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Activity 1 : Gaia and the parallax

Teacher's guide

During this activity students will work in groups of two or three to gain an understanding of how stellar parallax can be used to measure the distance to relatively nearby stars. Students will actively measure the distance to an object using a base line, angles and trigonometry and older students will derive the parallax equation and calculate the percentage error in their result.

This activity compliments the Gaia – space surveyor activity and can be used to allow students to gain an understanding of parallax before attempting the space rulers task.

Suitability:

Using trigonometry to measure the distance to an object: 12 – 16 year olds.

Deriving the parallax equation: 13 – 16 year olds.

Curriculum links:

Astronomy/science: stellar distances.

Maths: Pythagoras and trigonometry, small angle approximation.

Prior knowledge:

A basic understanding of trigonometry is useful but not essential.

Additional resources required:

For each group

- 2 meter rulers
- Giant protractors printed out, mounted on card and cut out
- Cocktail stick or other thin object to act as the measuring stick
- Calculators
- A traffic cone or other object to represent the nearby star
- A student worksheet per student

Teacher will need

- Trundle wheel or measuring tape
- Parallax activity powerpoint

Activity Notes:

This activity works best in a large space such as a hall or a field. A traffic cone or similar object will need to be provided for each group to represent the star that they are calculating the distance to. The objects to be measured should be placed around 6m away.

Students need to get down on the ground to make accurate angle observations, so if this activity is being conducted outside, plastic bin bags or sheets may need to be provided for students to lie on to protect their clothing.

Starter/introduction :

Setting the scene: The students should observe that the position of the thumb has appeared to change with reference to the background, when watching it alternatively with one eye, and this effect is known as parallax.

Activity 1 : Gaia and the parallax

Teacher's guide

Main:

- (1) Describe how the parallax effect works using the thumb example and define in words what parallax is.
- (2) What does this have to do with stars? Effectively the thumb demonstration is a small scale example of what we observe when looking at relatively nearby stars from the Earth. The nose (the mid-point between the eyes) represents the Sun, the eyes represent two points in the Earth's orbit 6 months apart and the thumb represents a nearby star. From an observer on the Earth, the position of the nearby star appears to change compared to the background stars which, being much further away, do not appear to move. This effect is known as stellar parallax.

Note: Sometimes this is also referred to as heliocentric parallax since the Sun is at the centre point of the baseline created by the Earth at the two points in its orbit.

- (3) Parallax activity:
 - a) Take the students and all the equipment to the area where the practical part is to be conducted.
 - b) Get the students to set up their star as explained in the student sheet. Before they begin to take measurements, measure the actual distance to the star for each group using a tape measure or trundle wheel. Do not reveal the distance to the group yet as they will discover once they have done their calculations how close they are.
 - c) Since repeat measurements must be taken, each student in the group can have at least one attempt at measuring the angles to the object.
 - d) Once the students have their three sets of data, return to the classroom to allow them to calculate their averages.
 - e) **AT THIS POINT IT MAY BE NECESSARY TO GIVE A BRIEF SUMMARY OF TRIGONOMETRY AND PYTHAGORAS' THEOREM IF THE STUDENTS ARE UNFAMILIAR WITH IT.** Using the principals of Pythagoras' theorem, students calculate the distance to their object. They can then check with the teacher what the actual distance was and comment upon how close they were to the actual answer.
 - f) At this point, errors within the practical could be discussed.
- (4) Extend the idea of parallax to stellar distances. Older or higher ability students can then derive the parallax equation.

Plenary

Discuss the relationship between parallax angle and distance to the star as well as the limitations of this technique due to the parallax angle being increasingly difficult to measure accurately the further away the target star is.

Explain that the European Space Agency's Gaia mission will very accurately measure the parallax of stars using the same method as the students have just used (see the activity "Gaia, space surveyor").

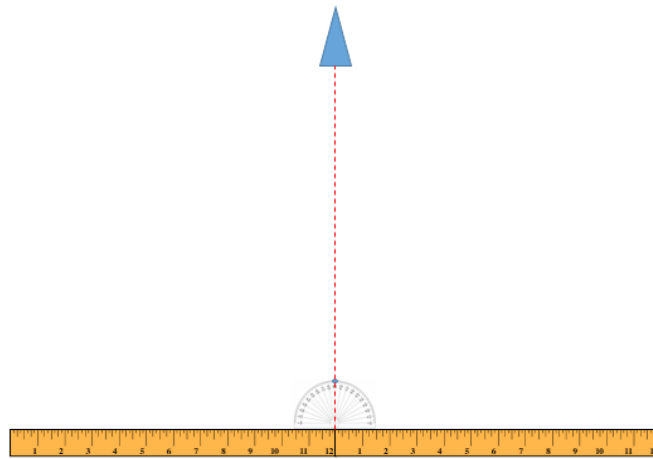
Activity 1 : Gaia and the parallax

Student sheet

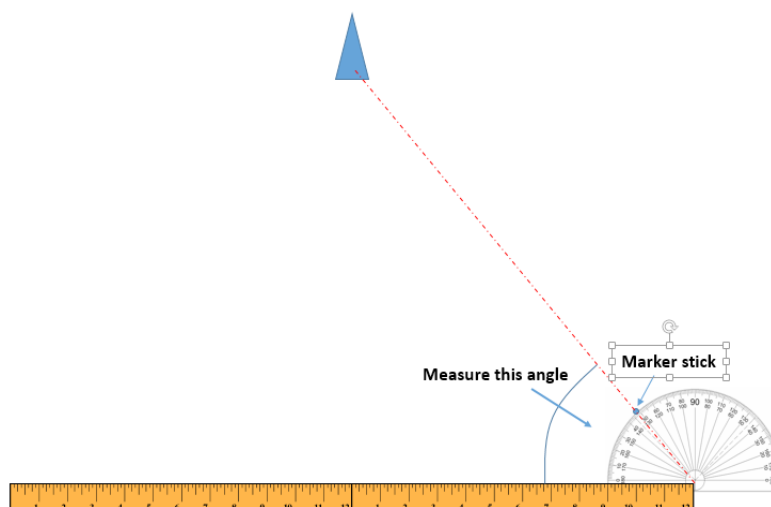
Measuring the Distance to Objects Using the Parallax Method

For all readings you will need to get down on the ground so that the protractor can be placed parallel to the baseline and accurate readings taken.

1. Take the two metre rulers and place them end to end creating a 2m baseline. Position the rulers using the protractor and marker so that the join between the rulers is lined up with the centre of the distant object with the baseline at right angles to the distance line.



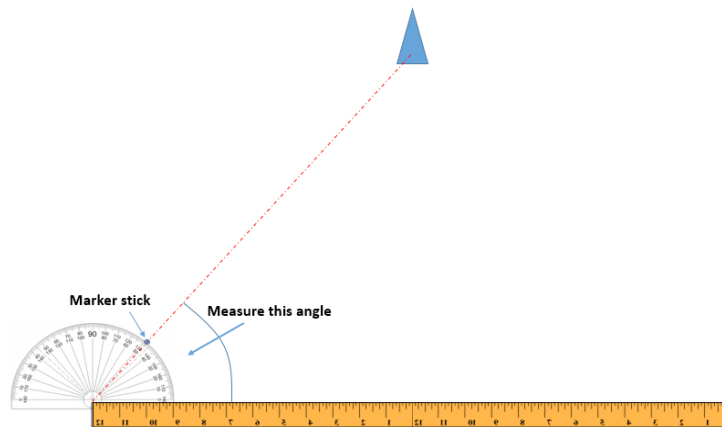
2. Place the protractor so that the centre is lined up with the edge of the right hand ruler. Lay down on the ground and line your face up so that you are looking along this centre line. Take your marker stick and carefully move it around the protractor until it is lined up with the centre of your distant object. Note the angle between the baseline and the marker and write this in the table on the next sheet.



Activity 1 : Gaia and the parallax

Student sheet

3. Repeat this procedure with the left edge of the baseline. If you lined up the centre of your baseline with the object correctly then the angle you observe should be about the same at that for the right edge. If this is not the case you may need to adjust the position of your baseline. Write your result in the table below.



4. Repeat this procedure so that you have three sets of results. Take an average of your results for both ends of the baseline and use the average to calculate the distance to your object. Check with your teacher how close your calculations are to the actual distance.

Results:

	Right edge angle (degrees)	Left edge angle (degrees)
1		
2		
3		
Average		

Calculations:

Using right edge average angle the distance to the object is:

Using left edge average angle the distance to the object is:

Actual distance was:

Percentage error of my results:

Activity 2 : Parallax on sky

Teacher's guide

This activity will allow the students to understand the parallax method used on the sky to determine the distances from the stars. It completes the activity “Gaia and parallax”

Suitability:

15-18 year olds.

Curriculum links:

Pythagoras and trigonometry, small angle approximation

Prior knowledge:

Previous activities linked to the parallax: « Parallax I »

Knowledge of trigonometry

Material:

- The giant protractor constructed in the activity « Parallax I »
- Small LED lamps, with different colours if possible
- A photographic camera
- A tape measure
- A rope with minimum length equal to the length of the classroom used for the activity

Notes on the activity:

This activity should be carried out in a room which can be darkened. This will allow to have good images of the “stars”. The room should be cleared out to perform the activity.

Introduction:

To remind the parallax effect, show the video of the person travelling in the car with the apparent movement of the closer objects and with the Moon that does not change its apparent position.

Activity:

1. Once the students embodying the Sun and the background stars are in their places, the angular distance between them must be determined. A rope will be handled by the student in the place of the Sun with the opposite end reaching the background stars. The rope will help to place all the background stars at the same distance from the Sun.
2. With the help of the giant protractor, placed as indicated in the power point, we will measure and note the angle from each background star.
3. The student handling the star to measure will be placed several meters in front of the background stars.

Activity 2 : Parallax on sky

Teacher's guide

4. The student handling the camera will define its trajectory around the Sun, taking care of being placed at the same distance to the right and to the left of the Sun. These two spots should be correctly marked to be identified in the dark. Do not forget to measure the distance between the student in the place of the Sun and the Earth.
5. Once the room is in the dark and the LEDs are on, the student at the place of the Earth takes the photographs in the marked spots.
6. These photos are transferred to the students to let them estimate the separation of the star between the two photographs. They can measure the distances between each star with the help of a ruler, and determine afterwards the movement of the star between both photographs. This displacement should be expressed in degrees.
7. Students will compute then the distance to the star with the help of the formulas presented in the power point. This formulas can be deduced by the students.

Several discussions can follow this activity:

1. Divide the class in several groups and reproduce the measurement with all the groups of students. Compare the results. Where are the most important sources of error? Is it useful to make the average of the measurements to find the distance closer to reality?

The most important error sources that will appear in this activity are on the one hand the mapping of the sky: the measure of the angles between the stars in the background. On the other hand, the determination of the displacement in the sky of the star to measure.

This last source of error is the true limit in the determination of distances by the parallax method in real life. Using the average value will help to homogenize the dispersion in the measurements.

2. Is there a point over which it is not possible to measure the distance of the star with this system? Why?

Usually, the parallax method should work with all the distances that we can find in a classroom. The limit appears when the apparent movement of the star with respect to the background stars is too small to be detected.

Activity 3 : Gaia, space surveyor

Teacher's guide

During this task students will build on their knowledge of parallax by using real Gaia data to calculate the distance to a number of stars known to have exoplanets in orbit. Students will look up the parallax angles using the Gaia database and use these to calculate the distance to each star in km, parsecs and light years.

Suitability:

Higher ability KS4 or KS5

Curriculum links:

Astronomy: heliocentric parallax to calculate the distance to nearby stars, the parsec as a unit of distance, describing how astronomers use space probes to learn about the Universe, the existence of exoplanets, space travel.

Science/Maths: handling data, trigonometry, standard form, angles, converting units, error.

Astrophysics: heliocentric parallax to calculate the distance to nearby stars, the parsec as a unit of distance, error.

Prior knowledge:

Students should have already completed lesson 1 on how to calculate parallax using nearby objects on Earth. There is some revision of these ideas before going on to the calculations.

Students should be familiar with standard form and trigonometry.

Additional resources required:

- ICT access (preferably for students working in small groups but can be done as a class with a teacher PC and projector).
- Scientific calculators.

