DEEP SPACE: X

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Students will get familiar with **one** exoplanet detection method and with the process of finding an exoplanet using simple tools. They will need to do some calculations and use their analytical and logical thinking in order to spot an exoplanet. If possible, an exoplanet will be observed with a telescope.

The following section will give a general overview of the activity (i.e. educational context, educational objectives, connection to the curricula & educational approach). The “Orienting & asking questions” section contains basic information about exoplanets and can be read by teachers and students. Text written in green is mainly for teachers to read. Instructions for students are written in black.

EDUCATIONAL CONTEXT

AGE

+11 years

DURATION

~2 hours

PREREQUISITES

Average calculations
Basic knowledge of graphs (discrete mathematics) of advantage

EDUCATIONAL OBJECTIVES

COGNITIVE OBJECTIVES

- To learn about deep space, i.e. other objects in the universe than our solar system; specifically about exoplanets
- How exoplanets can be detected using simple tools and basic mathematics (it is no rocket science)
- How exoplanets are being discovered/ observed from Earth
- How much information one can get from one simple graph
- To analyze graphs and interpret one’s results

AFFECTIVE OBJECTIVES

- To make students understand there is more than “our” planets
- To tech students how different or similar exoplanets are
- To create passion about studying distant objects
- To learn that the work of an astronomer also includes a lot of mathematics, analyzation and interpretation

PSYCHOMOTOR OBJECTIVES

- To be able to use open-source software to process astronomical images
- To use common tools to create data sets and graphs
- To be able to identify exoplanets with the help of images

CONNECTION TO THE CURRICULA

Nature and technology education

“Nature as the basis of human life appears in many different forms, including technically modified forms. Knowledge of the interrelationships of nature is to be presented as a prerequisite for conscious handling and use with the help of modern technology.
Understanding of phenomena, questions and problems from the fields of mathematics, natural science and technology form the basis for orientation in modern society, which is characterized by technologies.
The students are therefore to acquire fundamental knowledge, decision-making skills and action competence within the framework of the lessons. The students are to be enabled to deal with value concepts and ethical questions in connection with nature and technology as well as man and the environment. Formalization, model building, abstraction and spatial imagination are to be taught as essential prerequisites for the analysis and solution of problems.”[1]

This activity can be implemented in different schools (in Austria: AHS, MS, HS, PTS, Sonderschulen). Subjects where the activity would fit best are:

- Mathematics
- Physics
- Chemistry
- Informatics
- Digital Basic education

EDUCATIONAL APPROACH

Inquiry based learning

ORIENTING & ASKING QUESTIONS

“ Ἀλλὰ μὴν καὶ κόσμοι ἄπειροί εἰσιν, οἵ θ' ὅμοιοι τούτῳ καὶ ἀνόμοιοι."

'Furthermore, there are infinite worlds both like and unlike this world of ours.'

- Epicurus (341-271 BCE)

Ideas of an existence of other worlds can be traced back to the Classical/ Hellenistic period as this quote in "Letter to Herodotus", written by Greek philosopher Epicurus, shows. Through the years, a wide variety of people have studied stars, constellations, planets, and our solar system. Positions and motions of celestial bodies have already been measured when technology was not as advanced as it is today. This was done measuring tiny angles that divided up the sky accurately, which forms the basis of 'Astrometry'. Nowadays, it as a branch of Astronomy, but it originated more than two

[1] Source: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20007850

thousand years ago and deals with the precise measurements of positions and motions of planets, stars, galaxies, clusters of galaxies within the Universe. Using this technique, in the 1850s, a celestial body in the binary star system '70 Ophiuchi' was suspected to be a planet. Years later, this hypothesis was falsified, but it still represents the first published approach of finding 'another world' - a planet outside of our solar system.

Planets outside our solar system are called 'exoplanets', sometimes also referred to as 'extrasolar planets'.
For an extrasolar body to be considered an exoplanet, the Working group on extrasolar planets (WGESP) of the International Astronomical Union (IAU) decided on some required properties. Those were created in 2001 and have lastly been modified in 2003. This 'working definition' includes the following properties:

1. Objects with true masses below the limiting mass for thermonuclear fusion of deuterium (currently calculated to be 13 Jupiter masses for objects of solar metallicity) that orbit stars or stellar remnants are “planets” (no matter how they formed). The minimum mass/size required for an extrasolar object to be considered a planet should be the same as that used in our Solar System.
2. Substellar objects with true masses above the limiting mass for thermonuclear fusion of deuterium are “brown dwarfs”, no matter how they formed nor where they are located.
3. Free-floating objects in young star clusters with masses below the limiting mass for thermonuclear fusion of deuterium are not “planets”, but are “sub-brown dwarfs” (or whatever name is most appropriate).

