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Bringing Nobel Prize Physics in the Classroom

The search for exoplanets

Linda Healy

Dervilla Moran

Nectara Elena Mircioaga

DCU

ELLINOGERMANIKI AGOGI

NUCLIO

EGO EUROPEAN GRAVITATIONAL OBSERVATORY

IASA

Paris Centre for Cosmological Physics

Co-funded by the Erasmus+ Programme of the European Union

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Background information for teachers

Overview of this lesson pack:

Name of the activity	Transit Light curve
Topics introduced	Why would scientists want to find other planets? What properties of the exoplanets would be of greatest interest to the scientist? What methods do scientists use to discover planets? What information can we gather about the exoplanet using this method? What are benefits and drawbacks associated with space exploration.
Curriculum Connection	IRELAND: ES1 Describe the relationship between various celestial objects ES3 Interpret data to compare the Earth with other planets ES8 Discuss the future role and implications of space exploration in society NOS1 Appreciate how scientists work and how scientific ideas modified over time NOS4 Produce and select data, critically analyse data to identify patterns and relationships, identify anomalous observations, draw and justify conclusions NOS10 Students should be able to appreciate the role of science in society and its personal, social and global importance and how society influences scientific research. PW3 Student should be able to investigate patterns and relationships between physical variables ROMANIA:Studying geographical space, making connections with information acquired in other school subjects Elaboration of an investigative approach from the perspective of lifelong learning and for everyday life 1.1 Use of geographical terms in different contexts 1.2.Description of geographical elements, phenomena or processes observed directly or indirectly 2.1. Use of map/land orientation techniques 2.2. Relation of the scale of proportion to geographical reality 2.3. Reading simple graphics and cartographic 3.1. Description of geographical elements, phenomena, and processes using notions of mathematics, sciences, and technologies 3.2.Specify the links between geographical reality and phenomena in the field of science and technology 3.3.Description of the natural diversity of geographical reality by making correlations with information acquired in other school subjects 4.1. Use of simple methods of investigation 4.2. Ordering geographical elements according to certain criteria 4.3.Applying knowledge and skills acquired in new contexts/real-life situations

Overview of this lesson pack:

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Show summary video</td><td>answer questions</td></tr>
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Discuss hypothesis, variables and safety considerations
Support students through calculations</td><td>Identify hypothesis, variables and safety considerations
Complete experiment
Answer Questions</td></tr>
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Lead discussion of questions</td><td>Analyse graphs generated by Salsa J
Prepare report</td></tr>
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For experiment: Light sensor, styrofoam spheres or spherical object, lamp, timer</td></tr>
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ES3 Properties of planets in the solar system such as mass, size and composition
ES4 Use a model of the Earth-sun-moon system to describe eclipses of the sun and the moon and seasons</td></tr>
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Background and overview of the discovering alien worlds demonstrator:

This demonstrator introduces the concept of an exoplanet and how they have been discovered in our universe. Students are introduced to the transit method of exoplanet detection. Students will perform an experiment to generate data for their own light curve using the transit method. In addition, students will be given light curves to analyse.They will estimate the rotational period of the exoplanet and its diameter. Students can present their work to the class and discuss how they compare with the most accurate results that astronomers have.

Presentation for students

Teacher guidelines can be found in the notes attached to each slide

Introductory Activity

What do you know about the Universe?

Open the following link:

https://spaceplace.nasa.gov/all-about-exoplanets/en/

Read the website page and answer the questions provided.

Questions

1. Define the term exoplanet.
2. Why is not possible for astronomers to use telescopes to detect stars?
3. Fill in the blank: Astronomers detect exoplanets by looking at the effects that potential planets have on the ……. they orbit.
4. **Suggest** some of these effects.
5. One way to search for exoplanets is to look for wobbly stars. Explain this method.
6. Outline one disadvantage of relying solely on this method.
7. **Suggest** why astronomers wish to find earth-like planets.
8. **Suggest** properties of the earth that astronomers may wish to find in other planets.
9. What was the name of the spacecraft launched by NASA in 2009 to look for exoplanets
10. **Suggest** why there are not astronauts onboard Kepler.
11. What is the name of the method used by Kepler to detect exoplanets.
12. Briefly describe the principle behind this method.
13. List the two properties of the planet that can be calculated using this method.
14. Describe the potential significance of these findings.