Differentiation:

- Data in the 'useful information' box on the student sheet can be added/removed depending on the ability of the students and what they have covered previously.
- The number of stars to complete calculations for can be reduced if necessary.
- The number of different distance units to convert to can be reduced if necessary.

Starter/introduction:

Setting the scene:

Start with an introduction to Hipparcos and Gaia. Show animation illustrating the difference between Gaia and Hipparcos in terms of how far out they can measure stellar distances.

Discuss how Gaia might help us to discover more about exoplanets.

Main:

- (1) Explain the task to students and give them a refresher on how to calculate distance using parallax angle if needed. Students use the Gaia catalogue to look up the parallax data for stars.
- (2) The angles can then be used to calculate the distance to each star.

Activity 3 : Gaia, space surveyor

Teacher's guide

- (3) Students answer questions about which is the nearest star system containing an exoplanet and whether it would be feasible for us to travel there.
- (4) Class discussion of findings so far including what we know about Proxima Centauri. Students can self or peer assess their answers to task 1 at this point.
- (5) Discussion of the amount of error in their calculations. Students complete task 2 to determine the error in their calculation of distance using Hipparcos and compare this error to the one obtained by Gaia.

Plenary:

Discussion – why is Gaia important?

Activity 3 : Gaia, space surveyor Student sheet

Task 1: Using Gaia data to calculate the distance to a star.

With a web browser, open the Gaia catalogue website: <https://gea.esac.esa.int/archive/>
Click on the « Search » button to reach the following page.

The screenshot shows the Gaia archive search page. The 'gaia archive' logo is at the top left. Navigation tabs include HOME, SEARCH, STATISTICS, VISUALIZATION, HELP, and DOCUMENTATION. Below the tabs are buttons for 'Simple Form', 'ADQL Form', and 'Query Results'. The 'Position' section has radio buttons for 'Name' (selected) and 'Equatorial'. The 'File' section has a 'Target In' dropdown set to 'Circle' and a 'Radius' of '10' arc sec. A search box contains 'Tycho' and a dropdown is set to 'Simbad'. The 'Search In:' dropdown is set to 'Gaia Source'. The 'Extra conditions' section is expanded, showing a list of columns with checkboxes. Three columns are selected: 'name', 'parallax', and 'parallax_error'. The 'Display columns' section is also expanded, showing a list of columns with checkboxes. Three columns are selected: 'name', 'parallax', and 'parallax_error'. The 'Max. number of results:' is set to '500'. At the bottom, there are buttons for 'Reset Form', 'Show Query', and 'Submit Query'.

1. Name
2. Tycho-Gaia Astrometric Solution (TGAS)
3.a Display columns
3.b Select All / None
3.c parallax
3.d Submit Query

1. Insert the name of the star.
2. Select the Tycho-Gaia Astrometric Solution (TGAS). This catalogue uses the most recent Gaia data but also data from the Hipparcos mission to have a best estimate of the parallax.
3. We are only interested on 3 columns. Hipparcos name, parallax and parallax error. To select only these columns, [3.a] click on “Display columns” and then unclick “Select All/None” [3.b]. Click then the 3 interesting columns [3.c].
4. Submit query

Activity 3 : Gaia, space surveyor

Student sheet

5. You can now complete the rest of the table. Convert the angle into degrees and use your knowledge of parallax to calculate the distance to the star. Use the “useful information” box to help.

Star Table

Star	Constellation	Parallax angle (milli arc seconds)	Parallax angle (arc seconds)	Parallax angle (degrees)	Distance (kilome- tres)	Distance (parsecs)	Distance (light years)
HIP 116454	Piscis						
HIP 14810	Aries						
HIP 57274	Ursa Major						
HIP 91258	Draco						
HIP 97233	Aquila						
HIP 2247	Cetus						

Useful information:

One milli arc second = 0.001 arc seconds

One arc second = 1/3600 degrees

One astronomical unit (AU) = 149 597 871 km

One km = 3.24×10^{14} parsecs

One parsec = 3.26 light years

Activity 3 : Gaia, space surveyor

Student sheet

Questions:

1. Each of these star systems contains at least one planet, which of them is closest to the Earth?
2. Do you know the name of the closest star to the Sun? A planet has been found orbiting this star. The star is not yet in the Gaia database, but the Hipparcos parallax for this star is **772** mas. Can you calculate fill the table for this particular star?

Star	Star name	Constellation	Parallax angle (milli arc seconds)	Parallax angle (arc seconds)	Parallax angle (degrees)	Distance (kilometres)	Distance (parsecs)	Distance (light years)
HIP 70890	Proxima Centauri	Centaurus	772					

3. The Voyager 1 space probe launched in 1977 is currently near the edge of the solar system travelling at a speed (relative to the Sun) of approximately 61200 km/h. If we could send a spacecraft to the nearest exoplanet travelling at this speed how long would it take to get there? Will Voyager keep going at this speed? Explain your answer.
4. If an astronomer on Earth was to send a radio signal to a space probe orbiting the nearest exoplanet, how long would it take them to get a response?
5. Do you think it is feasible for the European Space Agency (ESA) to send a space probe to the nearest exoplanet? Explain your answer.
6. Why do you think missions such as Hipparcos and Gaia are so important when trying to learn more about exoplanets?

Task 2: Error analysis

1. It is important to understand how much error there is in the distances you have calculated. Can you calculate the mean error in the Gaia parallax measurements using Table 1?
2. Hipparcos' mean error was +/- 1 milli-arc second. Can you calculate the effect of Hipparcos' error and the change produced with Gaia for the star closest to Earth ? Please, complete the table below.

Activity 3 : Gaia, space surveyor

Student sheet

Star	Parallax (arc seconds)	Original computed (light years)	Hipparcos error (arc seconds)	Highest possible distance using Hipparcos error (light years)	Lowest possible distance using Hipparcos error (années-lumière)	Gaia mean error	Highest possible distance using Gaia error (light years)	Lowest possible distance using Gaia error (light years)

3. Do you think that the error found using Gaia accuracy is large? Explain your answer.

Activity 3 : Gaia, space surveyor

Answer sheet

Hipparcos and Gaia – space rulers

Task 1: Using Gaia data to calculate the distance to a star.

Star	Parallax angle (milli arc seconds)	Parallax error (mas)	Parallax angle (arc seconds)	Parallax angle (degrees)	Distance (kilometres)	Distance (parsecs)	Distance (light years)
HIP 116454	16.22	0.24					
HIP 14810	19.7	0.3					
HIP 57274	38.28	0.25					
HIP 91258	21.83	0.27					
HIP 97233	10.05	0.29					
HIP 2247	28.82	0.28					

Questions:

1. Each of these star systems contains at least one planet, which of them is closest to the Earth?
HIP 97233
2. The Voyager 1 space probe launched in 1977 is currently near the edge of the solar system travelling at a speed of approximately 61200 km/h. If we could send a space craft to the nearest exoplanet travelling at this speed how long would it take to get there?
6.80 x 10⁸ hours, 77,596 years!

Activité 3 : Gaia, arpenteur de l'espace

Feuille réponse

- If an astronomer on Earth was to send a radio signal to a space probe orbiting the nearest exoplanet, how long would it take them to get a response?
4.223 light years x 2 = 8.446 years!
- Do you think it is feasible for the European Space Agency (ESA) to send a space probe to the nearest exoplanet? Explain your answer.
No! Travel time, communication time, technology, fuel etc
- Why do you think missions such as Hipparcos and Gaia are so important when trying to learn more about exoplanets?
They enable us to learn more about these systems without having to travel there.

Task 2: Error analysis

- Can you calculate the mean error in the Gaia parallax measurements using Table 1?
0.27 mas
- Hipparcos' mean error was +/- 1 milli-arc second. Can you calculate the effect of Hipparcos' error and the change produced with Gaia for the star closest to Earth? Please, complete the table below.

Star	Parallaxe (arc seconds)	Original computed (light years)	Hipparcos error (arc seconds)	Highest possible distance using Hipparcos error (light years)	Lowest possible distance using Hipparcos error (années-lumière)	Gaia mean error	Highest possible distance using Gaia error (light years)	Lowest possible distance using Gaia error (light years)
Proxima Centauri	0.772	4.223	+/- 0.001					

Activity 4 : Gaia, space sentry

Teacher's guide

During this task students will learn about how astronomers discover objects such as planets and asteroids in the night sky with a particular focus on the planet Pluto and the asteroid Apophis. They will use Stellarium, a numeric planetarium, to calculate the velocity of asteroid Apophis and discuss why the Gaia mission is an important step forward in the study of potentially hazardous near Earth objects.

Suitability:

Locating Pluto and Apophis: all 11 – 16 year olds

Calculating the velocity of Apophis: higher ability 14 – 16 year olds, 16 – 18 year olds

Curriculum links:

Astronomy: the discovery of Pluto, near Earth objects, potentially hazardous objects, celestial co-ordinates, distance units in astronomy, the use of planetarium software.

14-16 year old Science/Maths: Pythagoras, standard form, angles, converting between arc seconds, degrees and radians, speed/distance/time.

Prior knowledge:

Some knowledge of the celestial co-ordinate system would be useful before completing the calculations.

Knowledge of radians and angular velocity would be useful in order to fully understand the conversions in the calculations.

Young students with less mathematical knowledges could note down qualitatively how Apophis moves across the sky over time rather than completing all of the calculations.

Additional resources required:

- ICT access. Computers will need to have Stellarium installed. Stellarium is a free planetarium program for multiple operating systems that can be downloaded from this site: <http://www.stellarium.org/>
- A copy of the Apophis blink method pictures will also be required on each computer
- Scientific calculators.
- Printed copies of the Pluto images to hand out to groups for analysis.

Starter/introduction:

Setting the scene:

Slides #1 and #2: Share the aims of the session and ask the students to predict where they think Pluto is in a night sky image from 1930. Ask the students for ideas on how we might go about identifying it.

Main:

- (1) Slide#3: Introduce the work of Clyde Tombaugh and hand out a pair of Pluto images to each group of students. Ask them to try to locate Pluto in the images by looking for an object that has moved between the first and the second picture. Ask the students to feedback about how they have found this task and whether there could be any easier way to do it.

Activity 4 : Gaia, space sentry

Teacher's guide

- (2) Slide #4 : Describe the use of the blink comparator and demonstrate this by blinking the jpeg Pluto images on the board. To do this, load them in windows picture viewer and cycle rapidly between them. The students should easily be able to spot Pluto moving in the images. If they struggle show them the location image with Pluto circled and then repeat the blink activity.
- (3) Slide #5 : Show the image of the original photographic plates used to locate Pluto and play the BBC clip about Tombaugh's work found at this link: http://www.bbc.co.uk/science/space/solarsystem/scientists/clyde_tombaugh#p005y0lq
- (4) Slide #6: Explain that the same method can be used to find other objects such as asteroids.
- (5) Slide #7: Discuss with the students some of the asteroids that have been in the news recently and why it is important that we can track them. For Astronomy students include what is meant by NEOs (near earth objects), PHOs (potentially hazardous objects) and the Torino scale (the method of determining the threat of an impact by comparing its kinetic energy with the probability of impact).
- (6) Slide #8: Introduce the students to asteroid Apophis by giving them the key facts about it. Get them to load the jpeg images of asteroid Apophis into windows picture viewer and locate it using the blink method. Again if they struggle to locate it, show them the location image.
- (7) Slide #9 and #10: Explain how Gaia helped with the quest to better understand the orbit of Apophis.
- (8) Explain to the students that they are now going to use Stellarium to help them find the velocity of Apophis by looking at its changing position over time. Explain that making accurate measurements of the positions of asteroids in order to find more of them and about them is one of the tasks that Gaia will be doing once it is in position.
- (9) Give out the student guide and get the students to complete the calculations.
- (10) Give the students an opportunity to feedback what they have found.

Plenary:

Discussion/debate – what should we do if we discover a large object on a collision course with the Earth? Students can share their ideas on whether we should try to destroy/deflect/evacuate etc. This could be extended into a homework activity.

