

INSTRUCTIONS

Attention!; this document was made with the French versions of Excel and SalsaJ. Maybe a few of the following instructions will not be accurate.

I- HOW TO BEGIN WITH THE ANSWERFILE

1- Upload the 20 photographs contained in the file **photographs** (.zip), available at the end of the Internet exercise. When you unzip the images, put them in the same file as SalsaJ executable software.

2- Now upload the Excel **Answerfile**. Open it so that it is ready to be filled in and used.

3- You have 20 photographs available, on which you can see exactly the same stars, but at different days and hours of the night. These dates can be known by reading the titles of each image. For example, **Cep-43522-1999-10-24-03-23-25** was taken on October, 24th 1999 at 03hours 23minutes and 25seconds. Fill in the first column « **Day and hour when the photograph was taken** » in your Excel Answerfile, taking care of writing down the images from the less to the most recent.

4- Fill in the second column of your Excel table untitled « **Interval time (days)** ». To do that, find out for each image the time (in days) that separates it from the first one, taken on October 24th, 1999. Note that you can neglect the minutes but not the hours.

II- PHOTOMETRY ON SALSAJ

5- Open SalsaJ. Once the software is open, the SalsaJ toolbar appears:

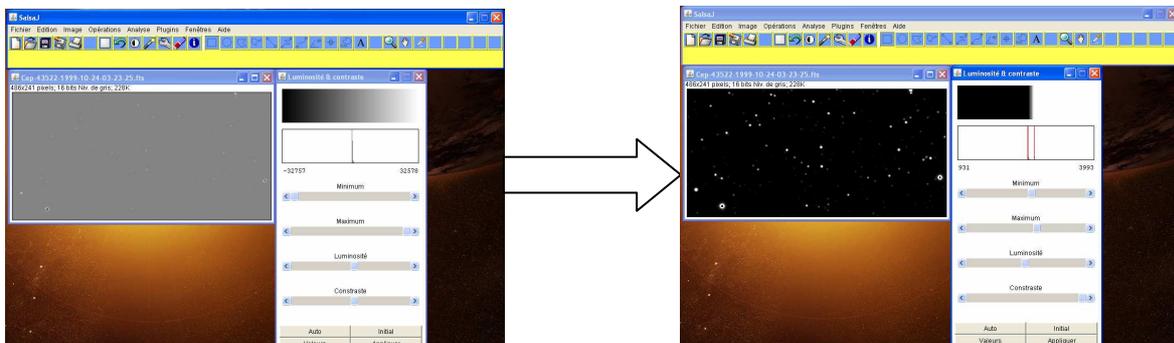


6- In SalsaJ toolbar, click on « **file** », then « **open** ». Open the first photograph **Cep-43522-1999-10-24-03-23-25**.

7- Click on the button in the toolbar « **luminosity and contrast** »:

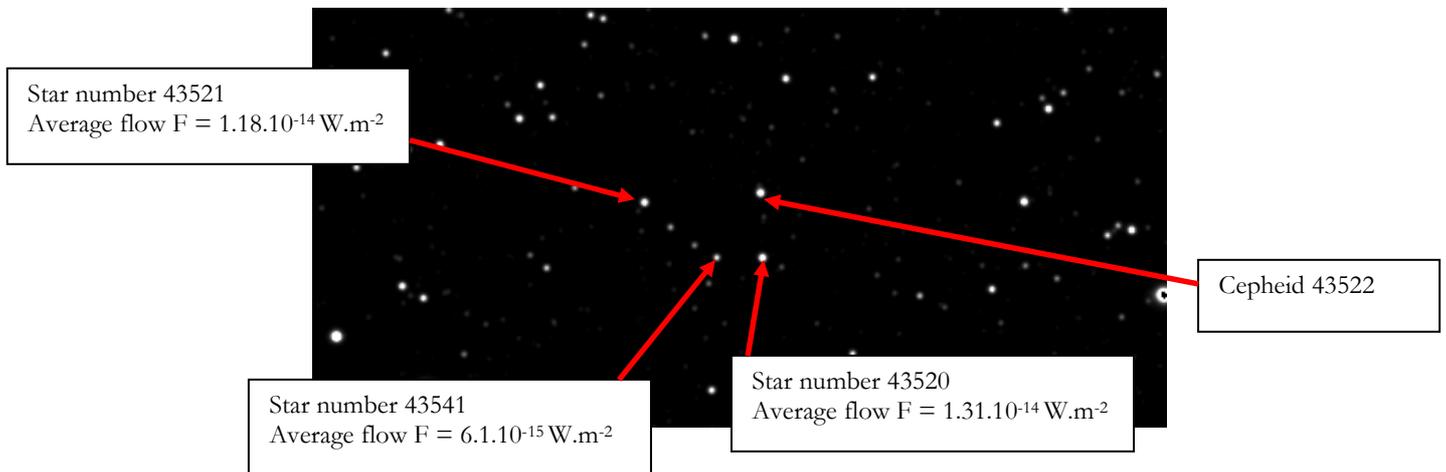


A new window appears. Click on « **Auto** »: the stars will seem much more visible. Next, if necessary, move the cursors « **luminosity** », « **maximum** » et « **minimum** » (« **luminosity** » is most of the time enough) in order to have a beautiful image. Close the window « **luminosity and contrast** ».

