Discovering variable objects in the sky

How to create and analyze light curves

Metadata

General Info

Title: Discovering variable objects in the sky

Short description: This project aims to provide an experience of photometry and construction & analysis of light curves from sets of images of objects of variable brightness, leading the student to an entire investigative project practice.

Keywords: light curves, variable star, brightness; supernova, asteroids, exoplanets; reporting research, photometry

Educational Context

Context: It is extremely important to provide students with scientific skills on data collection and transformation, as well as transformation and analysis of results from a graphical representation.
Age: 16-18 years old (High school)

Prerequisites: Computer knowledge at the user level to install and use the indicated software parts. Knowledge of Simple Concepts of Physics, Astronomy and Mathematics is also desirable.

Lv. Of difficulty 4/5

Duration: (15 hrs max depending of the set choosed)

Educational Objective

Cognitive Objectives: Problem-based learning to reinforce physics and mathematics concepts.

Affective: Promoting group working and collaboration

Psychomotor: Development of skills of observation and precision and visual dexterity.

Subject Domain

Big Ideas of Science: The Solar System is a very small part of one of millions of galaxies in the Universe.

Subject Domain: Physics, Astronomy, Mathematic and ICT.

<u>Orienting & Asking Questions</u>

Looking at the night sky gives us a sense of tranquility and immutability that hides the huge variety of phenomena of different objects that we are not able to detect with our eyes alone.

If some celestial objects have a constant brightness, others may exhibit brightness variations whose origin may be in the characteristics or behavior of the object, or caused by the interposition of others that absorb part of its light. That's what we call **variable objects.** Some examples of variables objects:

Variable stars - stars that change its apparent brightness as seen from Earth;

Supernovas - powerful and luminous stellar explosion that occurs at the death of a massive star, that emit enormous amounts of radiant energy abruptly.

***Question**: What happens to light that's emitted from an object that's exploding? Does it stay bright, or fade over time?*

Exoplanets - planets outside the solar system that orbit other stars.

Question*: what happens to the amount of light we receive from the star when the planet passes in front of it?*

Asteroids- small rocky objects revolving around the sun that are too small to be called planets. Usually they have non-spherical shape and rotates during their orbit around the sun.

Question*: Being rotating and not having a regular shape, do you think it will always reflect the same amount of light or will it vary??*

If you answered that the light received varies in all these situations, you are on the right path. But, if they all vary, we must understand how can we differentiate each of them from the others and, if possible, extract even more information about the behavior of each of these objects. This is where we will show you how Science is done - measuring light and building **Light Curves**.

So, a **lightcurve** is just a plot of how the brightness of an object changes over time. So, from a set of several images of a region of the sky, using Salsa J, (or other software for this purpose), we are able to do **Photometry** and generate light curves that will be extremely important tools to unlock the secrets of the Universe and discover new and exotic objects.

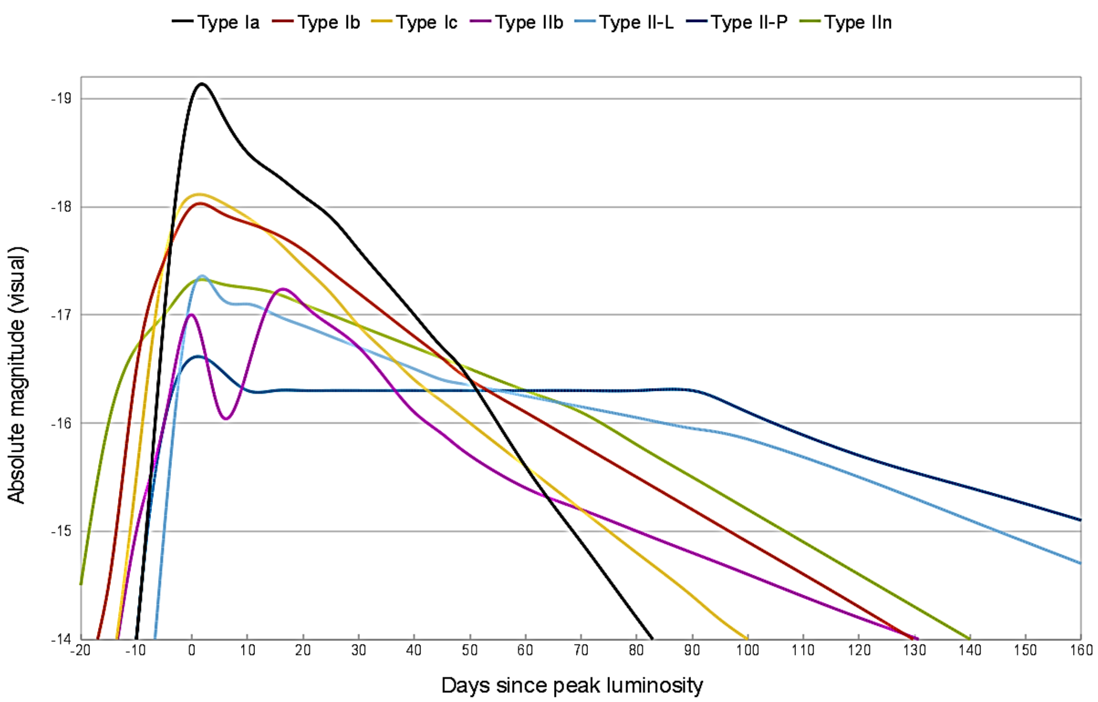
This is the challenge of this activity that uses real data to put you in the role of a scientist in search of the secrets of the Universe.