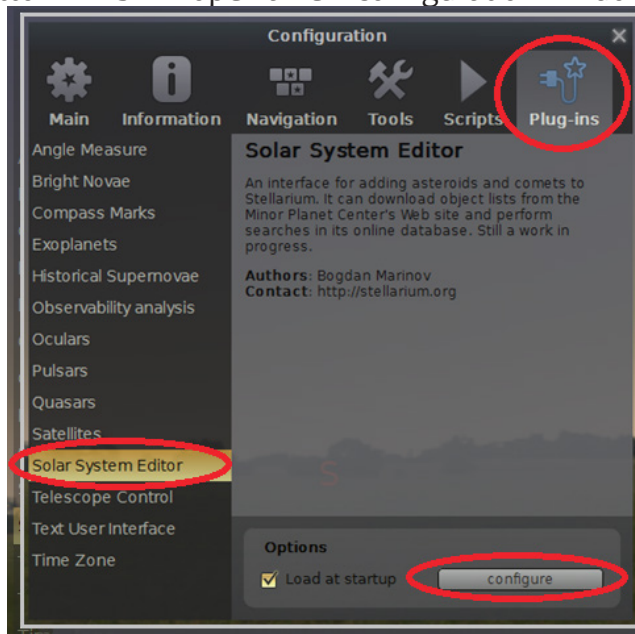
Activity 4 : Gaia, space sentry

Student sheet

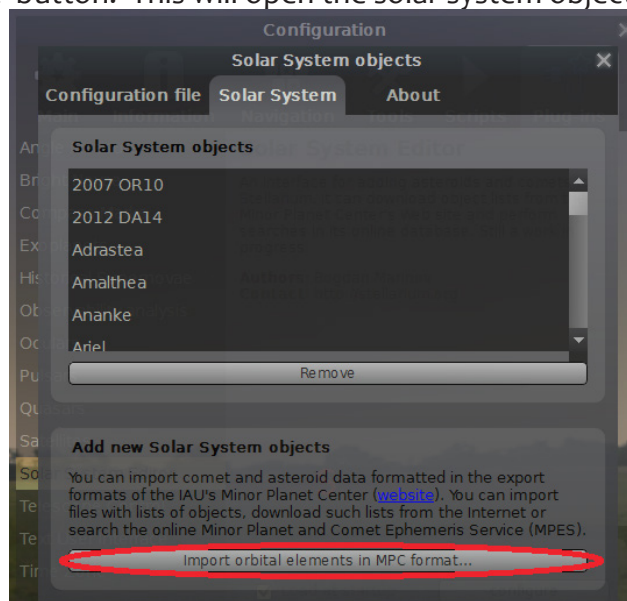
Task 1: adding Apophis to Stellarium

In order to analyse the asteroid Apophis, the data needs to be added to Stellarium.

1. Open the Stellarium program.
2. Press F2 to bring up the configuration window. Select 'Plug-ins' from the top panel.
3. Select 'Solar System Editor' from the left hand side and tick the 'Load at startup' box if it is not already ticked.
4. Press the 'configure' button. This will open a new configuration window.



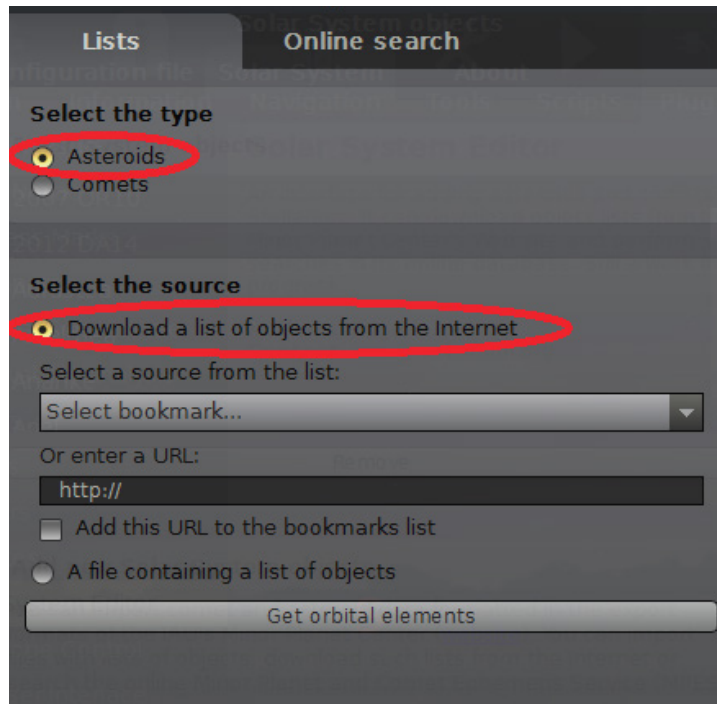
5. Select the 'Solar System' option from the top of the window and then press the 'Import orbital elements in MPC format' button. This will open the solar system objects window.



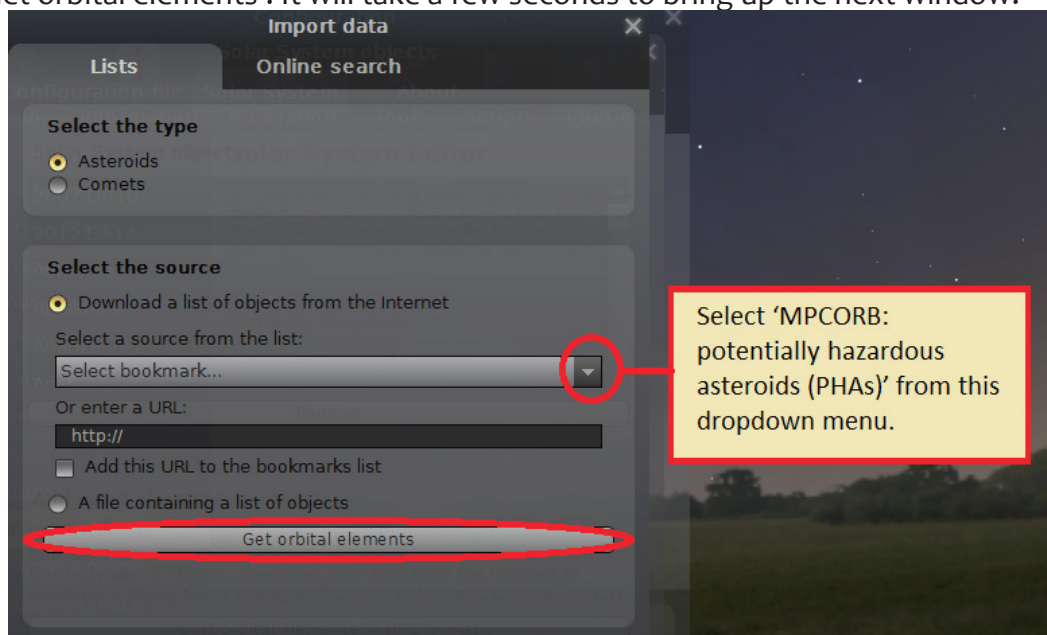
Activity 4 : Gaia, space sentry

Student sheet

6. In the 'Import data' window select type as 'Asteroids' and 'Download a list of objects from the Internet'.



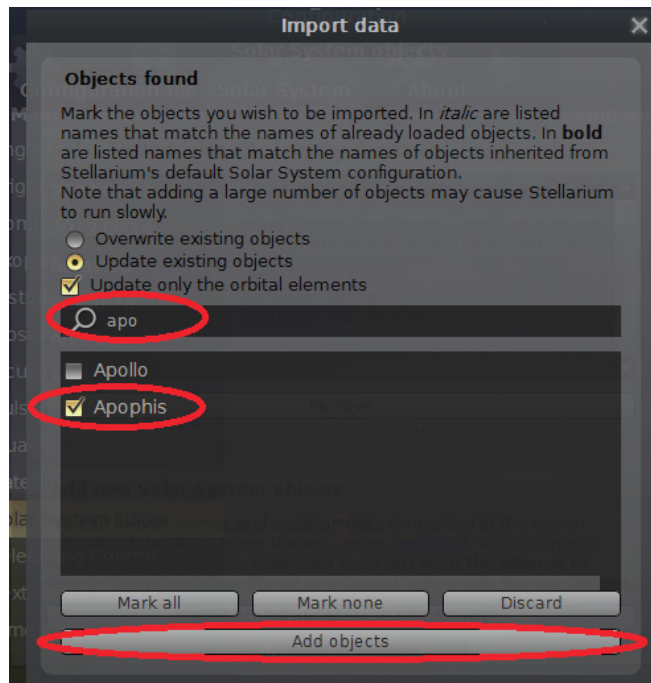
7. From the dropdown menu select 'MPCORB: potentially hazardous asteroids (PHAs)'.
8. Click 'Get orbital elements'. It will take a few seconds to bring up the next window.



9. In the search bar of the 'Import data' window type the first few letters of Apophis. When it has been found put a tick in the box next to it and press the 'Add objects' button. Stellarium may take a few seconds to do this.

Activity 4 : Gaia, space sentry

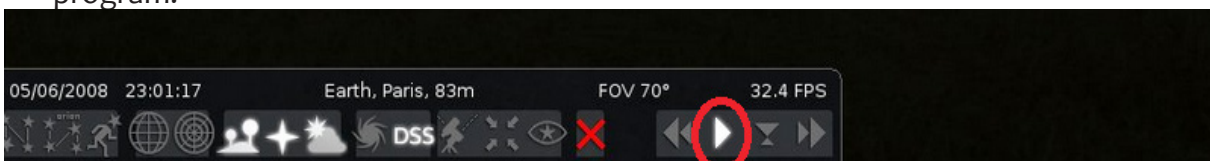
Student sheet



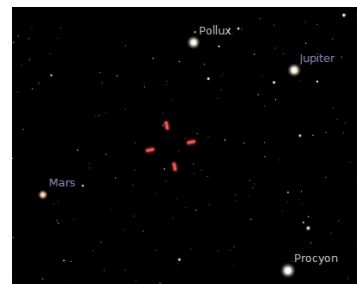
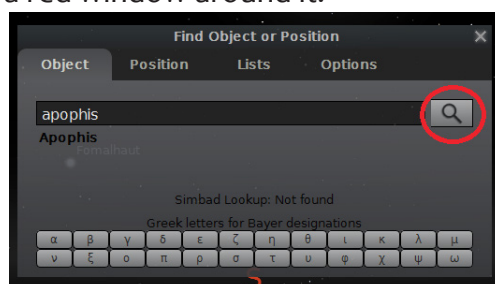
10. Restart stellarium for the changes to take effect. To quit, hold the ctrl button and press Q.

Task 2: calculating the speed of Apophis

1. Open Stellarium.
2. Press 'G' on your keyboard to remove the ground and 'A' to remove the atmosphere.
3. Hover your mouse over the bottom of the screen to bring up the tool bar, press the play button on the right hand side. As it plays, it will turn into a pause button that you can use to pause the program.



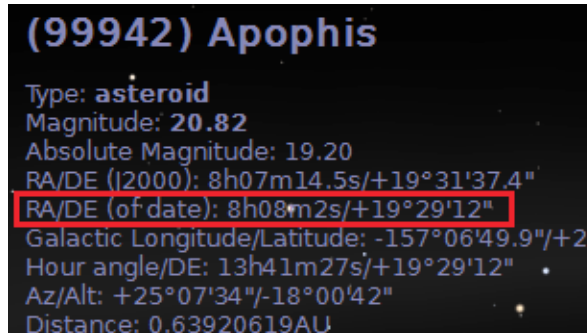
4. Press F3 to bring up the search window, type 'Apopis' and press enter. Apophis should now be centred with a red window around it.



Activity 4 : Gaia, space sentry

Student sheet

5. On the left hand side of the window is some information about Apophis. The line of data to be used is shown in the image below. This is its right ascension (RA) and declination (dec) co-ordinates (for that date).



Note: In the program the declination is represented by DE.

Note: Right ascension is usually measured in hours, minutes, seconds and declination is usually measured in degrees, arc-minutes, arc-seconds.

Since this is the first set of data to be noted, it can be considered as time (T) = 0. Use this information to note down the right ascension (RA) and declination (Dec) of Apophis.

T = 0: RA: ___ h ___ m ___ s Dec: ___ ° ___ ' ___ "

6. Press F5 to bring up the date and time window, use the arrow to move time forward by one hour.

7. Note down the co-ordinates of Apophis again:

T = +1 hour: RA: ___ h ___ m ___ s Dec: ___ ° ___ ' ___ "

8. You will notice a slight change in the position of Apophis compared to an hour earlier, this is due to the speed and direction that Apophis is travelling relative to the Earth.

