


# Exoplanet detection

## Teaching with AI (TAI)

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Subject: Physics

Activity duration: 150 min

Lesson outline:

1. Introduction to exoplanets and detection methods (5 min)
2. Initial research with an AI assistant, checking its answers against reliable sources (15 min)
3. Planning and building a model transit experiment (40 min)
4. Collecting and analysing light-curve data (75 min)
5. Calculating the size of your group's real exoplanet (15 min)

Learning goals:

- Explain how a transit light curve can provide information about an exoplanet.
- Design a fair experiment by changing one variable and controlling the others.
- Collect, plot, and interpret light-intensity data.
- Reflect on how scientists know what they know (Nature of Science): for example, the difference between an observation and an inference, and why scientific knowledge is reliable but can change.
- Use an AI research mentor critically, checking whether its suggestions make scientific sense.

# Exoplanet detection

*Experimenting with help of AI*

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*How are exoplanets detected? How can scientists infer properties of a planet that is many light-years away? In this lesson, you will build a model of a distant solar system with a star and an orbiting planet. By measuring the star's light curve, you can detect the model exoplanet. By testing different model planet sizes, you will investigate how planet size affects the transit signal.*

## Initial ideas

**Question 1: How do you think that exoplanets can be detected?**

## Constructing new ideas

### Assignment 1: Initial research

Use an AI assistant to research the questions below. Ask specific questions, and ask it to explain ideas at your level. You should be able to explain your answers to your classmates.

**Check your sources.** An AI assistant can sound confident and still be wrong, and it sometimes invents facts or even sources that do not exist. Use its answers as a starting point, and check the important claims:

- Ask the AI where its information comes from, and open those sources yourself. Does the source exist, and does it really say this?
- Prefer sources from scientific organisations, such as space agencies, universities and research institutes.
- Look for the same claim in a second, independent source.

**Question 2: What are the most common ways that exoplanets are detected?**

**Question 3: What is a transit, and what information can we gain from it?**

**Question 4: What is a transit lightcurve? Sketch a graph of the typical shape of a transit lightcurve.**

**Question 5: How would the transit graph look for a bigger exoplanet?**

**Question 6: What is *transit depth?***

**Question 7: Which reliable source did you use to check the AI's answers? Write down the source, and explain in one sentence why you trust it.**

**Question 8: Compare the AI's answers with your source. Did they agree? Describe one thing that was different, missing, or that you could not check.**

## Assignment 2: Model an exoplanet

### The challenge

**Goal:** Build a model of an exoplanet transit and investigate how the size of the planet influences the transit light curve.
At the end of this class, you should deliver:

- One figure of a transit, showing light intensity as a function of time.
- One plot of your results, showing how the transit depth depends on the size of the planet.
- A five-sentence conclusion about your research.

### Constructing new ideas

**Start a chat with Emmy, your AI research mentor.** Emmy is not an app: she is a prompt that you paste into a chatbot. Open the file `Emmy_prompt_exoplanet_lesson.txt` that your teacher shares with you, copy all of its text, and paste it as the first message in a new chat with the AI chatbot your school allows. Emmy will introduce herself and take it from there.
Emmy does not give you a recipe to follow. She helps you set up your own investigation by asking questions, one at a time. You can ask her questions in return, and you can ask her for a hint whenever you get stuck. Remember: the AI is a helper, not the final authority. You are responsible for checking whether your plan is safe, fair, and scientifically reasonable.

**Real research is not a straight line.** Scientists do not follow one fixed "scientific method". They move back and forth between different practices as their ideas develop. Emmy keeps a **research map** at the top of each message, so you can see where you are:

- **Question:** what exactly do you want to find out?
- **Model:** what do you think is going on, and what do you predict?
- **Design:** how will you test it fairly?
- **Measure:** collect your data carefully and honestly.
- **Make sense:** what do your data actually show?
- **Share:** what can you claim, based on which evidence?

Going back to an earlier step, for example after a surprising measurement, is part of good science. A few times, Emmy will also ask you to **think like a scientist**: these questions are about how science itself works.

**Solution:** **Expected physics (Make sense):** the fraction of the star's light blocked during a transit equals the ratio of the projected areas, so the *transit depth* is

$$\text{depth} = \frac{\Delta F}{F} = \left(\frac{R_{\text{planet}}}{R_{\text{star}}}\right)^2 .$$

For a fixed star, depth $\propto R_{\text{planet}}^2$, so a graph of transit depth versus planet size squared should be an approximately straight line through the origin, with slope $1/R_{\text{star}}^2$. Larger model planets should therefore produce deeper transits.