Answers

1. Planets that orbit around other stars
2. They are hidden by the bright glare of the stars they orbit.
3. Stars
4. Students suggestions
5. A star that has planets doesn't orbit perfectly around its center. From far away, this off-center orbit makes the star look like it's wobbling.
6. Only big planets—like Jupiter, or even larger—can be seen this way. Smaller Earth-like planets are much harder to find because they create only small wobbles that are hard to detect.
7. Students suggestions
8. Students suggestions
9. Kepler
10. Students suggestions
11. Transit method
12. When a planet passes in front of its star, it's called a **transit**. As the planet transits in front of the star, it blocks out a little bit of the star's light. That means a star will look a little less bright when the planet passes in front of it.Astronomers can observe how the brightness of the star changes during a transit.
13. Size of planet and distance from the sun
14. Scientists could figure out temperature and potential presence of water.

To summarise watch: link:
https://www.youtube.com/watch?time_continue=161&v=VC7Q2aSQktw&feature=emb_title

Main Activity 1:
Experiment - Using the transit method to discover exoplanets

Link: https://www.cfa.harvard.edu/~avanderb/tutorial/tutorial.html

Write a hypothesis for this experiment (If, then statement)

_____

State

(a) Independent Variable (variable that is changed)

_____

(a) Dependent Variable (variable that is measured)

_____

(a) Controlled or fixed variables (variables that will be kept the same)

_____

Identify relevant safety considerations for this experiments

_____

Light curve

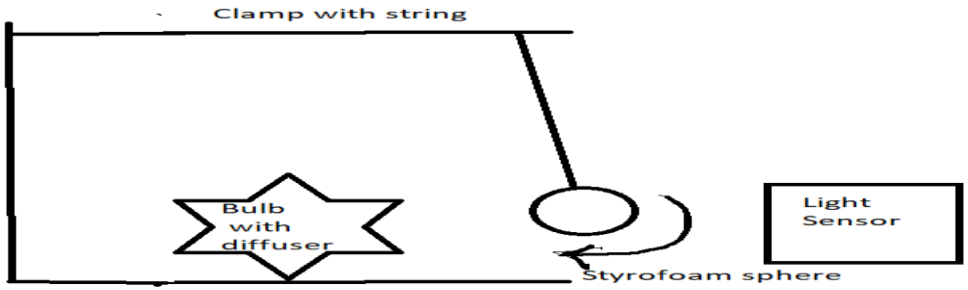
A light curve is a plot of the % brightness of a star over time. Predict what do you think your light curve will look like?

Experiment details

Materials required

- Lamp (should be a bulb with a diffusing globe preferably)
- Styroform balls,
- thread,
- Tripod,
- Light sensor
- Stopwatch if data logger is not used.

Apparatus set up



Method

1. Point the light sensor at the lamp.
2. Attach the string to the retort clamp so that the styrofoam sphere is free to rotate in circles around the lamp.
3. Adjust the clamp so the sphere passes between the lamp and the light sensor.
4. Turn off classroom lights and pull blinds/curtains to ensure the light measurements are as accurate as possible while measurements are taken
5. If a data logger is not being used, record the light levels at normal when the sphere is not in front of the lamp and during the drop when the sphere is in front of the lamp. Additionally the length of time that the light drop occurs for needs to be recorded

Worksheet

1. Complete a table of results:

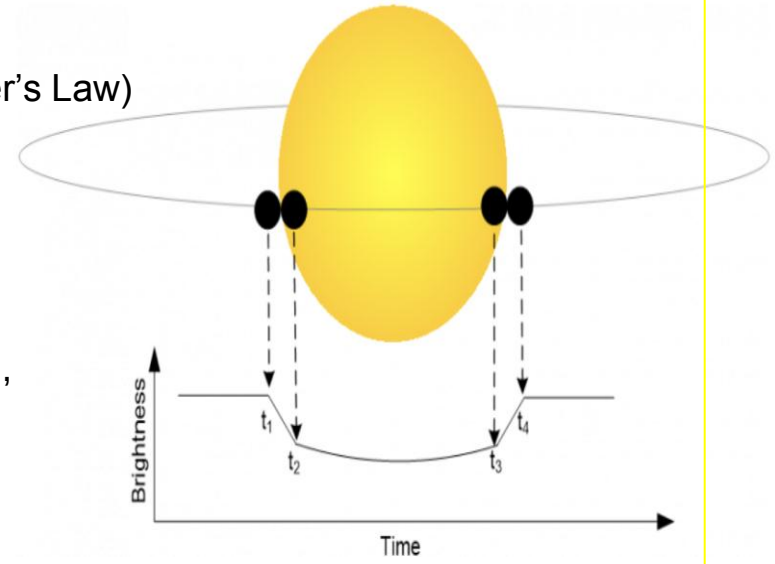
Time (s)						
Light Intensity (lux)						