9. Note down the change in RA in seconds and the change in Dec in arc-seconds ("):

Δ RA _____ sec Δ Dec _____ "

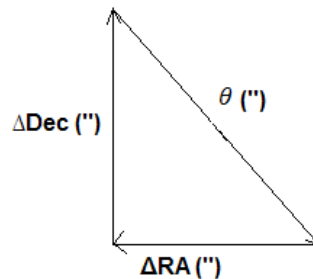
10. To complete the calculation the value Δ RA (change in RA) must be converted from seconds to arc-seconds("). Since the Earth rotates 360 degrees in 24 hours, each hour represents 15 degrees of a circle. To convert from seconds to arc-seconds multiply the value in seconds by 15.

Δ RA(") = Δ RA(sec) x 15 = _____ »

11. Now Pythagoras' theorem can be used to calculate the total angular shift (θ) between the two observing times:

Activity 4 : Gaia, space sentry

Student sheet



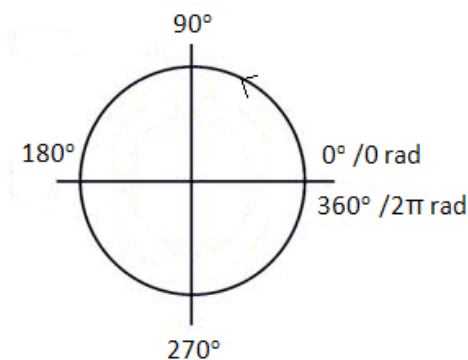
$$\theta = \text{_____}''$$

This is how much the position of Apophis appears to shift over an hour in arc seconds.

12. For the next part of the calculation the angle must be converted to radians. First convert to degrees. Since there are 3600 seconds in an hour, and one hour represents 15 degrees of a full circle this can be done by dividing the value in arc seconds (") by 3600:

$$\theta = \text{_____}^\circ$$

360 degrees = 2π radians, or 1 radian = 57.3 degrees. So to convert from degrees to radians divide by 57.3.



$$\theta = \text{_____} \text{ rad}$$

13. Now that the angular shift is known in radians it is possible to calculate the angular velocity of Apophis. The angular velocity is how fast it appears to move across the sky.

Activity 4 : Gaia, space sentry

Student sheet

$\Delta\theta$ = change in angle (rad)

Δt = change in time (seconds)

The angular change that was calculated above took place over an hour. Convert this to seconds to find Δt :

Δt = _____ sec

Now work out the angular velocity of Apophis:

Angular velocity = _____ rad/s

14. The angular velocity tells us how large an arc angle Apophis covers in the sky per second, but it is more useful to know how fast Apophis is travelling in km/s. To calculate this it is necessary to know how far away Apophis is. The further away it is, the larger a distance it will cover for a given angular change. Go back to Stellarium and look at the information about Apophis on the left hand side. Note down its distance in astronomical units (AU).



Distance to Apophis = _____ AU

One AU is the average distance between the Earth and the Sun. There are 149 597 871 km in an AU. So to convert from AU to km, multiply the value in AU by this number.

Distance to Apophis = _____ km

15. To find the velocity that Apophis is travelling at relative to the Earth the following relationship can be used:

$$\text{velocity (km/s)} = \text{angular velocity (rad/s)} \times \text{distance to Apophis (km)}$$

Velocity of Apophis = _____ km/s

16. The cruising speed of a typical passenger airliner is about 0.25 km/s. How many times faster than this is Apophis travelling?

Activity 5 : Gaia, planet hunter

Teacher's guide

During this activity students will work in small groups to model the transit of an exoplanet in front of its parent star using the “star in a box” and plot a light curve for the transit. Students will also gain an understanding of how Gaia will detect new exoplanets by observing regular reductions in the observed brightness of a star. Some students can calculate the size of their exoplanet from the ratios of brightness and surface area.

Suitability:

Measuring the change in brightness of an exoplanet and drawing the light curve: 12 -16 year olds
Calculating the size of the exoplanet: 12 – 16 year olds.

Curriculum links:

Astronomy/science: Light curves and the transit method.
Maths: Fractions, areas and percentages.

Additional resources required:

For each group

- One “star in a box” with light sensor and torch (check beforehand what the light sensor is measuring)
- Graph paper (one per student)
- Calculators

Teacher will need

- Gaia planet hunter powerpoint

Starter/introduction:

Setting the scene: How many planets are there? Discuss with students how many planets are within our solar system. Are there more planets than those in our solar system? How many stars are in a galaxy? And how many galaxies in the Universe? If only a tiny fraction of these stars have their own planets then that is still a huge number of planets.

Main:

- (1) (Slide #2) Give the definition of an exoplanet.
- (2) (Slide #3) Ask students why it is so difficult to detect planets outside of our solar system. Think about the size of the planets in our solar system compared to our Sun. Now look at the star field and how small the stars appear. A planet crossing the star would not be noticeable to us and that is why we need very sensitive instruments to detect the light variation.
- (3) (Slide #4) Discuss the Gaia mission and the fact that the telescopes on board are incredibly sensitive. Gaia will be mapping the skies in 3D, modelling movements of objects, determining the distances to them and observing tiny regular changes in the brightness of the stars, looking for exoplanets.

Activity 5 : Gaia, planet hunter

Teacher's guide

- (4) So how can we use the light from a star to detect an exoplanet? You may wish to demonstrate the idea by passing an object in front of a light and asking students what they notice about the brightness as it passes in front of the light. (slide #5) Reference the animation on the powerpoint of a transiting planet and emphasise that the change in brightness is very small due to the ratios of the size of the planet and the star. You might prefer to use this simulation: <http://frantzmartinache.eu/index.php/2017/01/16/transit-photometrique/>
- (5) Students can use the “star in a box” model to plot a light curve activity using the transit method. Hand students the worksheets and graph paper. Explain to them exactly what the sensor they are using is measuring (luminosity, flux or something else). See the student sheet.
- (6) Discuss the light curves obtained. You can compare it to the simulator here: <http://frantzmartinache.eu/index.php/2017/01/16/transit-photometrique/>
Were there any obvious sources of error? How could the experiment be improved? Discussion should include the ‘stalk’ of the exoplanet blocking additional light, the LED array not being a true uniform source, the flat disc nature of the model star and reflection of light within the box.
- (7) Calculating the size of the exoplanet:

If we know the size of the parent star is it possible to calculate the size of the exoplanet from the light curve? (Slide #7) Get students to derive an equation for finding the radius of the exoplanet (with step by step help for younger students). See powerpoint for steps.
- (8) Students finally can apply this to their own light curve by measuring the magnitude of the change in brightness from their graph and using the equation they derived. As the teacher, it may be a good idea to estimate this beforehand for the size of exoplanet in the “star in a box” to the size of the torch used.

Further information :

For additional information on how Gaia will be able to find exoplanets using the transit method, as well as information on other methods of detecting exoplanets, go to ESA's “little books of Gaia search for planets” page at this link:

http://esamultimedia.esa.int/docs/edu/LittleBooksGaia/English_the_search_for_planets.pdf

This, and all of the other little books of Gaia are designed so that they can be printed out and folded for students to reference as a small book of information.

The citizen science project “planet hunters” allows students to not only have access to a huge number of light curves for potential exoplanet systems, but it also allows them to actively contribute to research by analysing these curves and looking for exoplanets. Several members of the public have already discovered exoplanets and been referenced in scientific papers.

<http://www.planethunters.org/>

Activity 5 : Gaia, planet hunter

Student sheet

This activity is related to the model built from instructions “star in a box”. It may be realised with another model reproducing a planet orbiting a star whose brightness can be measured. In this activity you are going to record the amount of light being detected from a distant star as a planet transits in front of it. The circle on the bottom of the box can be turned to move the planet inside across the star. Each division marked on the circle represents 10 days.

Task 1 :

1. Turn the torch at the end of the box on.
2. Turn the light sensor on (or make sure it is connected to your data logger/computer).
3. Check that you are getting a reading from the light sensor (you may have to wait a minute for it to stabilise).

What units is your light sensor measuring in?

My light sensor is measuring in _____

4. Fill the units in to the top row of the table
5. Make sure that the turning circle is set so that the first reading point (number 1) is lined up with the left corner of the box.
6. Record the lux/brightness reading in the table.
7. Turn the circle gently while disturbing the box as little as possible to the next reading point and note your reading in the table.
8. Repeat this procedure until you have reached the last recording point.
9. If you have time, repeat the experiment and take an average of your results.

Table :

Reading number	Brightness ()	Brightness ()	Average Brightness ()

Activity 5 : Gaia, planet hunter

Student sheet

Task 2:

On graph paper, draw a graph of average brightness against time. Remember that each division was equal to 10 days of time. Time should go on the x axis and brightness on the y axis.

Task 3:

1. You are now going to calculate the percentage drop in brightness. To do this first we need to note the original brightness of the star.

Original brightness = _____

2. Then we need to note the lowest brightness of the star as the planet passed across it.

Lowest brightness = _____

3. Use these figures to calculate by what percentage the brightness dropped.

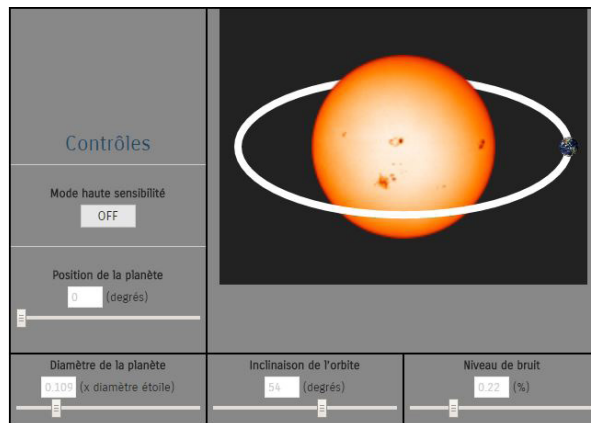
The brightness dropped by _____%

Activity 5 : Gaia, planet hunter

Student sheet

Task 4:

Go on the following website: <http://frantzmartinache.eu/index.php/2017/01/16/transit-photometrique/>



You can simulate brightness variations from a star when a planet passes in front of it. Change the parameters and note what happens:

- Planet diameter
- Planet position (on its orbit)
- Orbit inclination
- Noise level. What we call “noise” is an unwanted signal generated by captors. There is always noise in experiments.

1. Are your results from the experiment similar to your results from simulations? Is this a good model for the transit of a planet in front of a star? Explain your answer.
2. What errors could be affecting the results?
3. So far the majority of the exoplanets we have found have been very big. Can you think of a reason for this?

Activity 5 : Gaia, planet hunter

Instructions : «Star in a box»

These instructions describe how to construct a star in a box which will allow students to plot light curves for a simulated exoplanet around a distant star without the need to black out the room. This set up allows existing light sensors or data loggers to be used and can easily be customised for any shape or make of light sensor. The instructions also detail how to adapt the set up to allow students to investigate the inverse square nature of light.



Equipment needed (per set up):

- One large sheet of thick black card (it is fine if it is only black on one side)
- One torch or circular LED light array approximately 5cm in diameter
- One light sensor/luxmeter
- One cardboard box big enough to cut two 8 cm radius circles from
- Cocktail stick, wooden skewer or thick wire to mount the exoplanet on
- Modelling clay/small polystyrene ball to act as an exoplanet
- A split pin
- A pair of compasses
- Ruler
- Pencil
- Craft knife
- Glue gun or epoxy
- Black material
- Protractor
- A copy of the star in a box template sheet

Method:

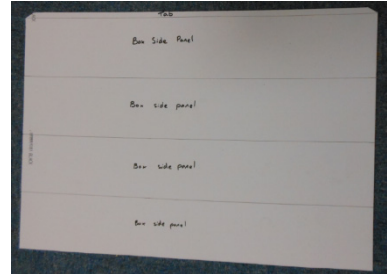
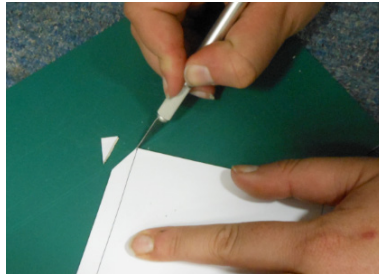
Using the star in a box template as a guide, draw out the components necessary on the thick black card.