Hypothesis Generation and Design

Different types of objects provide different light curves

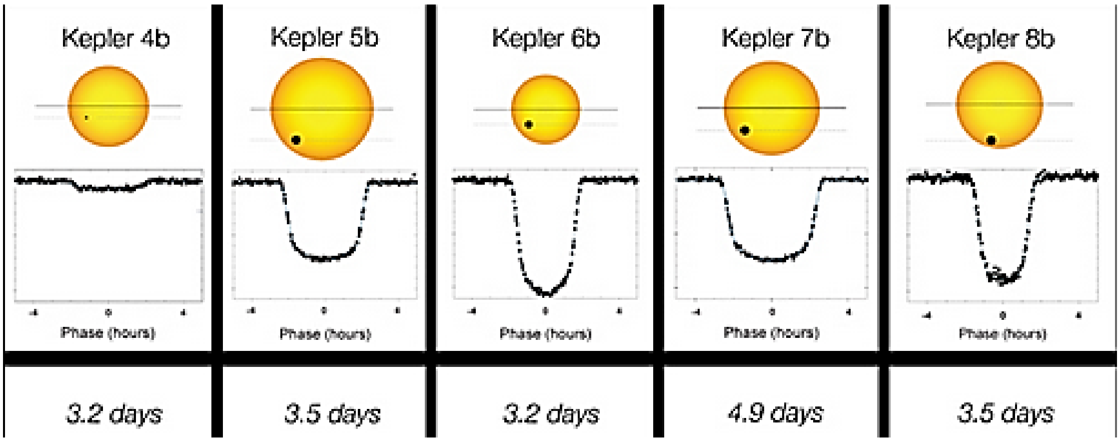
Depending on the phenomenon that creates a change in the light emanating from the object, we will have different types of light curves. Thus, by the form and duration of the phenomenon, we can classify it, and even interpret it.

Supernova - When a massive star reaches the end of its life, it can cause an explosion so luminous and so powerful that it is capable of both dazzling entire galaxies and releasing more energy than the Sun will be able to emit in its entire lifetime. These explosions are known as **supernovae** and are among the most powerful in space. A Light Curve of a **Supernova** (SN) depends a lot on the type of SN, but it will always be **very bright very quickly**, **then fade slowly**, as radioactive processes keep the expanding cloud glowing. So, the light curve with a rapid increase in brightness that gradually fades over time (usually 3-6 months).



Source: https://pt.wikipedia.org/wiki/Supernova

Exoplanets (Transit method) - Exoplanets, being very far from us, are detected indirectly. One of the methods for its detection is the transit method. When an exoplanet passes in front of its star, it will make it fade for a short time, before the planet moves away and the star returns to its normal brightness. So, we can obtain it also from a light curve



Source: adapted from https://www.planetary.org/space-images/transit-light-curves-for-keplers-first-five-exoplanets