1. Draw your light curve placing time on the x axis and light intensity on the y axis.

Calculations

If you find you need help with this activity consult https://www.cfa.harvard.edu/~avanderb/tutorial/tutorial2.html

1. Calculate the time taken for your planet to orbit the star (T) in earth years
   - What is the length of time between dips in your stars light assume seconds are days
   - Multiply this value by 100 to make it more realistic
   - Divide by 365.25
2. Calculate the distance of your planet from the sun (D)
   - Use the equation $T^2=D^3$
   - Explain why this equation can be used (Hint: Kepler's Law)
3. Calculate the diameter of your planet
   - Label your light curve as shown in the diagram
   - Identify values for t1 - t4
   - What does the value t1-t2 represent?
   - What does the value t2-t4 represent?
   - If the transiting body is moving at a constant speed, what does $(t_1 - t_2)/(t_2 - t_4)$ represent?
   - The literature value of the sun's diameter is 0.788.



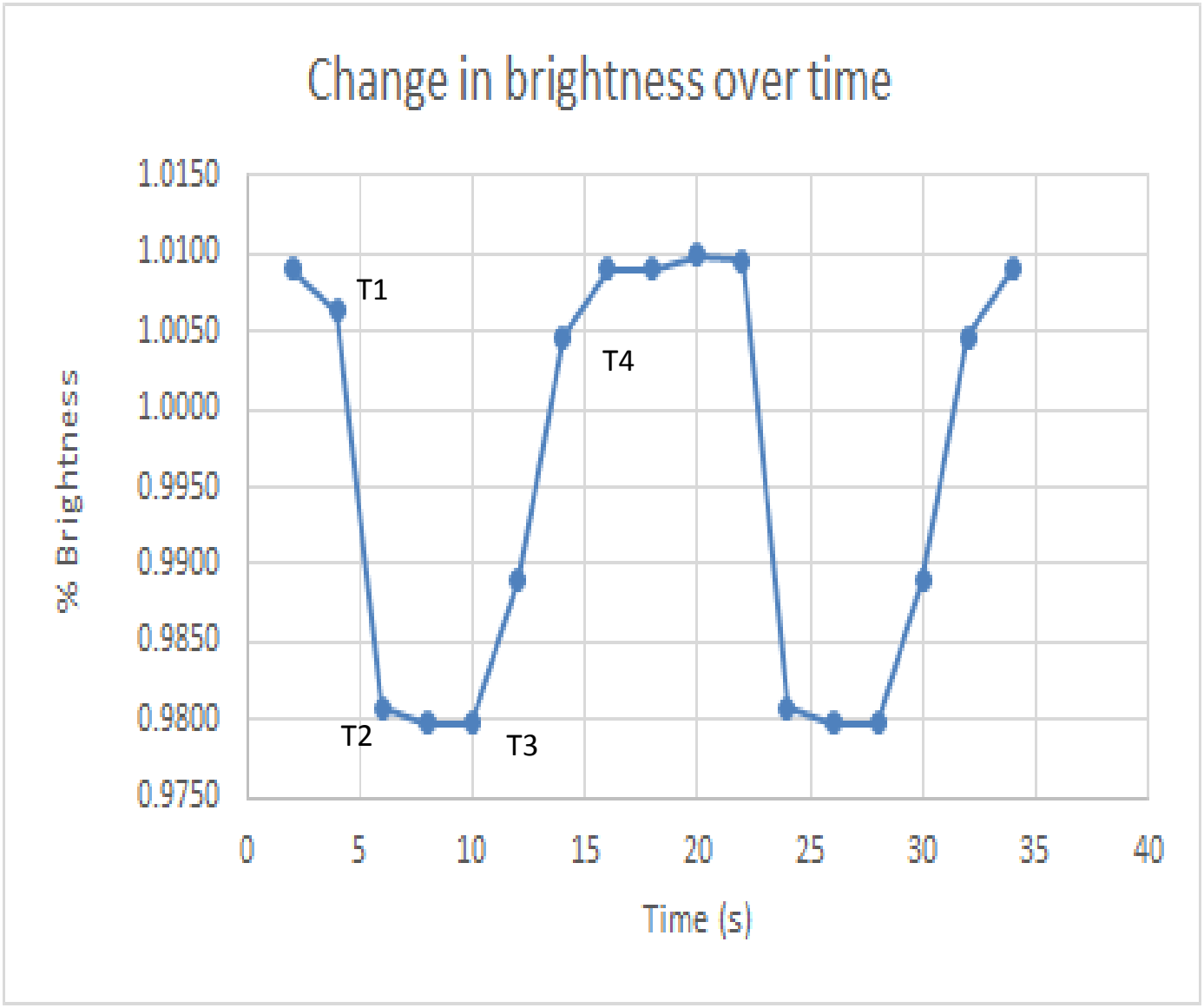
Use this formula to calculate the diameter of the planet.