Preparing the box:

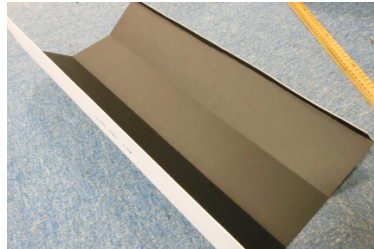
1. Using a craft knife and ruler, cut around the outside of the 4 side panel sections and tab being careful not to cut the individual panels out.

Activity 5 : Gaia, planet hunter

Instructions : «Star in a box»



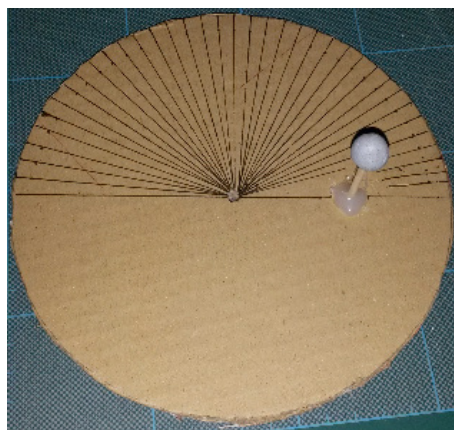
2. Using a craft knife and ruler, carefully score along the lines between each side panel as well as the tab join. Gently bend along the scored lines. Make sure that the black side of the card is facing inwards.



3. The next step is to prepare the revolving plate for the exoplanet to be mounted on. On thick card (a corrugated cardboard box is ideal for this), use the pair of compasses and a pencil to draw out 2 circles of radius 8cm and use a pin to push all the way through the card at the centre of the circle. Carefully cut both circles out with a craft knife. Glue the two circles together forming one thick circle and make sure that a pin can pass all the way through the centre of both layers.

4. Draw a line across the circle that passes through the centre splitting it into two 180° halves. Use a protractor and ruler to split one of the halves into 5° sections.

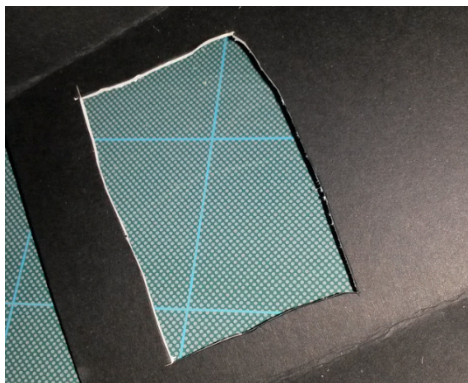
5. To make the exoplanet, cut a cocktail stick or wooden skewer a length of 6cm. Attach a modelling clay or polystyrene ball to the top of the flat end. Take the pointed end and choose a point on the centre line that is far enough away from the centre so as to allow the exoplanet to end up next to the torch. Use a glue gun or epoxy to further secure the exoplanet in place.



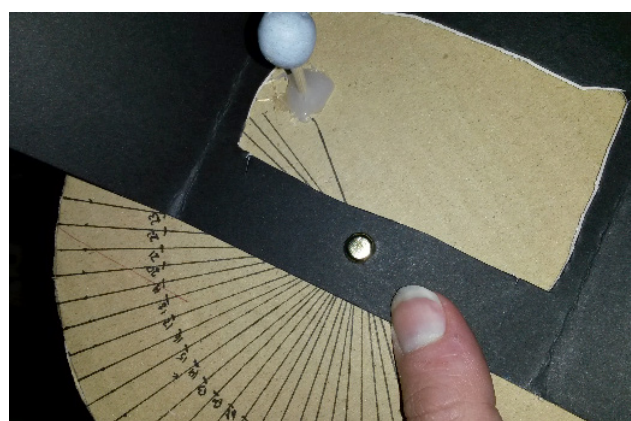
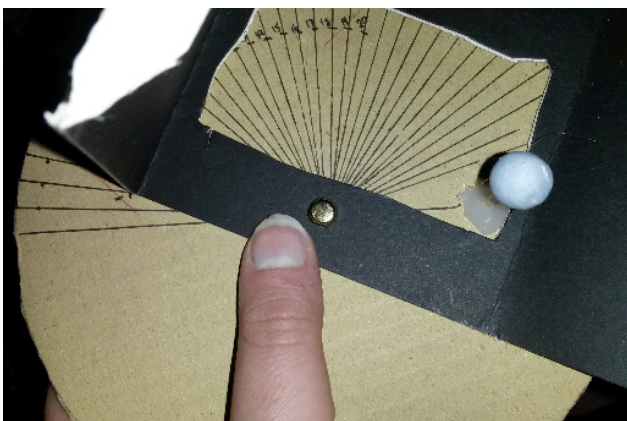
Activity 5 : Gaia, planet hunter

Instructions : «Star in a box»

6. The circle will be pinned into place underneath the box using a split pin. Using a craft knife, carefully cut a section of the bottom of the box out so that the exoplanet will be able to orbit freely in front of the light. It is also important to make sure that the circle will be pinned as close to the front of the light as possible. Feed the exoplanet up through the cut out section, making with the 5° ruled section at the back of the box. Use a split pin to secure the circle to the bottom of the box.



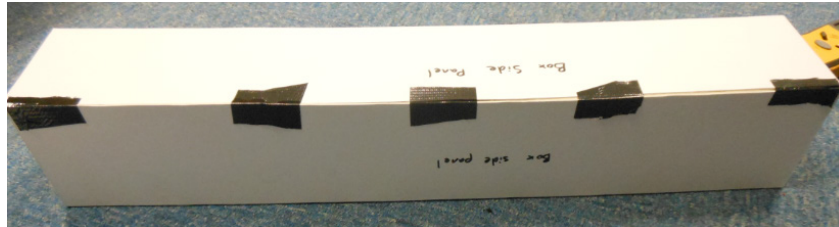
7. Move the exoplanet so that it is as far to the right as it can go. Mark the point where the corner of the box intersects one of the ruled lines on the circle and label this 1. This will be the first position that will be measured. Turn the circle through 5° and again mark where the corner of the box intersects the line and mark this as 2 – the second measurement position. Repeat this process until the exoplanet has fully transited in front of the light and is touching the other side. This mark corresponds to the final reading to be taken.



8. The rectangular tube is now ready to be glued. With a glue gun or epoxy, carefully glue the tab in place to form a tube, making sure that the black side of the card is facing inwards. If necessary, use tape to hold it in place while it dries.

Activity 5 : Gaia, planet hunter

Instructions : «Star in a box»



Building the light mount:

The light mount will slot into one end of the box. It is designed to be removable so that you can easily access the battery compartment and swap the torch for a point source if you chose to use the equipment for an inverse square law experiment.

1. Now build the light mount. With a craft knife and ruler cut out the light mount shape from the card.
2. Carefully score along the dotted lines and bend along the score lines to form a cap that will fit into the rectangular box. Again, make sure that the black side is facing inwards.
3. Carefully draw around the light that will be used as a star making sure that the centre of the light will be at the centre of the square and with a craft knife, cut this shape out.
4. To give the star mount cap more strength, cut 4 small 4cm strips of card about the same width as the tabs, and score them in the middle to form corner joints. Using a glue gun or epoxy glue these in place in the corners of the light mount.
5. Insert the torch into the cut out section, making sure that the on button will be on the outside.



Building the sensor mount:

1. With a craft knife and ruler cut out the sensor mount shape from the card.
2. Carefully score along the dotted lines and bend along the score lines to form a cap that will fit into the rectangular box. Again, make sure that the black side is facing inwards.
3. Carefully draw around the light sensor that will be used, making sure that the centre of the sensor is in the centre of the square and with a craft knife, cut this shape out.

Activity 5 : Gaia, planet hunter

Instructions : «Star in a box»

4. To give the sensor mount cap more strength, cut 4 small 4cm strips of card about the same width as the tabs, and score them in the middle to form corner joints. Using a glue gun or epoxy glue these in place in the corners of the light mount.

5. Insert the sensor into the cut out section. Depending on the type of sensor you may need to add extra support to the outside of the mount to keep it aligned with the centre of the star.



Final assembly:

The star in a box is now ready to be slotted together. Carefully push the light mount into the end of the tube that has the exoplanet. In the opposite end, push in the sensor mount. If you do not intend to use the box for an inverse square law investigation you can glue the mounts in place and use thick black tape to cover along the seals making the box as light tight as possible. If you do intend to use the box for an inverse square law investigation as well, then simply use some black cloth to cover any gaps.



Additional use – inverse square law investigation:

This equipment is very easy to alter for an inverse square law of light investigation. It will however require the construction of a few extra components.

Point source mount:

In order to get as close to an inverse square relationship as possible, the light source needs to be as close to a small point source as possible. This can be achieved by making a cover for the torch with a small hole in to allow a pinpoint of light through. Alternatively, you can make a separate pinhole mount.

Activity 5 : Gaia, planet hunter

Instructions : «Star in a box»

Note – this inverse square law experiment will only work with sensors that have a lead and as such can be placed at least half a metre from the device that displays the reading.

Building the pinhole mount:

1. With a craft knife and ruler cut out the pinhole mount shape from the card.
2. Carefully score along the dotted lines and bend along the score lines to form a cap that will fit into the rectangular box. Again, make sure that the black side is facing inwards.
3. Using a needle or the point of a very sharp knife make a small hole in the centre of the square.
4. To give the pinhole mount cap more strength, cut 4 small 4cm strips of card about the same width as the tabs, and score them in the middle to form corner joints. Using a glue gun or epoxy glue these in place in the corners of the pinhole mount.
5. Now a light source can be placed behind the mount and the pinhole will act as a point source. A torch with a single LED works best for this.

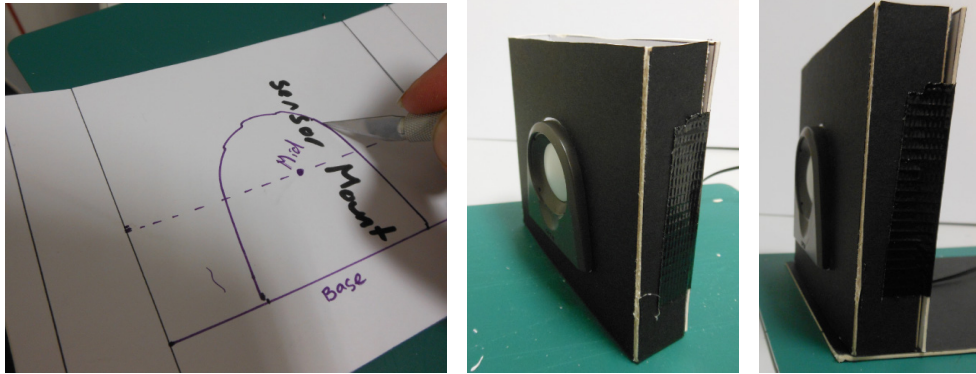
Building a moveable mount system for the sensor

In order to investigate the inverse square law of light, the sensor will have to be able to move within the box.

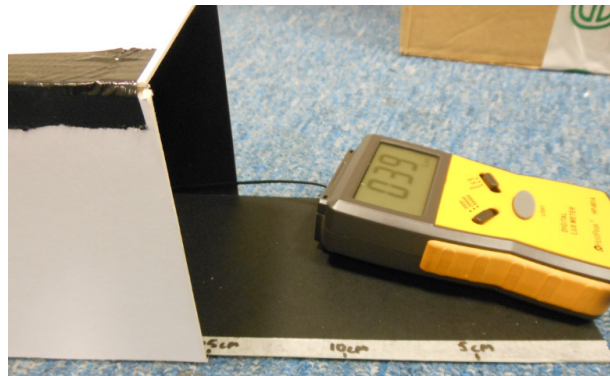
1. Cut out the sensor base from the card with a craft knife and ruler. This base is sized to be slightly less wide than the box.
2. With a craft knife and ruler cut out the “sensor mount (inverse square law)” and carefully score along the tabs. Depending on your light sensor you may want to alter the depth of the mount to increase stability.
3. Position your sensor so that it is in the middle of one of the squares on the mount and draw around it. Repeat this with the other square and using a craft knife carefully cut out the shape.
4. Fold the box together with the black side pointing outwards and slide your sensor through the gap. If necessary it can be firmly secured in place with tape.
5. Take the sensor base and lay it out with the black side facing up. Glue the sensor mount on to the base, lining up the front of the mount with the front edge of the base.