**Note for teachers (Nature of Science):** Emmy is designed to let students discover this relationship from their own data, so the student version of this worksheet does not mention "size squared". During the session she asks two or three *Think like a scientist* questions, each linked to one aspect of the Nature of Science: science is empirical; observation differs from inference (astronomers almost never see an exoplanet, they infer it from a dip in starlight); scientific knowledge is tentative; science involves creativity; expectations shape what we see; science is social (peer review); and there is no single scientific method. The *Peer Check* and the last question of the lesson are good moments to discuss these aspects with the whole class.

**Note for teachers (scaffolding the squared relationship):** students rarely spot depth $\propto$ size$^2$ from a graph alone, so three steps guide them to it. (1) The notebook first plots transit depth against planet *size*; the points curve upwards. (2) The grid task *From width to area* (research log, after Measure) lets students discover that a circle twice as wide covers four times as many squares, so a planet twice as wide blocks four times as much light. (3) Section 6 of the notebook lets students test models themselves (`x = size`, `size**2`, `size**3`) and compare how close their points lie to a straight line through the origin. Emmy offers the same steps as hints, one at a time, when a group asks for help. If a group is stuck, point them to the next step rather than to the answer.

**Follow the lead of your research mentor and get to work.** Below, you find a list of the available materials. After that, you can keep your research log.

## Available Materials

- Light sensor on your phone. Recommended applications: phyphox (Android only), Physics Toolbox or Arduino Science Journal.
- Image of a star (`Star_image_for_phone.png`), displayed on a phone and used as the star light source
- Cardboard box
- Sticks
- Cutting knife
- Tape
- Modeling clay
- Compass
- Geo triangle
- Caliper

**Use of AI for data analysis and programming:** You may use AI to help with all programming steps, including organising your data, writing code, calculating transit depth, making plots, and improving the layout of your figures. You may also ask AI to explain error messages or suggest better ways to analyse your measurements. However, you remain responsible for checking the results: make sure the code uses the correct data, the axes and units are labelled clearly, and the conclusions match your measurements.

## Analysing your data with Google Colab

You will measure the star's brightness with a light-sensor app on your phone (for example *phyphox* on Android, *Physics Toolbox* or the *Arduino Science Journal*). To load and analyse that data on your computer, use the ready-made notebook that your teacher shares with you:

`Exoplanet_transit_analysis_notebook.ipynb`

1. In your light-sensor app, record a transit and **export the data as a CSV file** (in phyphox, use the three-dot menu, *Export Data*, and choose *CSV (Comma, decimal point)*; in Physics Toolbox, use the share/export button; in the Arduino Science Journal, export the recording as CSV). Send the file to your computer. phyphox gives you a `.zip` file: you can upload it as it is.

2. Open the notebook in **Google Colab**: go to `colab.research.google.com`, choose *File* → *Upload notebook*, and select the notebook file (or use the link your teacher gives you). Then **run the cells from top to bottom**. When prompted, **upload your CSV**.

3. The notebook draws your **light curve**, helps you compute the **transit depth**, and, once you have tested several planet sizes, helps you plot how the **transit depth depends on planet size**. You can then **test which relationship fits your data best**.

4. You can ask Emmy (or your own AI) to help you **adapt or extend the code**: describe what you want and paste any error messages. Always check that the output uses your data and that the axes and units are labelled.

The notebook also accepts a **plain CSV file** (any file with a time column and a light or brightness column), so it works even if you use a different app.

## Research Log

Use the fillable boxes below to keep your research log, one box for each practice on Emmy's research map. Your notes do not need to be perfect, but they should show how your thinking develops. If you go back to an earlier step, add to that box and write down why.