The first confirmed exoplanet, PSR1257+12b, was discovered in 1992. Together with at least one more planet, it orbits a pulsar. Only a few years later, in 1995, the first confirmed planet around the main-sequence star 51 Pegasi was discovered: 51 Peg b, a Jupiter size planet. Nowadays, more than 5000 confirmed exoplanets have been discovered (Date: 08.11.2022), that led to an extreme increase of our knowledge of those planets outside our solar system.

Since a huge number of exoplanets exist, that cover a broad range of orbital distances and masses, they are usually described in relation to solar system planets. The main groups are Hot Jupiters, Hot Neptunes, Cold Jupiters, Super Jupiters, Super Earths, and Little Blue Dots:

Group	Characteristics
Hot Jupiters	$0.5M_{Jup} < m < 13M_{Jup}$ $a < 1AU$
Hot Neptunes	similar to Hot Jupiters, but lower masses $m_{min} = 0.03M_{Jup}$ (to be able to maintain hydrogen atmosphere)
Cold Jupiters	often small host stars $a > 2AU$ resemble Jupiter itself (especially when rotating quickly)
Super Jupiters	$5M_{Jup} < m < 13M_{Jup}$ upper mass limit $m = 13M_{Jup} -> $ transition mass to brown dwarfs.
Super Earths Jupiters	$1.5M_{\odot} < m < 10M_{\odot}$ smaller Super Earths are more likely to be rocky composition
Little Blue Dots	$m < 1.5M_{\odot}$ ('Exo-Earths') in habitable zone, so that liquid water can exist ('Goldilocks planets') oxygen-rich atmosphere + other requirements for humans to live there

Detection methods

Orbital distances of exoplanets discovered so far range from a = 0.0058AU to a = 2000AU. The closer they orbit their host stars, the smaller the angular separation, meaning a direct observation of the planets is extremely difficult. Furthermore, the host stars are usually much brighter than their companions, so that they can hardly be seen directly. This is why mainly indirect detection methods are used. Common detection methods for exoplanets are:

- Astrometry
- Direct Imaging
- Radial velocity
- Transit
- Microlensing

For the activity described here, we will focus on the transit method. The transit method works if a planet (periodically) passes between the host star and the observer, called a 'transit'. As the planet transits, it blocks some fraction of stellar light, thus the intensity of the star's light drops, which can be detected. However, if a planet is too small compared to the star, it will not block any light, therefore this method only works for sufficiently large planets. A variation of this method, observes specifically the transit time of a planet, hence it is called the 'transit timing variation' (TTV). Tiny variations can help detecting a companion of a star. The most popular missions that used this method are 'Kepler' (2009 - 2018) and 'Transiting Exoplanet Survey Satellite' (TESS) (2018 - recent).

HYPOTHESIS GENERATION AND DESIGN

Generation of Hypotheses or Preliminary Explanations

In this activity, you are trying to detect an exoplanet. But a scientist cannot just do whatever he/ she likes. They have to come up with a hypothesis that summarizes what they want to study and why that is important. To find a hypothesis, it is a good idea to ask yourself some questions that you would like to answer with this activity. Some example questions are given below:

- Which host star would be best to investigate? Why?
- Which data would we need?
- What can be do to strengthen our results?

A hypothesis usually consists of many sentences and should always contain a statement (WHAT?) and then an explanation (HOW?).