Activity 5 : Gaia, planet hunter

Instructions : «Star in a box»



6. The base will need to have a reference on for distance from the star. Lay the base with the sensor at the front along the top of the star box. Measure a distance of 10cm from the end of the star box and place the front of the sensor at this point. Holding the base in place, mark on the other end of the base where it first overhangs the other end of the box. Make a mark here and label it 10cm. This means that when you pull the base out to this point, the sensor will be 10cm from the light source. Repeat this procedure for 5cm increments of distance from the front of the box.



7. Remove the original sensor mount from the box and carefully slide the base with sensor into the box until the 10cm mark is reached. Since this sensor mount is purposefully designed to be slightly smaller than the box it will be necessary to place black material over the open end to reduce unwanted light interfering with readings.

Activity 6 : Spectrum of light, from bulbs to stars

Teacher's guide

The objective of this activity is to understand how the spectrum of a star can give us information about its characteristics. This is the way used by Gaia to determine the temperature and composition of the observed objects.

The students will observe the spectrum of different light sources. They will work, afterwards, with the stellar spectra. The second part of this activity is to identify the chemical elements present in the Sun using its spectrum.

Suitability:

Light bulbs and stellar spectra: 12-18 year olds.

Solar spectra: 14-18 year olds

Curriculum links:

Light, spectroscopy, chemical elements analysis

Prior knowledge:

Knowledge of the chemical elements to better understand the solar spectrum

Material:

- A spectroscope for each student group, that will be used in turns by all members of the group. A guide to build your own spectroscope with a CD or a DVD is given in “*Building a simple spectroscope*”
- Two light bulbs: one with an incandescent filament and the second one, an energy-efficient light bulb.

Introduction:

Remind the concept of light dispersion to the students. If you have a prism or an object that allows to disperse light (as the edge of a plastic ruler), you can use this to show the students a “rainbow” as introduction.

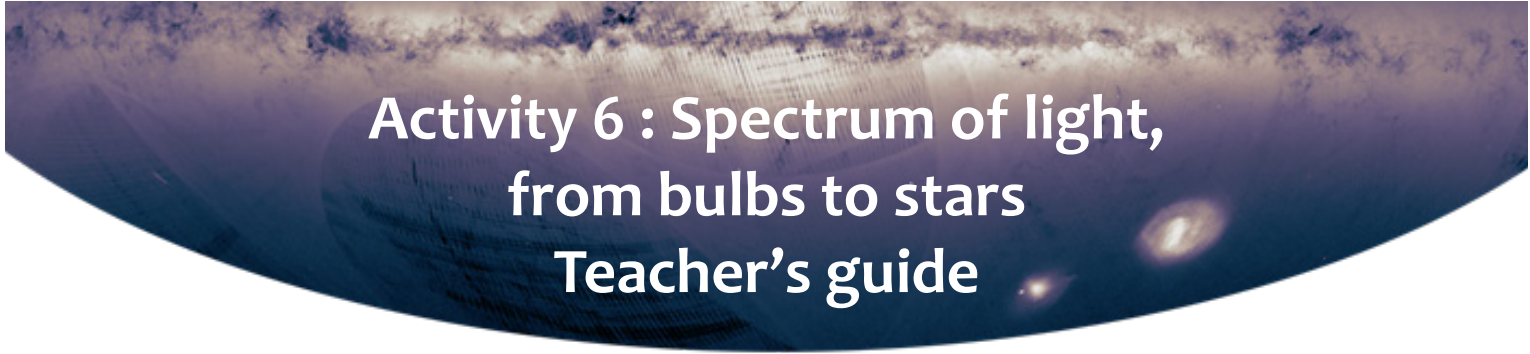
Activity 1. The spectra of light bulbs

The students should observe both light bulbs with the spectroscope. With the help of the questions in the student sheet they will understand the difference between a polychromatic continuum spectrum, a polychromatic discontinuous spectrum and a monochromatic spectrum

Activity 2. The colour of stars

The students must understand the passage from a 2-dimensional spectrum coming directly from the dispersion of light (what they have just observed), to a 1-dimensional spectrum. This is a plot showing in the x-axis the wavelength and in the y-axis the flux in each wavelength. To be precise in the study of the different spectral lines (absorption or emission) the plots of the 1-dimensional spectrum should be studied. We will do such in the following steps.

This activity evokes Wien's law: the relation between the wavelength of the maximum emission of a body and its temperature.



Activity 6 : Spectrum of light, from bulbs to stars Teacher's guide

Activity 3. Emission spectrum of a nebula

Nebulae have emission spectra, like those of the energy-efficient light bulbs. There is not a continuum source behind the gas, so we can only see the emission coming from the different excited atoms.

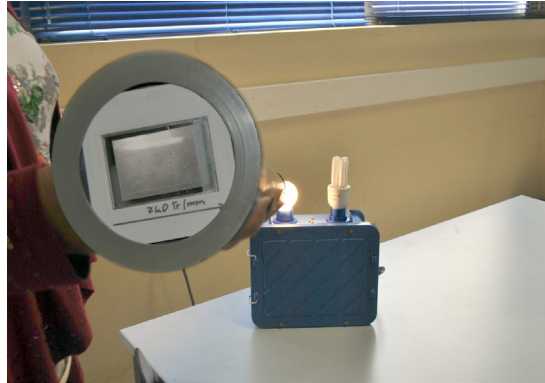
Activity 4. Element identification in the solar atmosphere

The study of the solar spectrum allows us to find the chemical elements responsible for the absorption lines observed in the solar spectrum, and thus, in the solar atmosphere.

A molecule (O_2) is also present in the spectrum. It is due to the contamination of the solar spectrum received at the Earth surface by the Earth's atmosphere. Discuss with the students about the problem of the spectroscopy from the Earth, and the advantage of satellites as Gaia to be free from the atmosphere.

Activity 6 : Spectrum of light, from bulbs to stars

Student sheet

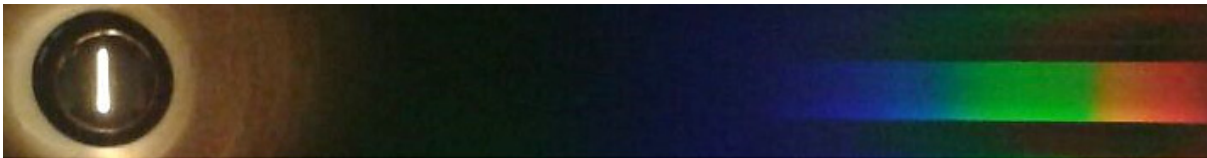


Activity 1. Experience with the light bulbs

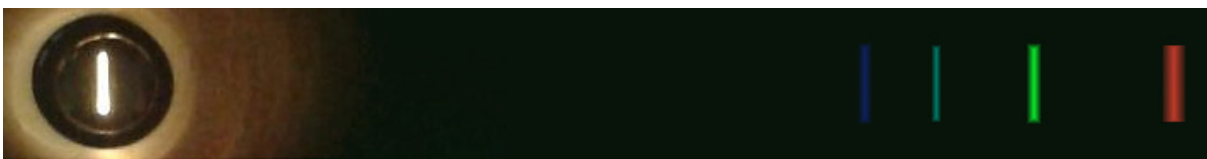
1) Look at the light bulbs through the spectroscope. Do not hesitate to put the spectroscope very close to the bulb to see the spectrum. If you wear glasses, remove them before observing.

What do you observe?

Do you see a continuous rainbow?



Or lines in different colours?





Results of observations: light spectra




Looking at the spectra given below, and using your observations, specify which spectrum corresponds to the filament bulb and which corresponds to the energy-efficient light bulb.

Activity 6 : Spectrum of light, from bulbs to stars

Student sheet

	 <p>Spectre polychromatique continu</p>
	 <p>Spectre polychromatique discontinu</p>

If your spectroscope allows you to observe the Sun precisely (do not forget NEVER to watch the Sun directly), can you identify which one of the following spectra corresponds to the Sun's? If you cannot perform directly this observation, search, using the Internet, a solar spectrum and identify it between those below.

	 <p>Spectre polychromatique continu</p>
	 <p>Spectre polychromatique continu avec raies d'absorption</p>
	 <p>Spectre polychromatique discontinu</p>

Spectre du laser

Using your previous answers, indicate if a laser spectrum is polychromatic or monochromatic. Then complete the white rectangle by drawing the spectrum of a red laser.

	<div style="border: 1px solid black; width: 100%; height: 20px; background-color: white; margin-bottom: 5px;"></div> <p>Spectre _____</p>
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Activity 6 : Spectrum of light, from bulbs to stars

Student sheet

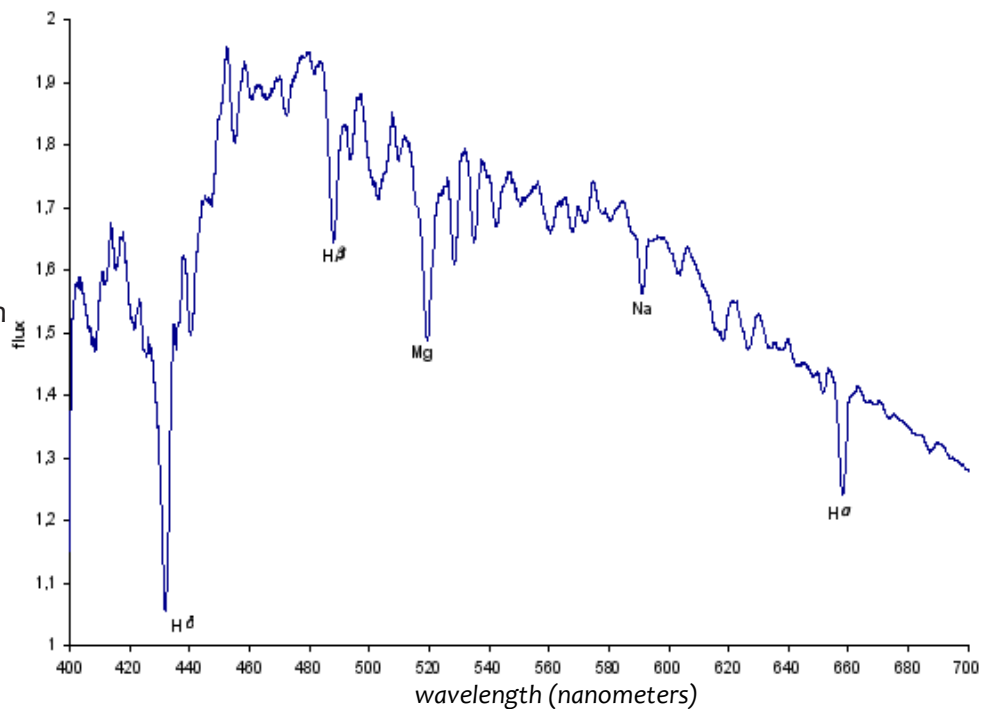
Activity 2. Characterization of stars: the color of stars

The spectra, as those that you have just observed, can be represented in a plot tracing, for each colour (wavelength) the quantity of light that we receive from this colour (flux).

Spectrum



Plot associated
with the spectrum



On the above graph, there are deep lines corresponding to the black absorption lines seen in the light spectrum. This plot allows us to measure the amount of light received (flux) for each color (wavelength). It also allows us to see in which color range the emission is stronger (in this case it is on the blue, around 460nm).