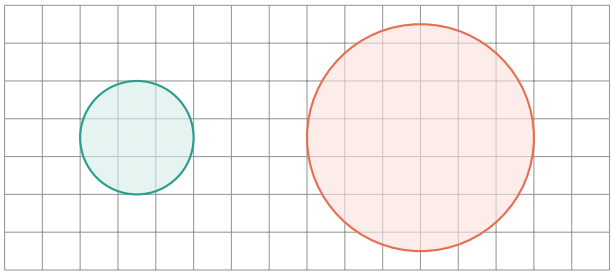
**1. Question:** *(What exactly do you want to find out? What will you change, and what will you look at to see the effect?)*

**2. Model:** *(What do you think happens to the light when the planet passes, and why? What does each part of your box represent, and in which ways is it different from a real star and planet?)*

**3. Design:** *(Which planet sizes will you test? How will you measure the dip? What will you keep the same between runs?)*

**4. Measure:** *(Record your measurements clearly, with units. Note odd runs, measurement problems, and anything you changed from your plan.)*

**From width to area.** *(Is your graph of transit depth against planet size a straight line? If not, this can help. A planet blocks the starlight with its whole disk, not only with its width.)*



A: diameter 1.5 cm  B: diameter 3 cm

*Count how many grid squares each circle covers (count a square if more than half of it is inside the circle). Circle B is twice as wide as circle A. How many times more squares does it cover? What does this tell you about how much light a planet that is twice as wide blocks?*

**5. Make sense:** *(What pattern do you see in your data? Does it match what you expected in your model?)*

**How did you calculate the transit depth?** *(Explain your method in a few sentences, so that another group could repeat it.)*

**6. Share: your conclusion in five sentences.** *(1. Your answer to your research question. 2. The evidence from your data. 3. Why this evidence supports your answer. 4. How sure you are, and the biggest limitation. 5. What you would investigate next.)*

**One suggestion for improving the experiment.** *(What would you change if you had more time?)*

**Think like a scientist.** *(Choose one of the* Think like a scientist *questions Emmy asked you. Write down the question, your answer, and what it tells you about how scientists work.)*

## Checklist

Before you finish, make sure you have prepared:

- One labelled figure of a transit, showing light intensity as a function of time.
- One plot of your research results, showing how the transit depth depends on the size of the planet.
- A short explanation of how you calculated the transit depth (research log, box 5).
- A five-sentence conclusion about your research (research log, box 6).
- One suggestion for improving the experiment (research log, box 6).

## Peer Check

Before scientists publish a result, other scientists check it. This is called *peer review*, and it is one of the reasons we can trust scientific knowledge.

**Exchange results with another group and discuss:**

- Are the axes, units, and labels clear on both graphs?
- Did both groups control the same variables during the experiment?
- Do the conclusions follow from the data, or are there alternative explanations?
- If your results differ, what could explain the difference?

## Closing the challenge

### Assignment 3: Calculating the size of your group's real exoplanet

**Question 9: If you are given a transit light curve of a newly found exoplanet, how can you estimate its size? Use the transit-depth relationship in your explanation.**

**Solution: Model answer:** rearranging depth $= (R_{\text{planet}}/R_{\text{star}})^2$ gives

$$R_{\text{planet}} = R_{\text{star}}\sqrt{\text{depth}}.$$

Measure the transit depth from the light curve, use the known (or modelled) star radius $R_{\text{star}}$, and compute $R_{\text{planet}}$. In the model experiment, $R_{\text{star}}$ is the radius of the star-disk image on the phone, and depth $=$ (baseline $-$ minimum)/baseline.

Now that you have found the relationship between transit depth and planet size, you can use it to find out the size of a real planet.

**From your model to your group's real exoplanet.** Until now, you worked with your clay model planets. Now switch to the **real exoplanet your group is studying in the Exoplanet Files** (for example TRAPPIST-1 e or WASP-76 b). Open the **planet file** of your exoplanet that your teacher shares with you (for example `Planet3_Trappist-1E.pdf` for TRAPPIST-1 e). You need:

- **page 3**: the single-transit graph of your planet. Read the transit depth from this graph.
- **page 1**, *Host star data*: the star radius, in solar radii ($R_\odot$).

Write the transit depth and the planet radius in the empty fields on page 1 of your planet file. Tip: 1 solar radius is about 109 Earth radii.

**Analyse the transit graph of your group's real exoplanet and calculate its radius.**

**Question 10: Show your calculation: the transit depth you read from the graph, the radius of the host star, and the radius of your exoplanet.**

**Question 11: How does the size of your exoplanet compare to the size of Earth?**

**Question 12: Your exoplanet orbits its own star, its *host star*. How does the size of this host star compare to the size of the Sun?**

## What have we learned?

**Question 13: What have you learned that you didn't know before?**

**Question 14: Astronomers have never seen most exoplanets directly. How is your model experiment similar to the way they find exoplanets, and how is it different? How sure can they be about the size of a planet they have never seen?**

**Question 15: How have you used AI in this lesson, and what did you learn from it?**