$(t_1 - t_2)/(t_2 - t_4)$ X 0.788

Compare the values of transiting body with that of Earth's and speculate the nature of the transiting body

Example answers

Time (s)	% Brightness
2	1.0090
4	1.0063
6	0.9808
8	0.9798
10	0.9798
12	0.9890
14	1.0046
16	1.0090
18	1.0090
20	1.0099
22	1.0095
24	0.9808
26	0.9798
28	0.9798
30	0.9890
32	1.0046
34	1.0090



Calculations Examples

Time (s)	% Brightness
2	1.0090
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32	1.0046
34	1.0090

If you find you need help with this activity consult
https://www.cfa.harvard.edu/~avanderb/tutorial/tutorial2.html

1. Calculate the time taken for your planet to orbit the star (T) in earth years
   - What is the length of time between dips in your stars light 14 s becomes 14 days X 100 to make more realistic
   - Multiply this value by 100 1400, divide by 365.25 to convert to earth years
   - Divide by 365.25 3.8356 earth years
2. Calculate the distance of your planet from the sun (D)
   - Use the equation $T^2=D^3$ $T^2 = 14.7118274$ therefore $D=\sqrt[3]{14.7118274}=2.4503AU$
   - Explain why this equation can be used (Hint: Kepler's Law) the further a planet is from the sun the longer its orbit
3. Label your light curve as shown in the diagram
   - Identify values for t1 - t4 t1 =2 t2=4 t3=10 t4= 12
   - What does the value t1-t2 represent? Time taken for planet to travel the length of its diameter.
   - What does the value t2-t4 represent? Time taken for the planet to travel the length of the star.
   - If the transiting body is moving at a constant speed, what does $(t_1 - t_2)/(t_2 - t_4)$ represent? Ratio of planet size to the star size.
   - The literature value of the sun's diameter is 0.788AU