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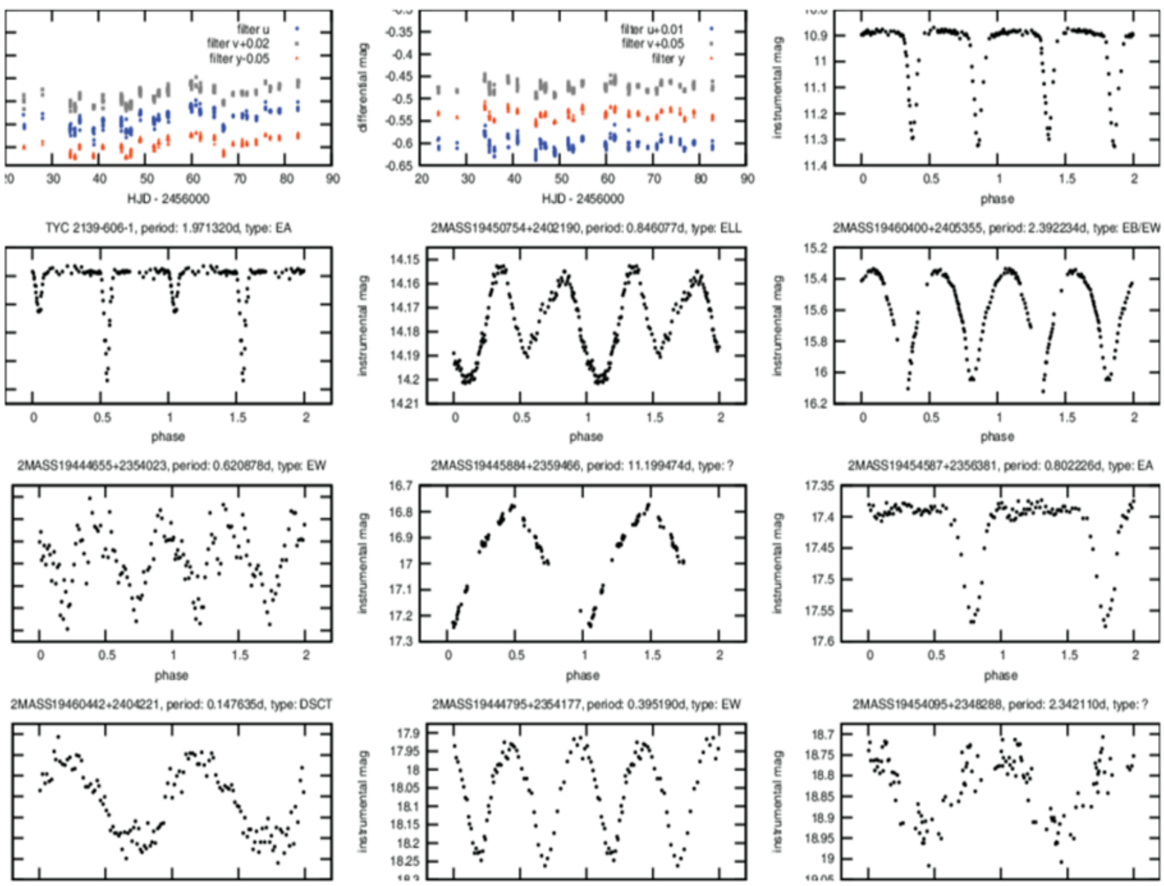
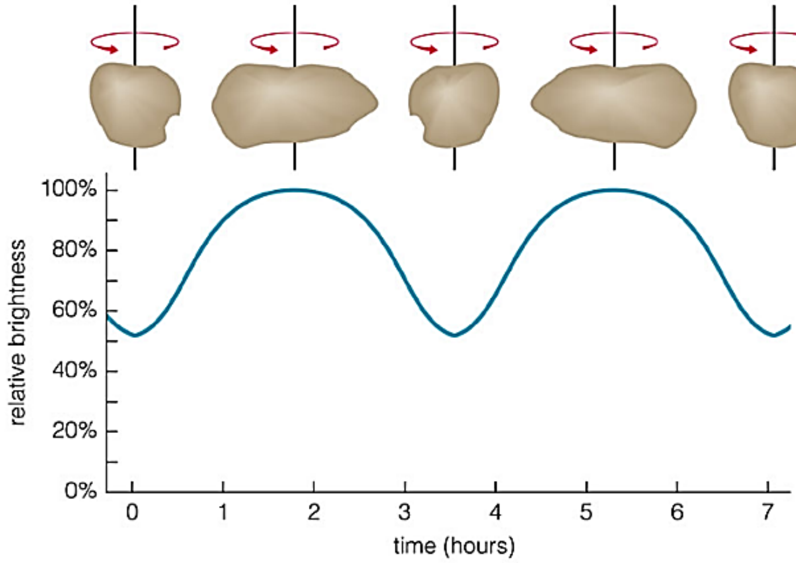
A **variable star**, by definition, is a star whose luminosity varies on a time scale of less than 100 years. It will show a regular periodicity in the increase and decrease in brightness. This regularity is graphically manifested in the light curves that present periodic signals (not necessarily sinusoids).



Resulting Light Curves Of The Variable Stars - Rotating Variable Stars Light Curve

Source: https://www.seekpng.com/ima/u2t4e6t4i1y3r5e6/

Asteroids - Asteroids are celestial bodies that orbit the Sun and are too small to be considered planets. As they usually have an irregular shape, when rotating they reflect light in a variable way, creating a pattern of brightening and fading, which repeats for periods in the range of a few hours to several days. Measuring this brightness over time we will have light curves that depict this brightness oscillation over short periods of time.



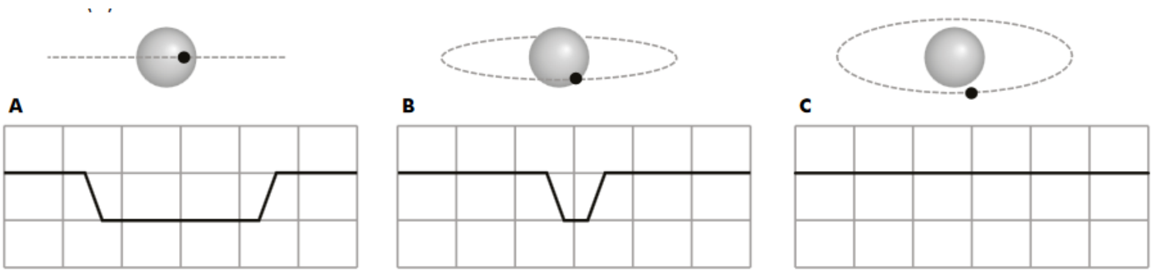
Source: https://community.dur.ac.uk/physics.astrolab/a_lightcurve.html

Planning and Investigation

Part I – Hands on activity

As we mentioned before, exoplanets are too distant and small to be seen directly, even with the most powerful telescopes. So how can astronomers detect them? When an exoplanet passes in front of its star (which we call transit), it blocks part of the star's light, dimming for a while the brightness that comes to us from that star. To do so, the exoplanet's orbit plane has to be aligned with our perspective of the planet.

So, by measuring the brightness of the star, this occasional dimming of light indicates that an object has come between us and the star, they can deduce that there is a strong candidate exoplanet orbiting the star.



