to the observed oscillations. The equation you’ll try to fit is f(t) = A*sin(omega*t + phi) + B.

15. In the cell to the right of “Variable B =”, enter the following formula “=E23”. The cell E23 is the average value of the oscillating signal, equal to the B variable.
16. For the cell to the right of “Variable A =”, enter “=MAX(E3:E22)-E31”. This formula calculates the difference between the average value of the oscillating signal (B) and the maximum value, i.e. the amplitude of the oscillations.

17. Estimate the oscillation frequency by visually estimating the oscillation period T by looking at the oscillation signal. Then in the cell to the right of “Variable omega = 2PI/T =“, type the formula “=2*pi()/T”, where T is your period estimate.
18. At this point, a red oscillating model should appear in the plot, but the model will be out of phase with the observed signal. Again, by eye, estimate the time offset F between the model and observation. Then, in the cell to the right of “Variable phi =”, enter the formula “=F*E29”, where F is your offset estimate. When you have the right value, the red curve should lie very nearly on top of the observed signal.

Finally, you need to convert your estimated period (shown in cell E37) to an intrinsic luminosity for our cepheid.

19. Look at the blue dots in the chart below and estimate the luminosity of the star Lc relative to the Sun Ls and enter this number into cell E43:



20. Into cell E40, enter the observed flux for the comparison star you chose (check the image image003.gif and keep in mind the French use commas instead of dots in numbers).

After entering all these numbers, you should have a distance estimate in the orange-colored cells at the bottom of the spreadsheet. How does your answer compare to correct distance of 179,000 lightyears?

For this lab, you’ll need to print out and and turn in your two spreadsheets.