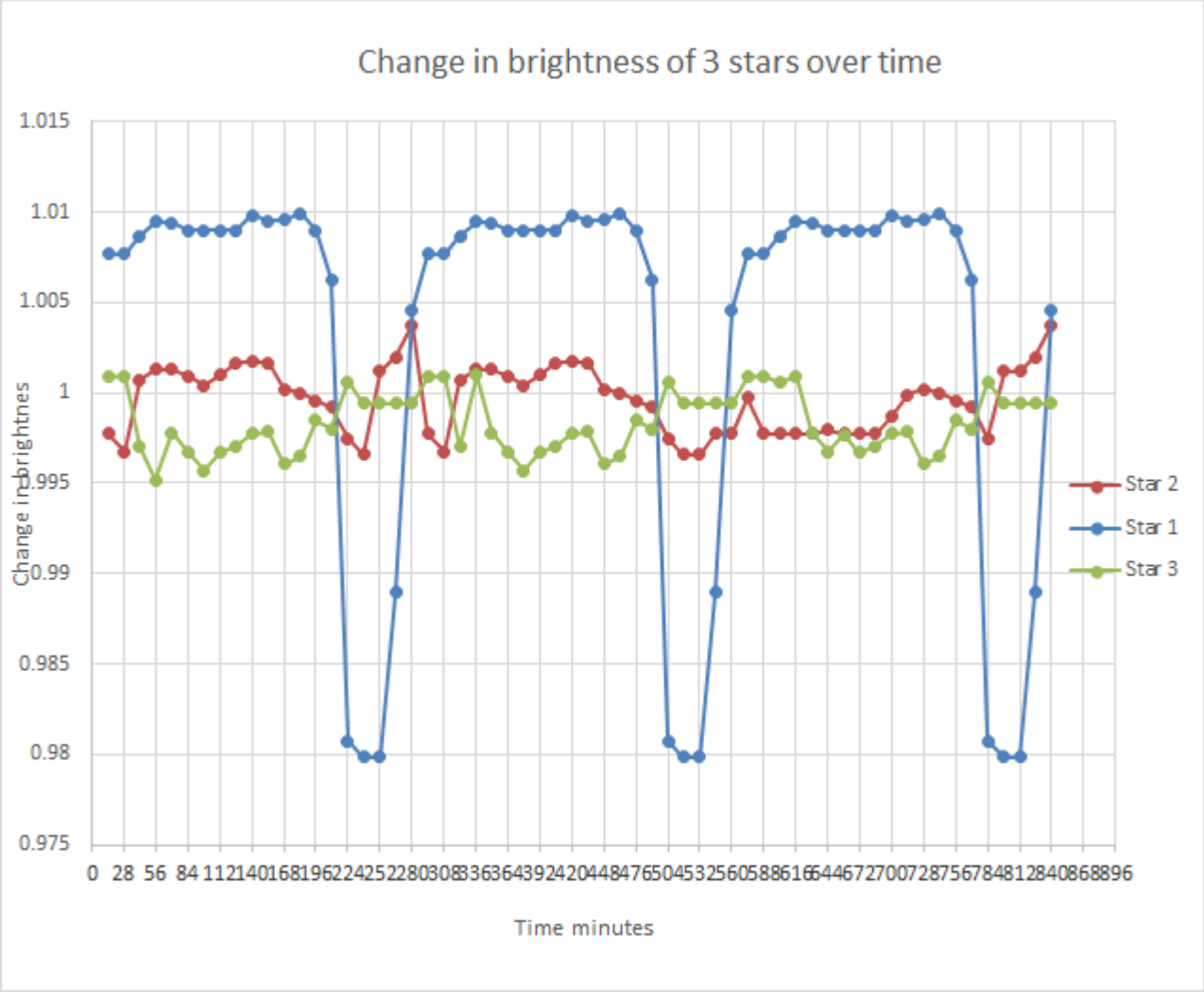
Use this value to calculate the diameter of the planet.

$(t_1 - t_2)/(t_2 - t_4)$ =2/8=0.25 X 0.788 = 0.197AU X 149654219=29481881km

Compare the values of transiting body with that of Earth's and speculate the nature of the transiting body Earth 12756 km

Bigger than Mars and earth but smaller than Jupiter so is it a gas or rocky planet?

Main activity 2



With your group, analyse the light curves and think about:

1. Of the three light curves, which one might have a transiting body? Write down your arguments.
2. For the star that you think has a transiting body, what information can you get from the light curve?

1. What do you think are the limitations of using the transit method to find planets?https://www.planetary.org/explore/space-topics/exoplanets/transit-photometry.html
2. Based on the data do you think the planet is more tilted or edge on?

1. With all of the information you have gathered what do you think this planet is like, give reasons for your answer.
   What do you think this planet is like if only one side of it faces its star?
   Suggest what this planet would be like if it is much smaller or larger than earth?

Answers

With your colleagues, analyse the light curves and think about:

1. Of the three light curves, which one might have a transiting body? Write down your arguments. Star 1 as large drop in stars brightness indicating object passing in front of star
2. For the star that you think has a transiting body, what information can you get from the light curve? Diameter of planet and star, Orbital period, distance from sun
3. What do you think are the limitations of using the transit method to find planets? https://www.planetary.org/explore/space-topics/exoplanets/transit-photometry.html
   Blocking planet may be a small star, measuring mass of exoplanet, doesn't find exoplanets that do not cross in front of star as seen from earth, transits generally only last short time in comparison to its total orbital period therefore unlikely to see them,