1Source: https://spark.iop.org/sites/default/files/media/documents/the_transit_method__teacher%20notes.pdf

In this activity you will build a model of exoplanet, orbiting a star, to collect data and investigate how can we use a transit to detect exoplanets.

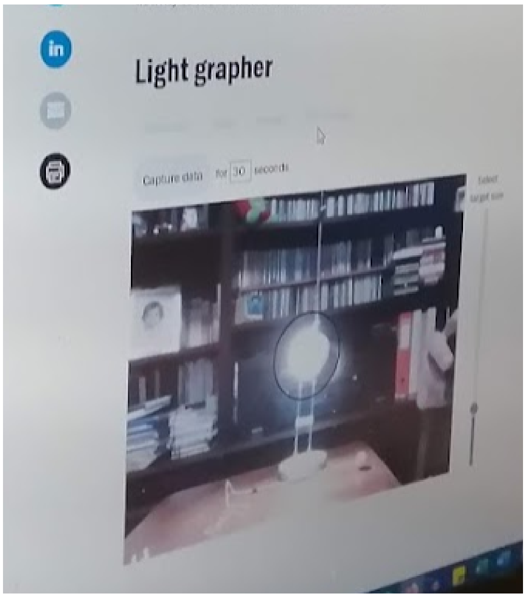
Apparatus and Materials (per group of 2 to 4 students)

- Lamp (vertical position)
- Two diferente polystyrene balls
- Barbecue skewers and wire
- Wire support bar.

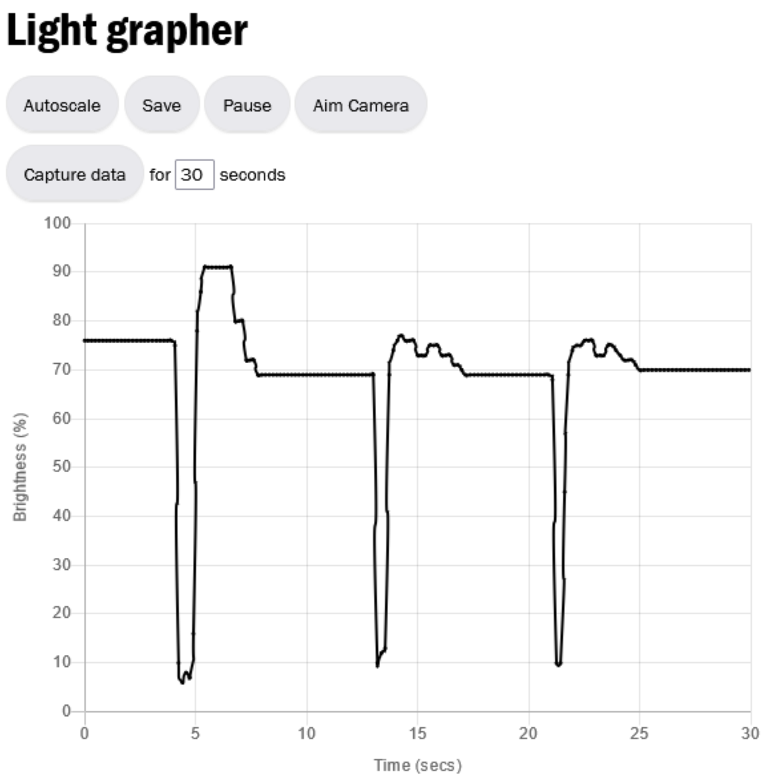
- Computer with webcam and Light-Grapher software (https://spark.iop.org/interactive-transit-method)

What you need to do:

1. Using the lamp as your star, decide how to model the transit of a planet as it orbits around the star. Remember that the suspended ball must be able to rotate around the lamp, at the height of the lamp. Assemble the apparatus so that the planet orbits the star.
2. Access the Light Grapher application and point the computer's camera towards the star (lamp). Activate the computer camera (or web cam) and adjust the target size so that it surrounds the star (lamp).



3. Sets the time to 30 seconds for sampling in Light grapher
4. Point the computer camera at the star, using the light graph, and place the planet in orbit around the star to record the transit.
5. **What if**: Think about how varying the size and speed of the exoplanet (test different balls with different speeds), or changes in other variables, might affect the shape of the graph. Idealize the way to proceed and record the "What if" varying one aspect at a time, indicating your previous prediction in each case sketching your prediction on the expected light curve.
6. Test each of the changes you devised and record the light curve produced. Compare the one you had imagined with the one you produced



7. Compare the data obtained for different balls, determine, for each case the period of each ball, and justify the differences observed.
8. Try changing the camera's aim by extending it to a larger area than necessary and repeat the experiment. What do you conclude?
9. Record all conclusions you have drawn and discuss your results with the class (compare your conclusions with the conclusions of the other groups).