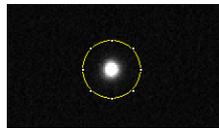


8- You are now about to start photometry. Click on « **analysis** », then on « **photometry** ». A new (white) window appears. This is the window where the values of intensity will be put by the software.

9- Locate attentively the 4 stars which are important for our exercise: Cepheid 43255 and three stars that we will call « comparison stars ». To locate them, use the photograph above.



10- Locate the Cepheid on your photograph. Click on its center. The star is now encircled and a value of intensity appears on the white window.



11- Choose a comparison star. Click on its center. Two values of intensity are now present in the white window you opened in step 8.

12- In your answerfile, you can now fill in the first line, which concerns the first photograph. In the column « **Luminosity of the Cepheid L_c** », enter the value of the luminosity you got in step 10. In the column « **Luminosity of the comparison star L_s** », enter the value of the luminosity you got in step 11.

The Excel file determines automatically the value of the ratio L_c/L_s in the 5th column.

13- Start from step 6 to step 12 again, with the 19 other photographs.

IMPORTANT NOTE: The comparison star you chose in step 11 has to be used for the 20 photographs. You must not change your comparison star during the exercise!

III- INTERPRETATION

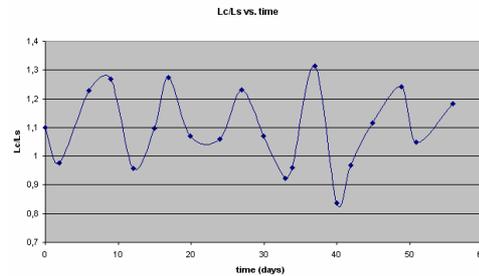
1- Average flow F_c of the Cepheid

14- In the bottom of the column « L_c/L_s » you can see in bold type the average value of the ratio L_c/L_s (when you have filled in every line). From the image in step 9 and this value, actually equal

to the ratio: (average flow Cepheid / average flow of the star F), determine the value of the average flow of the Cepheid. Now fill in the green cells in you answerfile.

2- Pulsation period of the Cepheid

15- Under your Excel table, the ratio L_c / L_s vs. time (in days) is automatically plotted.



16- The points on the graph are actually on a sinusoid, whose equation is :

$$f(t) = A \sin(\omega t + \phi) + B$$

où :

- A is the amplitude of the sinusoid i.e. half the « height » of the curve.

- ω is the pulsation of the sinusoid, that is to say $2\pi / T$, where T is the period of the sinusoid.

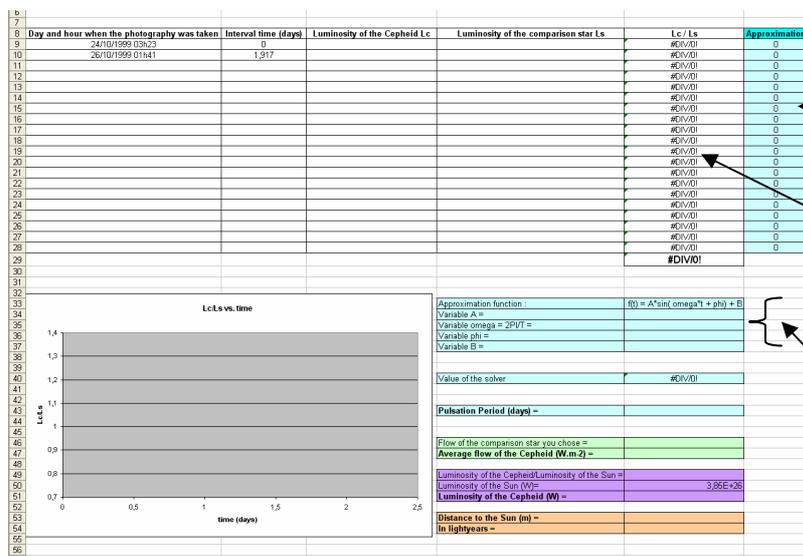
- B is the average value of the sinusoid, i.e. the average value of all the values of L_c/L_s .