1. Based on the data do you think the planets orbit is more tilted or edge on? Edge on as dip has a flatter shape instead of curved shape
2. With all of the information you have gathered what do you think this planet is like, give reasons for your answer.
   What do you think a planet is like if only one side of it faces its star?
   Length time between dips 504-252 =252mins/60=4.2hrs/365.25 = 0.00047912 earthdays=T
   $T^2=D^3$ T^2 = 0.0000002295597 therefore D= $\sqrt[3]{0.0000002295597}$ = 0.006123 AU distance from sun
   $(t_1 - t_2)/(t_2 - t_4)$ =28/56=0.5 X assuming starDiameter of sun 0.788= 0.394AU X 149654219km= 58,963,762km diameter of planet

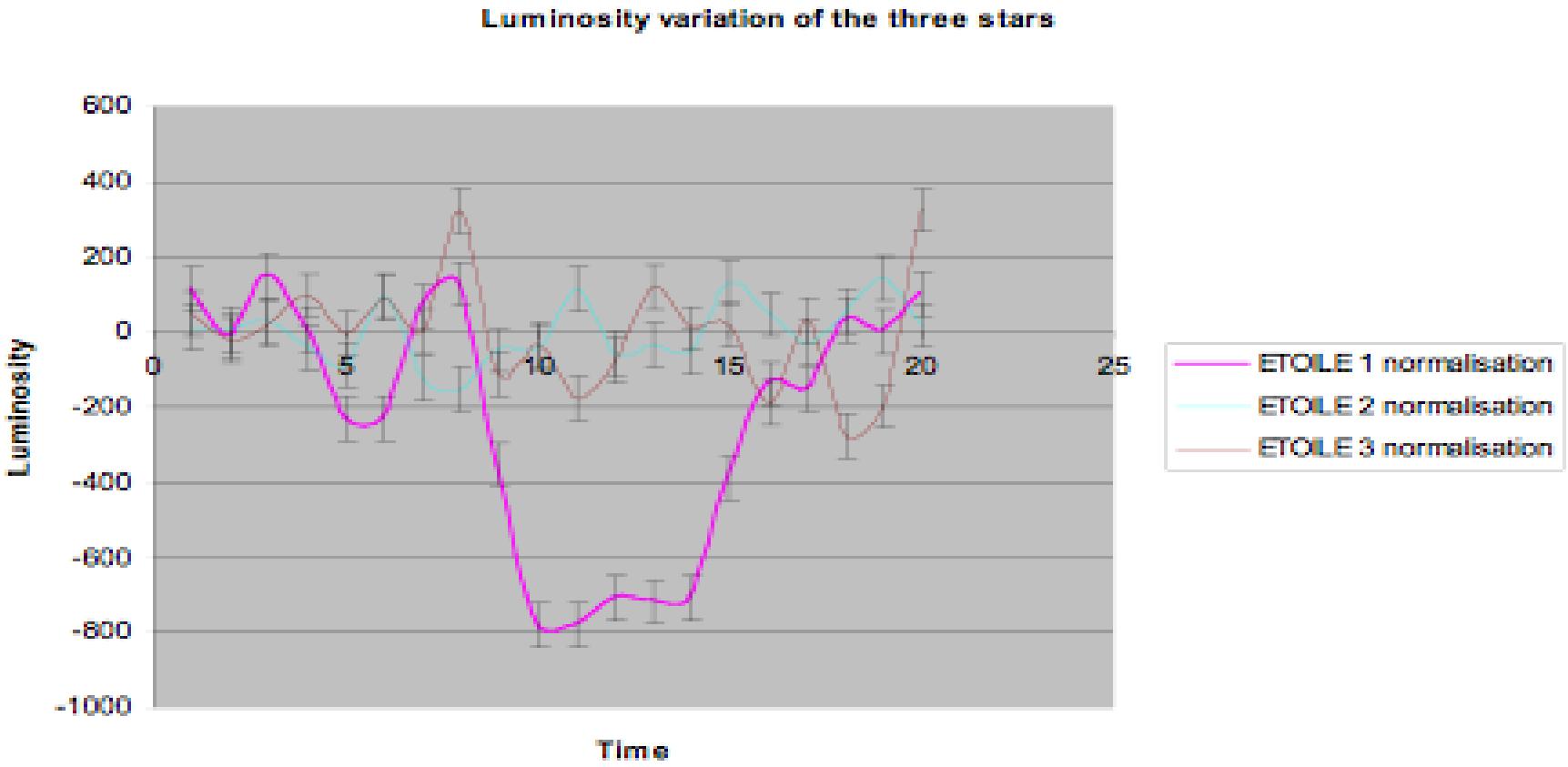
Homework

Its 2027 and **Elons Musks** Space X is ahead of schedule with a settlement on Mars and the company is now doing flights from Mars to Jupiter. The company have developed new technology that is capable of flying outside of the solar system. You are working as an **astronomer** for **Space X** and you have a team of astronomers generating data to anaylse, in the search for a new place to visit outside of the solar system. You will use data generated by **SALSA J** to identify exoplanets and examine available evidence to determine if candidate exoplanets have the potential to support life. You should present your findings in the form of a report.

Include the following:

- Evidence of a transiting body from the curves shown on the graph
- Information that can be gathered from the curve about the transiting body
- A comparison of the transiting body to Earth
- Limitations of the graph
- Conclusion: Would you recommend Space X travel to this exoplanet?

Which star has a planet we could visit?



Reflection

- What are the main concepts that you have learned?
- Which competencies did you improve or acquire?
- How do you feel about the activity?
- What would you do differently?
- What would you like to know more about in the study of exoplanets?

Extension Activity