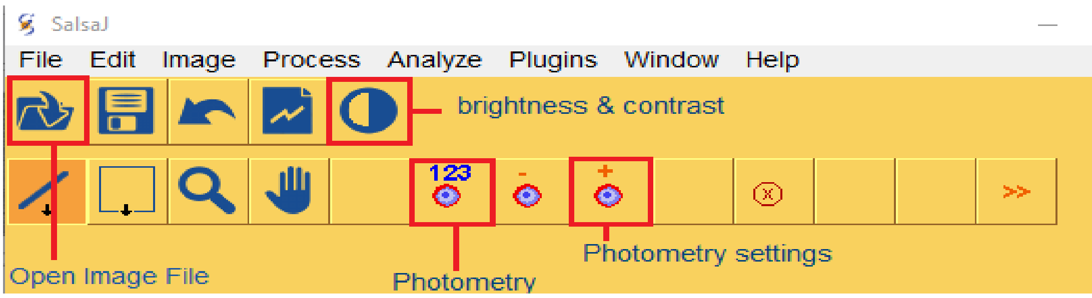
Note: If you improve the montage with a turntable (constant angular speed) you can still make the exercise more interesting as it will allow you to determine other physical parameters of the planet and its orbit.

Part II – Work on real data

How to create a light curve (photometry) using Salsa J

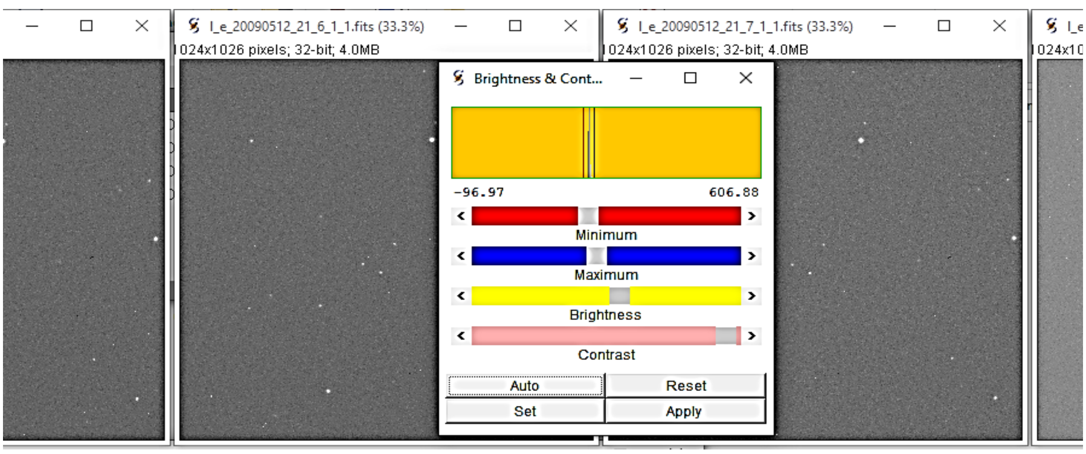
Photometry is calculated by correcting the integrated values of the pixels, provided by the light intensity of the object, by the value of the sky background. To process that we will use SalsaJ.

The operations indicated below can be selected through the menus that will be indicated in each case, or through the icons of the toolbar presented here.



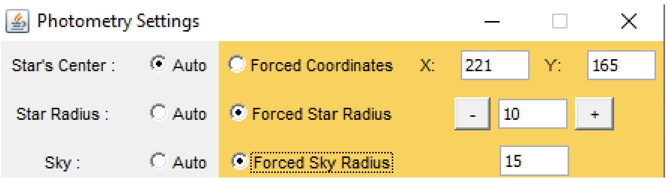
1. Open your image file: **File** > **Open.** After downloading and unzipping the image files, open each image (in chronological order) or select a group of images (max 10) and using **Windows** > **Tile** to distribute them on the screen.

2. Adjust the **brightness & contrast** of the image. Usually you may use the “Auto” button in Brightness & Contrast window. It will be easy with the tile distribution of images, just select each one and click on "auto". If it is not enough to show all the information under study, adjust the maximum and minimum bar so that the respective marks demarcate the borders where we find the signal. Adjust the brightness and contrast so that they all have a similar background. Do it to all and, if needed, adjust the brightness and contrast to set all images identically.