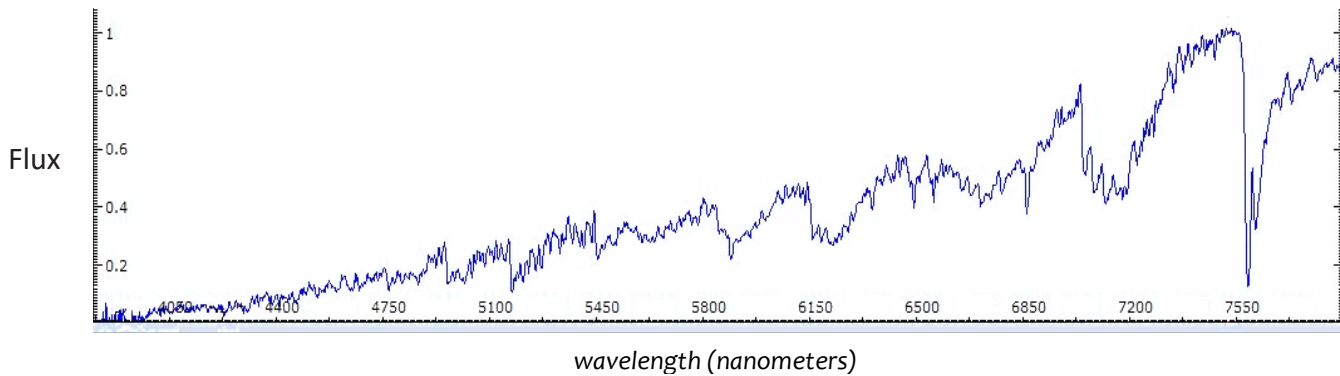
If our light source is blue, we will have more emission in the lower wavelength values.
If it is red, the emission will be stronger in the larger wavelength values.

Activity 6 : Spectrum of light, from bulbs to stars

Student sheet

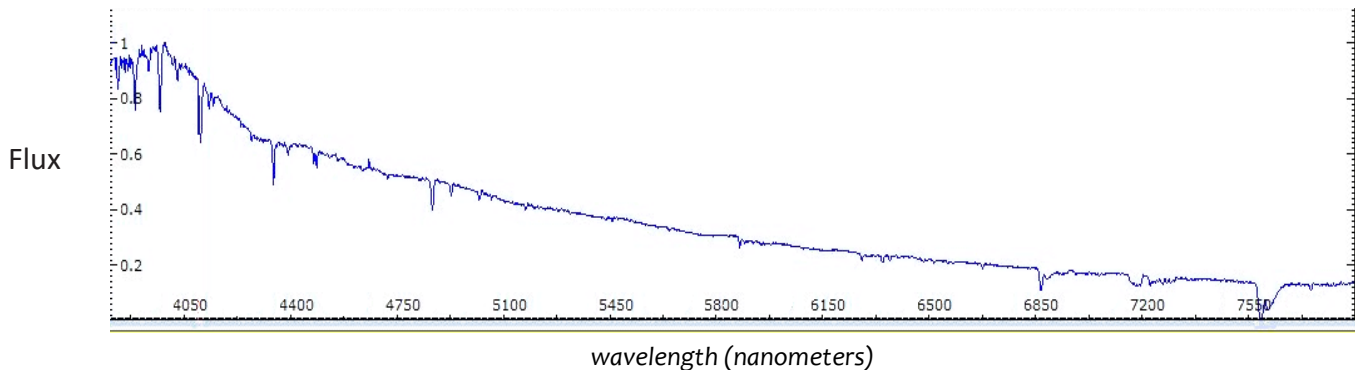
We can determine the color of the stars by plotting their spectra.
Below are the plots of the spectrum of two stars that have been observed.

GRAPHIQUE DU SPECTRE N°1



For which wavelengths do we get the maximum flux? _____
Does it correspond to red or blue colors? _____

GRAPHIQUE DU SPECTRE N°2

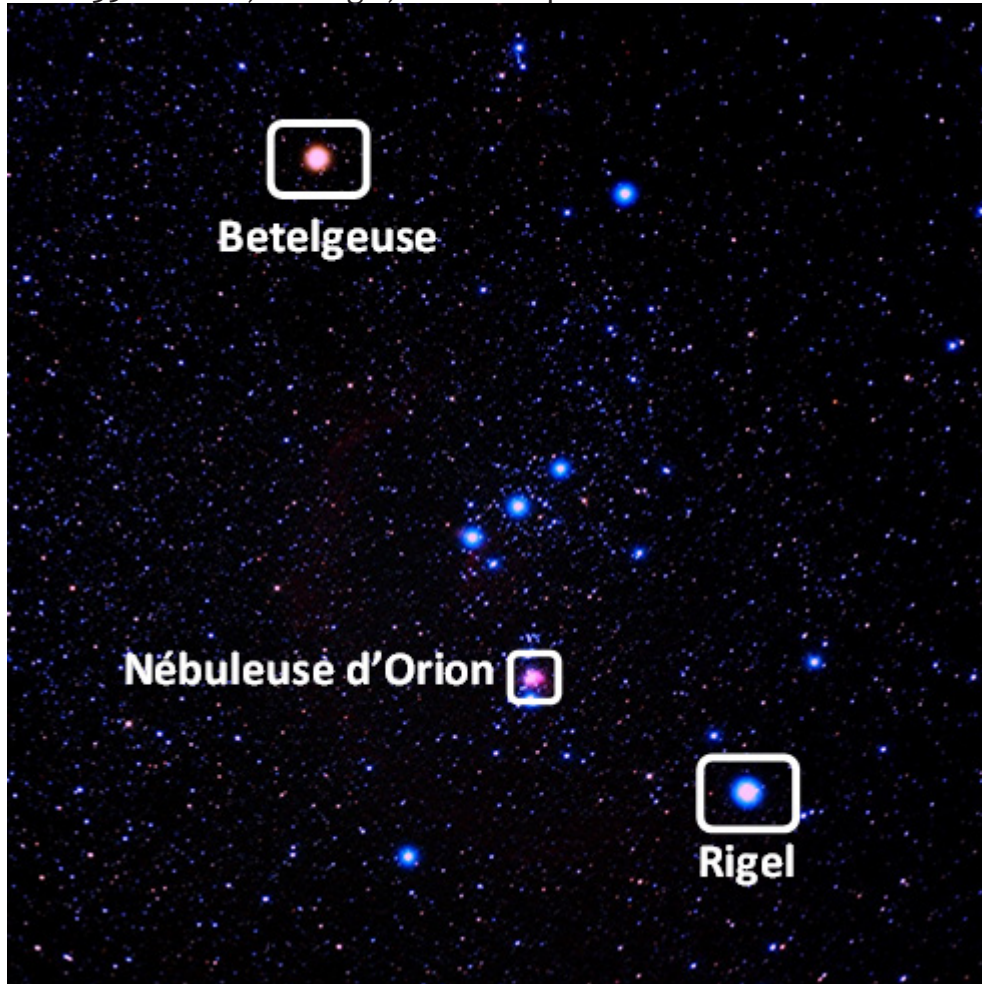


For this spectrum, in which wavelength is the maximum emission and what color does it correspond to?

Activity 6 : Spectrum of light, from bulbs to stars

Student sheet

The image below shows the Orion constellation. The two brighter stars are Betelgeuse, which has a temperature of 3500 Kelvin, and Rigel, with a temperature of 11000 Kelvin.



Which one of the two graphs of the previous page (graph 1 or graph 2) corresponds to Betelgeuse?

And to Rigel?

Color and temperature

What can you deduce about the temperature and the color of the stars? How are they linked?

Hot stars are colored _____

Cold stars are colored _____

Activity 6 : Spectrum of light, from bulbs to stars Student sheet

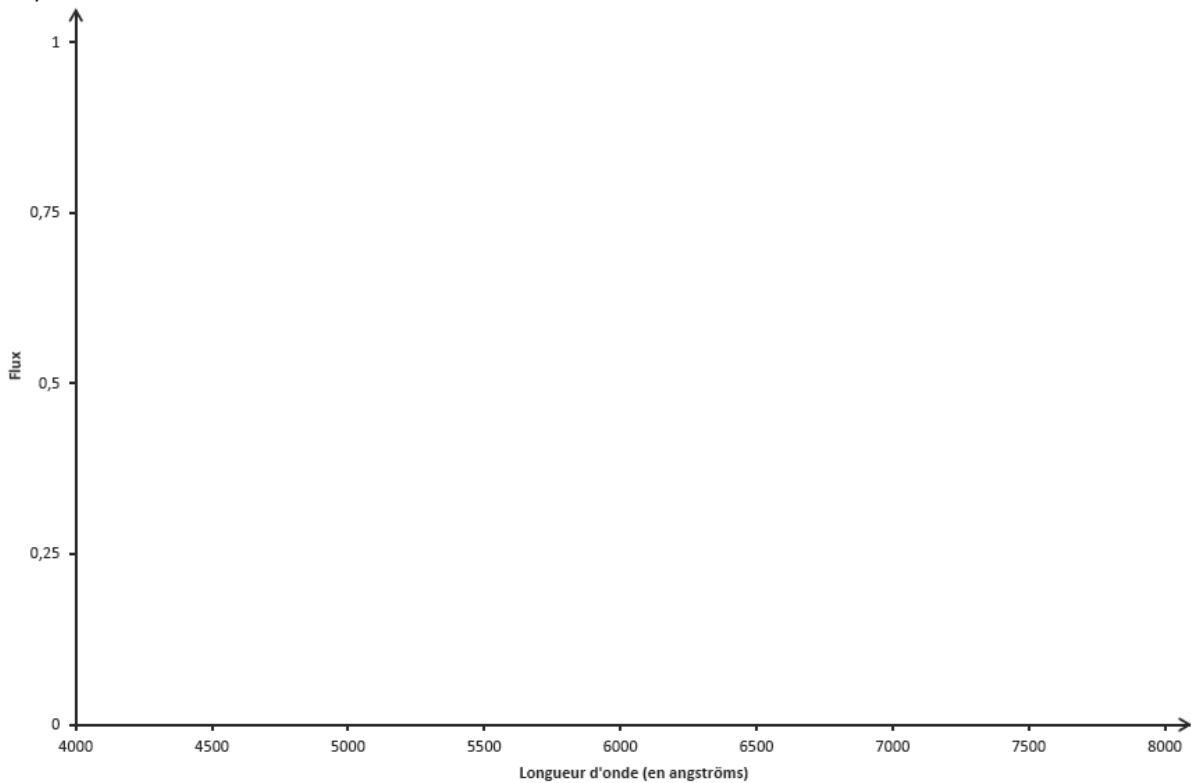
Emission spectrum of a nebula

If, instead of observing a star, we observe a nebula, we will be in the same case as the energy-efficient bulb, with “excited” gas emitting light corresponding to its chemical elements.

Can you draw the pattern of the graph associated with the emission spectrum, knowing that there are three emission lines :

1) The first is the line of Hydrogen at 6563 Angstroms, its flux is maximal

2) The two others are those of Oxygen at 4954 and 5007 Angstroms, their fluxes are respectively $\frac{1}{3}$ and $\frac{1}{2}$.



Spectre de la Nébuleuse d'Orion

Activity 6 : Spectrum of light, from bulbs to stars

Student sheet

Activity 4. Determine the chemical composition of the Sun from its spectrum

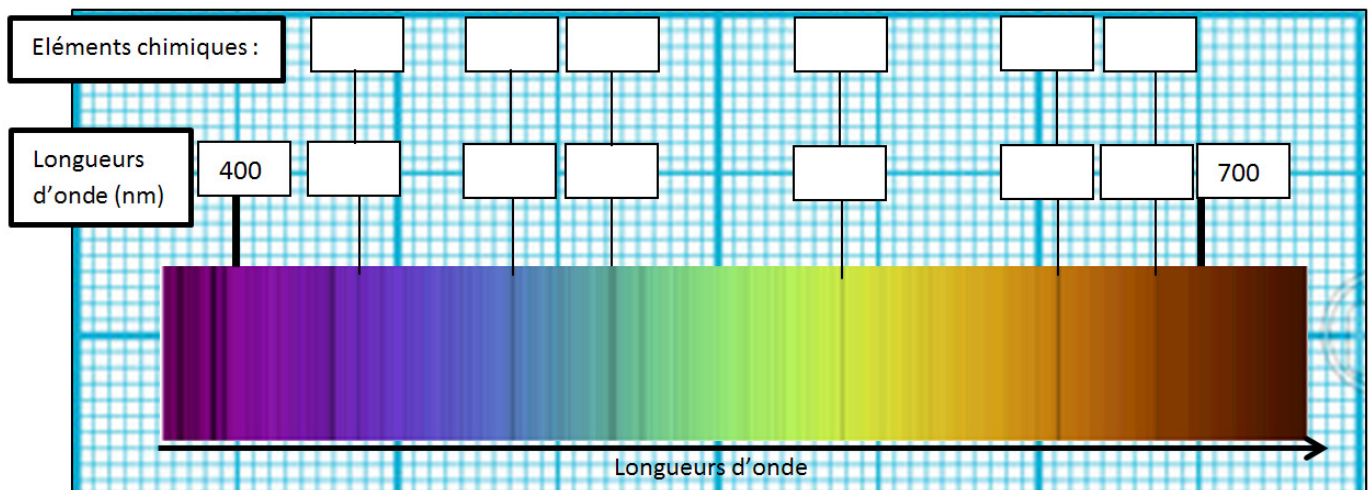
Observation of the solar spectrum with a spectroscope

As indicated in the activity 2, the solar spectrum is a polychromatic spectrum avec absorption lines. These lines are due to the chemical elements present in the solar atmosphere. If the Sun had a different atmospheric composition, we would find different lines in its spectrum.