- You can explore further using a simulation of a light curve during a planetary transit and the different parameters that influence the data you collect. The simulator lets you play with the parameters of the planet, of the star and the observing conditions. You can find it here: https://astro.unl.edu/naap/esp/animations/transitSimulator.html
- Would you like to help scientists find exoplanets. If the answer is yes click the following links
  https://www.cfa.harvard.edu/smgphp/otherworlds/ExoLab/lab/modelLab/model_lab.html
  https://www.zooniverse.org/projects/nora-dot-eisner/planet-hunters-tess

SPACE.com

www.SPACE.com

HUBBLE'S BLUE ALIEN WORLD

Light from the planet HD 189733b was captured by the Hubble Space Telescope and analyzed. Astronomers say that the giant planet has a deep-blue atmosphere, but conditions are in no way Earth-like.

ARTISTIC RENDERING OF PLANET BY M. KORNMESSER

Planet HD 189733b

Type: "hot Jupiter" gas giant

Distance from Earth: 63 light-years, in the constellation Vulpecula ("The Fox")

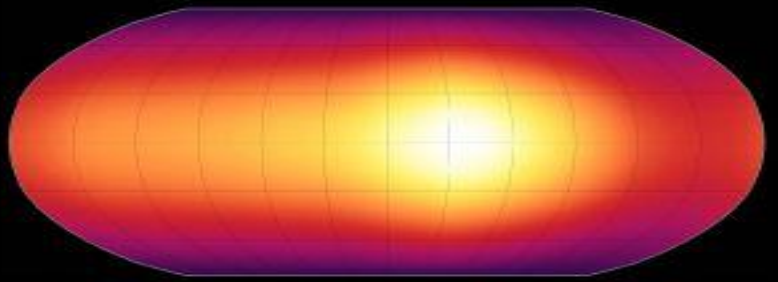
Day/Year: 2.2 Earth days (planet is tidally locked and one side always faces the parent star)

Temperature range: 1,800 degrees Fahrenheit (1,000 degrees Celsius) on the day side, 1,200 degrees F (650 degrees C) on the night side

Wind speed: 4,350 mph (7,000 km/hr)

Conditions: glass particles in atmosphere create blue color

In 2007, astronomers created a heat map of the surface of HD 189733b showing the hot spot on the side permanently facing the star. This was the first surface map made of a planet orbiting another star.



MAP: NASA/JPL-Caltech/H. Knutson (Harvard-Smithsonian CfA)

SOURCES: EUROPEAN SOUTHERN OBSERVATORY, HUBBLE, NASA, ESA

KARL TATE / © SPACE.com

Cool Science Facts

www.messagetoeagle.com

HD 189733b is a "blue marble" alien planet that resembles Earth in terms of color, but it's a very alien world. Located 63 light-years away, the daytime temperature is nearly 2,000 degrees Fahrenheit and it rains super-hot glass, sideways!

(Source: NASA, Space.com)