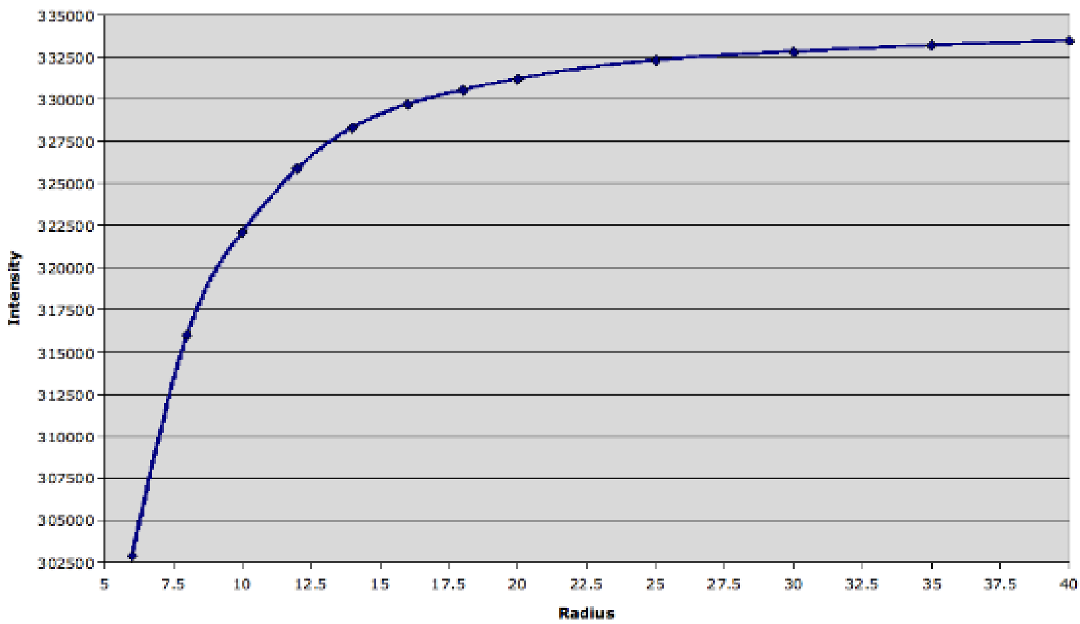


3. Go to **Analyse** > **Photometry Settings**.

You may choose to determine the centre and radius of the selected star and a suitable sky area automatically, or you can force the coordinates and radius of the star, and the value of the sky background.

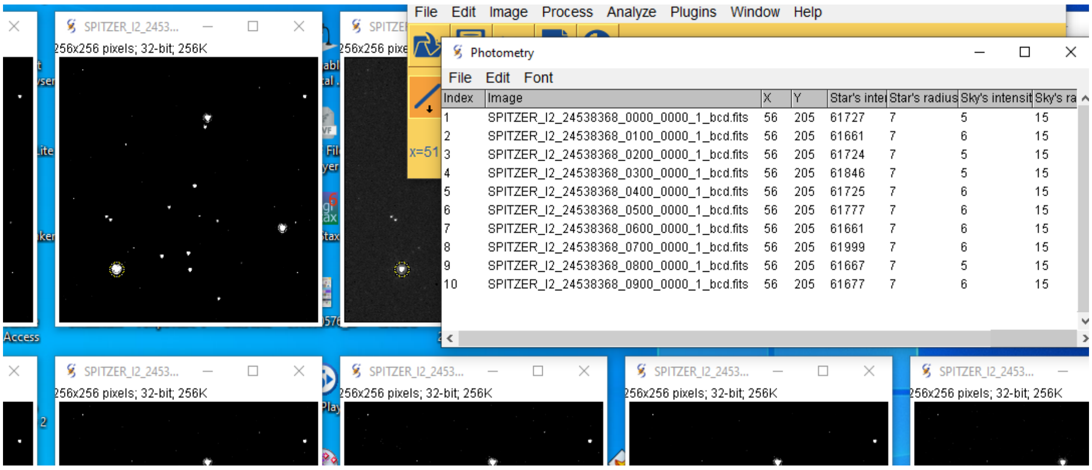


Stars in astronomical images have a specific profile when plotted as a graph of pixel values and that profile should be the same for each star in the image. To perform correctly photometry, it is advisable to establish the most suitable value for the star radius in order to obtain more accurate results. To know what is the best value of radius star you may test several different aperture radii and compare the intensity values you get for each radius by plotting a graph of radius against intensity with a spreadsheet.



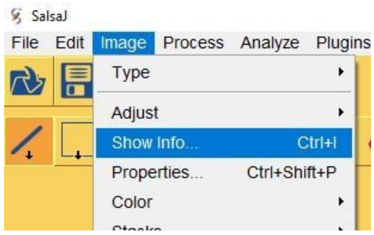
When the graph begins to flatten out, we have all of the star in the proper aperture. That's a nice choice to work on.

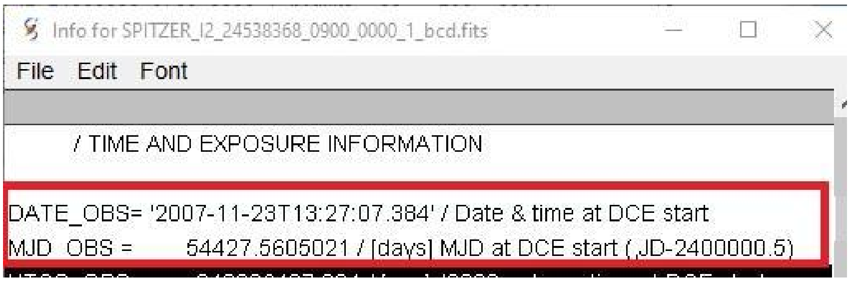
4. After setting the photometry parameters, go to: **Analyze > Photometry** (or the photometry button)**.** A new empty window "Photometry" will appear. Mark the same star in all images (just click on the center of the star). A circle of radius as specified in step 3 will be drawn on the image. The measured intensity and position values will also appear in the pop-up **'Photometry' window**.



A circle will be drawn on the image, whose radius will be in accordance with that defined in point 3. In the 'Photometry' pop-up window, the measured intensity and position values will appear.

6. Another data that is important to collect is the date and time, either in current format or in Julian Date. You can find this information on Salsa J at **Image – Show info** and search MJD_OBS in / TIME AND EXPOSURE INFORMATION.





7. Create a spreadsheet to produce the light curve.

You may create your own spreadsheet or use the proposed spreadsheet for this activity. What we need is the time and the brightness of the star in analysis and the reference stars.