- Phi is the phase of the sinusoid. Its value is between $-\pi$ (-3.14) and $+\pi$ (+3.14). If the first points of the curve are under the value of B, the phase is negative, if they are above, the phase is positive.

Try do determine, with a simple observation of the curve, the approximate values of A, T (and thus ω), and phi. B was determined automatically at the bottom of the column L_c/L_s .

17 – Write down these approximate values (A, ω , phi and B) in the blue cells made for that in your answerfile. As soon as all the values are typed, the blue column « **Approximation** » is automatically filled in next to your experimental values of L_c/L_s . This blue column is actually the theoretical values you would have got if you had directly calculated (without any mesures on Salsa) the ration L_c/L_s , just using the formula

$$f(t) = A \sin(\omega t + \phi) + B$$



Theoretical values

Experimental values

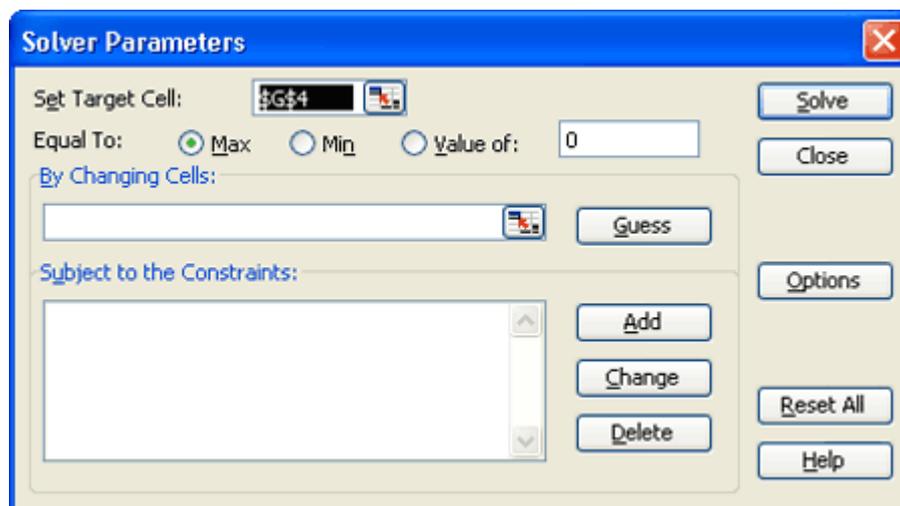
Approximate values of A, ω , B and phi just by observing the curve

18- As Excel, contrary to Regressi, does not have a function to determine the parameters of a sinusoid (A, B, omega and phi), we will use the Excel **Solver function**. Thanks to it, we are going to refine our values of A, omega, phi and B, so that our theoretical values are as close as possible to our experimental ones.

The average value of the differences between the experimental results and the theoretical ones for each image is written in the cell « **value of the solver** » in your answerfile. One understands easily that the higher this value is, the further the experimental results are from the theoretical ones. On the contrary, the closer it is to zero, the nearer the theoretical results are from the experience.

You are about to ask Excel to ripen the values you found for A, omega, phi and B in order to reach a value of the solver as close to zero as possible.

Click on the cell which contains the value of the solver (**G40** in your answerfile). This cell is your **Target Cell**. Now click on **Tools**, then on **Solver**. The following window is now on your screen.



19- Check that the cell G40 is written in « Set Target Cell ». If you look back on step 18, you will remember that this value must be as close to zero as possible. Thus choose “Equal To: Value of: 0”.

20- Don't close the window “Solver Parameters” yet. You are now about to tell Excel the values it can modify in order to find the value 0 in your target cell. Above “By Changing Cells”, click on  than select in your answerfile the approximate value of omega you found in step 16.