The most visible lines in the solar spectrum correspond to the following elements:

H (Hydrogen), Na (Sodium), Mg (Magnesium), Ca (Calcium), Ti (Titanium), Fe (Iron), and atmospheric O₂ (Oxygen).

1. Identify the wavelength corresponding to each absorption line marked in the spectrum.
2. Identify the chemical elements present in the spectrum with the help of the table below.



CHEMICAL ELEMENTS	Wavelengths in nm
H (Hydrogen)	388, 397, 410, 486, 656
Na (Sodium)	589
Mg (Magnesium)	309, 470, 517
Ca (Calcium)	422, 458, 526, 616
Cr (Chromium)	464
Ti (Titane)	466, 498
Fe (Fer)	389, 404, 426, 438, 452, 459, 536
Mn (Manganese)	402, 403
Ni (Nickel)	508, 509
O ₂ (Oxygen in that atmosphere)	686

Activity 6 : Spectrum of light, from bulbs to stars

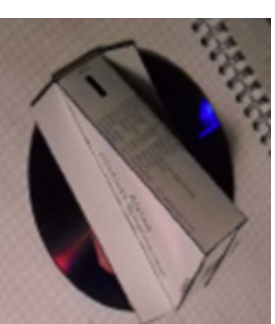
Manufacturing of the spectroscop

In 10 min we will build a simple spectroscope

INSTRUCTIONS

- Stick the white sheet with the pattern of the spectro on a black canson sheet in order to make it rigid
- cut along the black full lines with scissors
- with a cutter hollow the 2 rectangles with a cross
- with a pen and a ruler, overlay strongly through the dash lines (it will be easier to fold paper afterwards)
- Fold the paper following the model
- Put Glue or scotch on the flaps noted to paste
- Put a CD or DVD below as in the photo

Now you are ready to observe by placing your eye at the black circle and directing the other slot in the direction of a light source.



Activity 7 : Gaia's L2 orbit

Teacher's guide

During this task students will use the context of Gaia's orbit at the L2 Lagrangian point to explore the nature of orbits. Through a combination of revising the basics of gravity, and a hands on practical involving simulating orbits and observing their properties using gravity wells, students will gain a good overview of the basics of orbital mechanics and the unique nature of the L2 Lagrange point. This activity can also be extended to older students with more in depth mathematical modelling of the L2 scenario.

Suitability:

13 – 16 year old, extendable to post 16

Curriculum links:

Pre 16 Science: gravity, orbital period, Kepler's laws

Post 16 Science: Newton's law of gravitation, circular motion, angular velocity, centripetal acceleration

Prior knowledge:

Pre 16: A basic knowledge of gravity is useful but not vital

Post 16: Gravitational field theory equations, equations of circular motion

- Additional resources required:
- A computer to show the GAIA video (you need to register in .mp4 or .mov or directly watch on the ESA website if you have internet access).
- Prior to this session the gravity wells will need to be constructed:
<https://www.youtube.com/watch?v=-nSohIHtOyM>
<https://www.youtube.com/watch?v=WRrj3CTfPm8>
- For post 16: Scientific calculators.

Differentiation:

For post 16 you may wish to remove the slides giving the basic equations and set this as an open challenge for students to work on.

Introduction:

Slides #1 and #2 : Start with an introduction to Gaia. This link http://spaceinvideos.esa.int/Videos/2013/06/Gaia_scanning_the_sky gives a great overview of the mission.

Main:

(1) Slides #3 – #6: GRAVITY – Gravitational Force

Why do things orbit? The key is gravity and tangential velocity. When the two are just right, the resultant curving of the path will match the curve necessary for orbit.

The slides do contain Newton's law of gravitation which you may wish to remove for younger students, however analysis of it even on a simple level is very powerful – since the force of

Activity 7 : Gaia's L2 Orbit

Teacher's guide

attraction will only drop to zero an infinite distance away, every piece of matter affects every other piece of matter gravitationally. Although, as you can see it in the slide N°6 with the two students sat at a table, this is usually only by a very small amount. While everything with mass exerts a gravitational force on everything else with mass, the force of gravity is actually very weak.

Force of attraction due to gravity approximately $1/10\ 000\ 000\ \text{N}$

(2) Task 1:

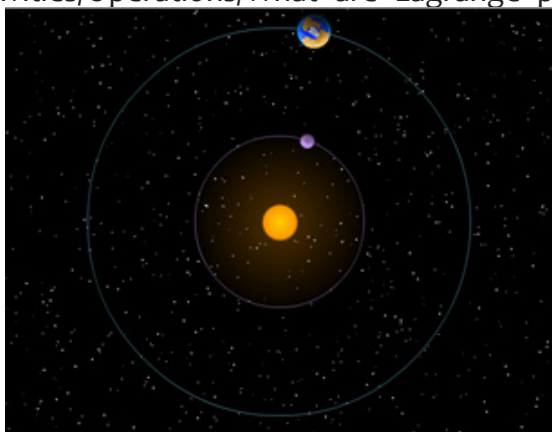
You can calculate the weight of the students, the gravitational force between the two students and compare it to the gravitational force between the sun and the earth or the earth and the moon.

The effect of gravity can be noted when massive objects like planets are involved.

(3) Slides #7 – #13: the Orbits

Show video from an orbit

[http://www.esa.int/Our_Activities/Operations/What are Lagrange points](http://www.esa.int/Our_Activities/Operations/What_are_Lagrange_points)



Earth and a spacecraft orbiting the Sun

The satellite rotates faster around the Sun than the Earth. The 2 objects are not «synchronized» and aligned with the Sun

(4) Practical – determining the link between orbital distance and periods using gravity wells.

(5) Task 2:

Experiment to be realized: manufacture of the well of gravity

(Health and safety note: students should wear goggles when conducting this practical).

Pulling down the material simulates a star. To represent a higher mass star you should pull it down further.

The marble will travel along a path determined by its velocity and the attraction to the star.

Give the marble (your planet) a tangential velocity.

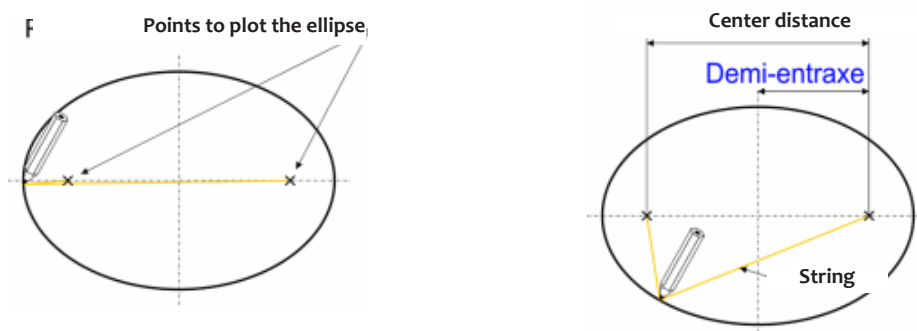
MAKE A REVIEW of this practical simulation: What did the students discover? Make them also think about the fact that the observed orbital are elliptical.

Activity 7 : Gaia's L2 Orbit Teacher's guide

(5) Task 3:

Draw an ellipse with a pencil and a string:

- Place two points on the longest axis of the ellipse, each at an equal distance from the center, after determining their positions with the tool below.
- Take a string a little longer than the long axis.
- Tie this string to the previously placed points (materialized by two tacks) without stretching it. The length of the twine between the two points must be equal to the major axis
- Then take a pencil, place it in such a way as to tighten the string as in the drawing opposite
- Drag it while keeping the string taut to draw the ellipse



Using slide 12 an extension to Kepler's 3rd law $T^2 \propto a^3$, if appropriate, can be introduced.

(6) Slides #15 – #18: Lagrangian points.

Students use their observations from the gravity well practical to predict what should happen to the orbit of an object at L2.

The animations linked on the powepoint are very useful for a general overview :

http://www.esa.int/Our_Activities/Operations/What_are_Lagrange_points

Thus, at Lagrange point L1, the gravity of the Earth is just strong enough to thwart some of the attraction of the Sun, attracting the spacecraft, slowing it down and forcing it to have the same period as the Earth. Missions such as SOHO are placed in this position.

At the L2 distance the gravitational pull from the Earth is just right to keep the craft in alignment with the Earth, causing it to move faster and forcing it to have the same period as the Earth.

(7) Task 4: The Lagrange points (on slide #16)

Think back to the gravity wells:

How did the period of more distant objects vary with respect to that of closer objects?

How did the closer object orbit in relation to the further object?

Why should we choose the L1 point rather than the L2 point?

Continue the slides and explain more precisely the choice of L2: protection of solar radiation (back to the sun); No shadow, close distance to send data

At the distance L2, the gravitational force of the Earth is just to keep the machine in alignment with the Earth.



Activity 7 : Gaia's L2 Orbit Teacher's guide

CONTINUATION OF THE WORKSHOP «TO GO FURTHER»:

Slides #20 – #24: Extension for post 16 students.

This activity allows students to use the concepts of circular motion and gravitational attraction to set up an equation allowing them to prove that 1,500,000 km is a solution for the L2 Lagrange point. The key to this is that in order for L2, the Earth and the Sun to be in alignment constantly, L2 must have the same angular velocity as the Earth.

See the Teacher Solution –finding L2

Activity 7 : Gaia's L2 Orbit

Student sheet

ACTIVITY 1: GRAVITATIONAL FORCES

- WEIGHT $P = m \cdot g$

Calculate the weight of each student: Data : $g = 9,81 \text{ m} \cdot \text{s}^{-2}$ (ou $9,81 \text{ N/kg}$)

- Gravitational force

Data : $G = 6,67 \cdot 10^{-11} \text{ m}^3 \cdot \text{kg}^{-1} \cdot \text{s}^{-2}$

Calculate the gravitational force between the 2 students:

- Comparison

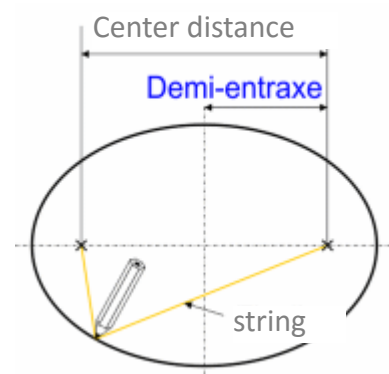
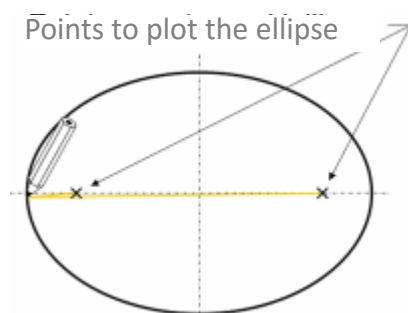
Task 2 : EXPERIMENT OF THE WELL OF GRAVITY

- Observations :

- 1) How does the speed of the planet vary with distance from the star?
- 2) How does the period of the orbit vary with distance from the star?
- 3) Do the planets remain aligned with each other? Describe their orbits in relation to each other
- 4) Are any of your orbits perfectly circular?

Task 3 : ELLIPTICAL ORBIT

Draw an ellipse with your pencil using a cord attached to both ends



Activity 7 : Gaia's L2 Orbit

Student sheet

Task 4 : LAGRANGIAN POINTS

Think back to the gravity wells:

- How did the period of more distant objects vary with respect to that of closer objects?
- How did the closer object orbit in relation to the further object?
- Why should we choose the L1 point rather than the L2 point?