By copying and pasting the data of each star from the **Photometry window** of Salsa J into an Excel spreadsheet, and time (Julian Date JD) collected as we saw before, we can structure this spreadsheet in order to create the light curves.

Photometric measurements on a Light Curve

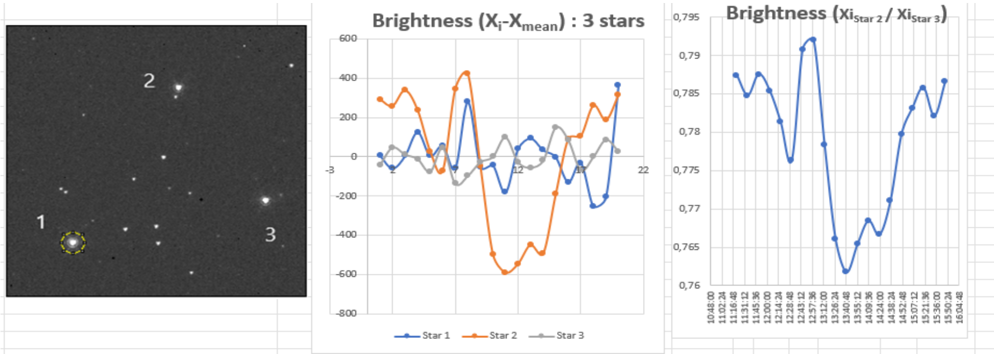
	Date	Time	JD	Star 1							Star 2							
				x	y	intensity	star radius	star intensity	sky radius	(Xi-Xmean)	x	y	intensity	star radius	star intens	sky radius	(Xi-Xmean)	B_Star2/ B_Star3
0_1_bcd-1.fits	23/11/2007	11:21:07	54427.4730033	56	205	61727	7	5	15	7,35	147	58	30330	7	5	15	291,75	0,787445
0_1_bcd.fits	23/11/2007	11:35:07	54427.4827254	56	205	61661	7	6	15	-58,65	146	58	30297	7	5	15	258,75	0,784795
0_1_bcd.fits	23/11/2007	11:49:07	54427.4924475	56	205	61724	7	5	15	4,35	146	58	30377	7	5	15	338,75	0,787581
0_1_bcd.fits	23/11/2007	12:03:07	54427.5021696	56	205	61846	7	5	15	126,35	147	57	30276	7	5	15	237,75	0,785431
0_1_bcd.fits	23/11/2007	12:17:07	54427.5118918	56	205	61725	7	6	15	5,35	146	58	30067	7	5	15	28,75	0,781326
0_1_bcd.fits	23/11/2007	12:31:07	54427.5216137	56	205	61777	7	6	15	57,35	146	57	29968	7	5	15	-70,25	0,776313
0_1_bcd.fits	23/11/2007	12:45:07	54427.5313358	56	205	61661	7	6	15	-58,65	146	58	30384	7	5	15	345,75	0,790818
0_1_bcd.fits	23/11/2007	12:59:07	54427.5410578	56	205	61999	7	6	15	279,35	146	58	30461	7	5	15	422,75	0,791997
0_1_bcd.fits	23/11/2007	13:13:07	54427.5507801	56	205	61667	7	5	15	-52,65	146	58	29992	7	5	15	-46,25	0,778386
0_1_bcd.fits	23/11/2007	13:27:07	54427.5605021	56	205	61677	7	6	15	-42,65	146	58	29540	7	5	15	-498,25	0,766119
0_1_bcd.fits	23/11/2007	13:41:07	54427.5702243	56	205	61539	7	5	15	-180,65	147	58	29448	7	5	15	-590,25	0,761777
0_1_bcd.fits	23/11/2007	13:55:07	54427.5799463	56	205	61760	7	5	15	40,35	146	57	29493	7	5	15	-545,25	0,765436
0_1_bcd.fits	23/11/2007	14:09:07	54427.5896731	56	205	61814	7	6	15	94,35	146	58	29590	7	5	15	-448,25	0,768512
0_1_bcd.fits	23/11/2007	14:23:07	54427.5993905	56	205	61754	7	6	15	34,35	146	57	29545	7	5	15	-493,25	0,766646
0_1_bcd.fits	23/11/2007	14:37:07	54427.6091126	56	205	61718	7	6	15	-1,65	147	58	29847	7	5	15	-191,25	0,771101
0_1_bcd.fits	23/11/2007	14:51:07	54427.6188393	56	205	61591	7	5	15	-128,65	147	58	30130	7	5	15	91,75	0,779701
0_1_bcd.fits	23/11/2007	15:05:07	54427.6285568	56	205	61689	7	6	15	-30,65	146	58	30144	7	5	15	105,75	0,783164
0_1_bcd.fits	23/11/2007	15:19:07	54427.6382789	56	205	61467	7	6	15	-252,65	146	57	30299	7	5	15	260,75	0,785824
0_1_bcd.fits	23/11/2007	15:33:07	54427.648001	56	205	61514	7	6	15	-205,65	146	57	30225	7	6	15	186,75	0,782119
0_1_bcd.fits	23/11/2007	15:47:07	54427.6577231	56	205	62083	7	5	15	363,35	146	58	30352	7	5	15	313,75	0,786627
					mean	61719,65							30038,25					

As the scale is different between the three graphs, we must **normalize** the data. To do that we calculate the average of the measurements and subtract each value to the average value.