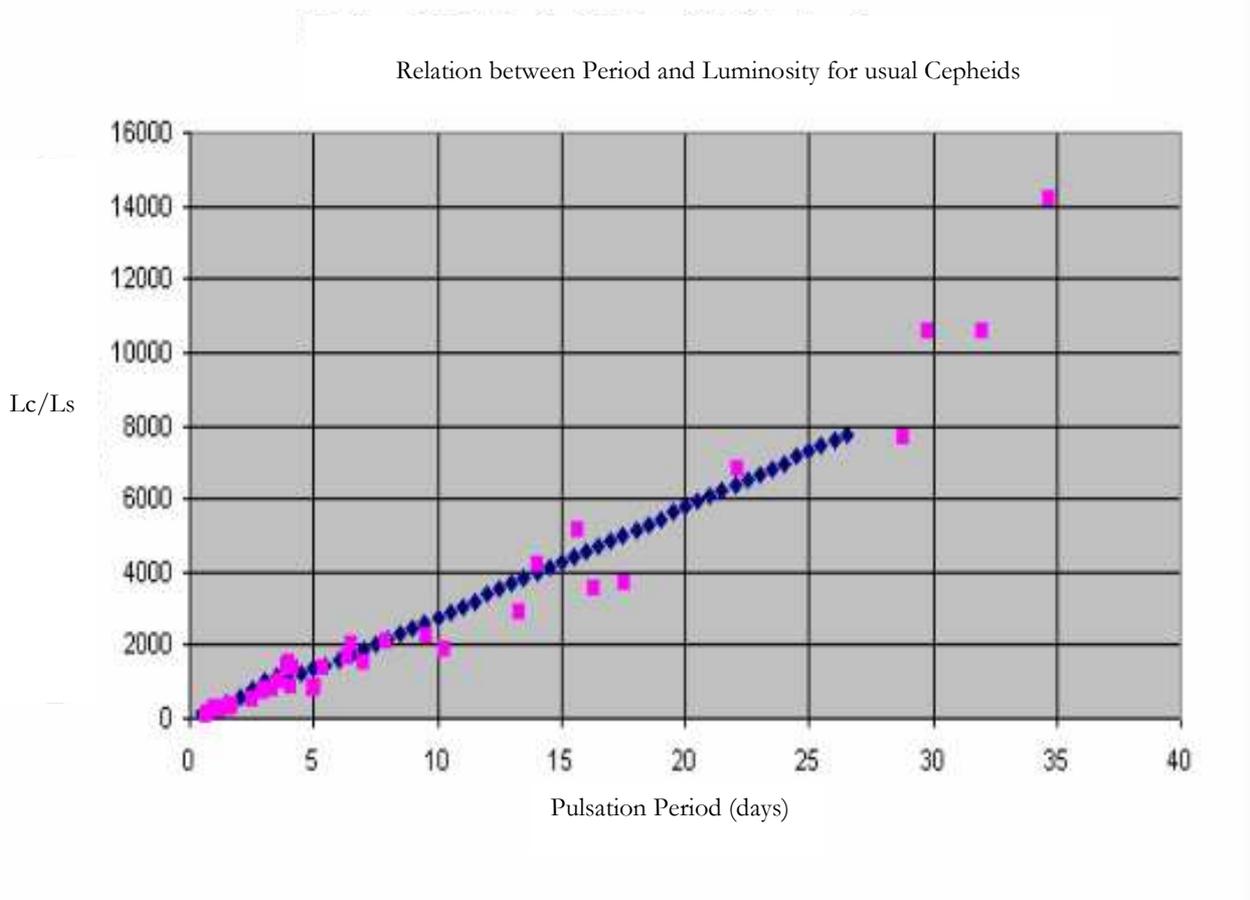
Click again on , then click on **Solve**. Your target cell is closer to zero now, and your value of omega has been a little modified.

21- Start again 3 times steps 18, 19 and 20 for the other Changing Cells A, phi, then B. You now have a more than correct theoretical approximation (look at the value of your solver and the values in the blue column “approximation” if you're not convinced!)

22- From the value of ω ($= 2\pi/T$) ripened by the solver, determine the period T of the sinusoid. This is the Pulsation Period of the Cepheid. Fill in the value you found out in the blue cell made for that in your answerfile.

3- Luminosity L_c of the Cepheid

23- Using the graphic below and the Pulsation Period you got from step 22, determine the value of the ratio L_c/L_s where L_s is the luminosity of the Sun.



4- Distance Cepheid/Sun

25 – From a distance r (in meters), a unity of surface perpendicular to the direction of the Cepheid receives a flow of energy F (in $\text{W}\cdot\text{m}^{-2}$) so that:

$$F = \frac{L}{4\pi r^2}$$

Where L is the luminosity of the Cepheid (in Watt), i.e. the energy it radiates every unity of time.

Thus if we know the luminosity of the Cepheid, and if we measure its flow, we can determine its distance.

From the values of F_c and L_c you found out in this exercise, all written in your answerfile, determine the distance r between the Cepheid and the Sun. Write it down on your answerfile in the cell made for that, first in meters, then in light years. (Indication : one light year

= $9.461 \cdot 10^{15}$ m). As the Cepheid is in the Large Magellanic Cloud, you've just found out the distance to the Sun from this dwarf galaxy in orbit around the Milky Way.

26 – The Large Magellanic Cloud is situated at 179 000 light years from our Sun. Does the distance you found seem correct? If not, can you explain why?

INDICATION: Don't forget that your result depends on the position of the Cepheid inside the Large Magellanic Cloud (even if this distance, unknown in this exercise, is very short comparing to the distance from the Cepheid to the Sun). But there are others kinds of incertitude. For example, the space between the Large Magellanic Cloud and the Earth contains little particles of dust that absorb part of the radiations. In your opinion, how does this phenomenon affect your results?