Plotting the **dispersion** of the data normalized of the three stars over time, in the same graph, it would be enough to understand the variability of the brightness of the stars.

We may also choose from the graph what is the best star (the one that keeps the brightness practically constant) to be used as reference stars. The brightness of the reference star in each image manifests the same way, the effects of various factors that can affect the measured values. To cancel these effects, simply establish the quotient between the brightness of the star under study and the reference star (the smallest value in numerator).

To illustrate what has been said, in this case we start by comparing the brightness of the stars together, using their averages as a reference, which allows us to understand that Star 2 suffers a sharp drop in brightness (graph 1). Then, we isolated only this one (that varies). We still tried using the approach of comparing star 2 with stars 1 and 3 used as a reference.



- Compare the curves. Which star deserves to be studied and which one should be the reference star?
- What was the duration of the star's dimming?
- What could caused this decrease in the star's brightness?

It's time to create and analyse your own light curves. Let's do it !

***Note**: "Julian date format" refers to a format where the year value of a date is combined with the "ordinal day for that year" (i.e. 14th day, 100th day, etc.) to form a date stamp. Using Excel you may convert a date on B5 cell to JD using =YEAR(B5,"yyyy")&TEXT(B5-DATE(YEAR(B5),1,0),"000)*

sources:

https://www.cosmos.esa.int/web/hipparcos/examples-part-a

https://www.cosmos.esa.int/web/hipparcos/examples-part-b

https://www.aavso.org/about-light-curves

https://www.aavso.org/variable-star-astronomy

https://www.aavso.org/sites/default/files/education/vsa/Chapter11.pdf

https://sites.google.com/view/faulkestelescopeproject/resources/photometry-with-salsaj?authuser=0

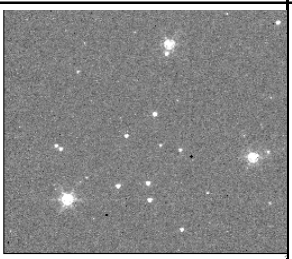
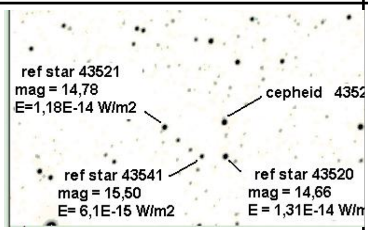
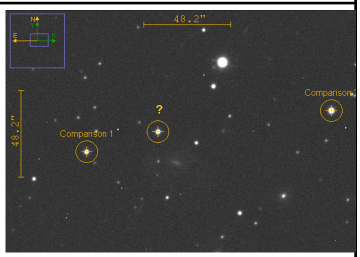
Part III – Do it yourself

Now that you've got some basic concepts about variables objects and how to make and interpret light curves, it's time to roll up your sleeves and start working on real data, casting hypotheses, making light curves, and interpreting the results. It's time to put yourself in the scientist's shoes.

We suggest that students be distributed in work groups, and each group be distributed a set of images to investigate the type of variable object.

Perform Investigation

- First of all, you must download and install SalsaJ (http://www.euhou.net/index.php/salsaj-software-mainmenu-9)
- Distribute sets A, B and C among the working groups..

• **Set A**;	• **Set B**;	• **Set C**
		
Use the 3 brightest stars to produce the light curve	Choose cepheid 43522 to plot the light curve	Chose the star marked with **?** to plot the light curve

- Use the procedure described above and the worksheet created for this activity, choosing the page separator corresponding to the respective set. You can use the spreadsheet provided or create your own.
- The brightness is always plotted on the vertical (y) axis. Time, in the Julian Day unit, is usually used, but for better interpretation, you may use our conventional format of date and time, always plotted along the horizontal (x) axis.

- Draw a smooth "best-fit" curve through your data points. The general trend of the points will give us the information we want about the star's behavior (not the individual points).
- If necessary, reformulate the parameters or reference stars in order to clarify the type of object being analyzed.

Analysis & Interpretation

- Identify when, on your graph, Star in analysis is brightest and dimmest.
- A complete variation in light output of a variable star, from maximum to maximum (brightest points) or from minimum to minimum (dimmest points), is called a cycle. Has your star gone through one or more cycles? What is the length of the cycle (what we call the **period**)?
- Identify what kind of variable object correspond to your set of images.

Conclusion & Evaluation

Now that you have found the answers to the problem, carry out some research that will help you to better understand this type of celestial object and, based on that and the results of the light curve that you have produced, characterize it in more detail.

Prepare a written work/electronic presentation about your object of analysis in order to present it to the class with your results.

Compare your result with the results of your classmates. Why did they find different results? Since you had the same data and you followed the same directions shouldn't you have the same outcome?

If you used the same data from another group and came up with results that show differences (even if you end up with the same conclusions), discuss those differences and the reasons for them.

What was the most interesting part of this exercise and what did you find least interesting? Mark the concepts you had to use to solve this activity.

About the importance of this little project for you, rate from 1- very poor to 5-Very good each topic:

- The interest that this activity represented for you.
- The knowledge acquired/reinforced
- the skills you worked