PLANNING AND INVESTIGATION

Here you can see the planned schedule for this activity and the tools used for each individual part:

Activity	Duration	Tools used
Energizer	~10 minutes	
Presentation	~30 minutes	**Stellarium**
Detecting an exoplanet I	~15 minutes	**SalsaJ**
Break	~10 minutes	-
Detecting an exoplanet II	~25 minutes	Excel
Telescope session*	~30 minutes	**Faulkes telescope**

*Back-up activity in case the session is not working: http://exoplanet.eu/; Quiz using Mentimeter

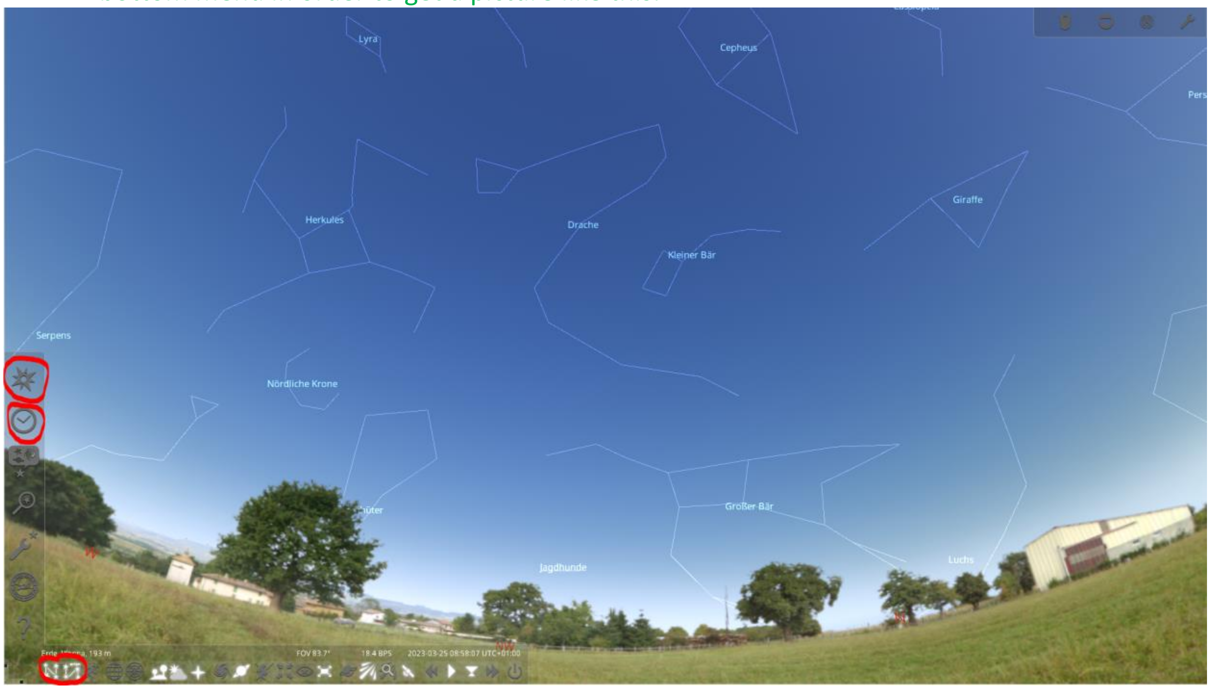
The **energizer** will be chosen by the teacher and can be any activity that will "activate" the students' brains.

The **presentation** consists of information about exoplanets, for instance:

- Exoplanet definition
- Number of confirmed exoplanets
- Location & distance to exoplanets
- Composition of exoplanets' atmospheres
- Habitable zones of exoplanets
- Purpose of researching exoplanets
- Naming exoplanets
- Different exoplanet detection methods
- …

To create a more interactive presentation, *Stellarium* can be used:

1) Open *Stellarium* and enter a location you want to see by clicking on the first icon of the left panel.
2) Click on the icons "star constellations" and "constellation names" on the left side of the bottom menu in order to get a picture like this:



3) See if the children are able to recognize some star constellations; guide them through the sky using the indicators for North, East, West, and South and tell them a bit about the most common constellation, where and how to find them, etc.
   Note: this is a frozen picture for a specific time – the view of the sky will change as time goes on!
4) Next change the time of observation (second item from the top in the left menu) to an evening/ night time to get a darker sky as can be seen in the next picture.
5) Now you can click on the icon "exoplanets" in the bottom menu (in red circle) and green dots will appear all over the sky, marking where exoplanets are located.
6) If you zoom into the sky, more and more dots will appear, i.e., you will see more and more exoplanets.
7) If you click on one dot, you will also get some more information about the selected exoplanet.

8) Play around for some time with the application before proceeding to the next step

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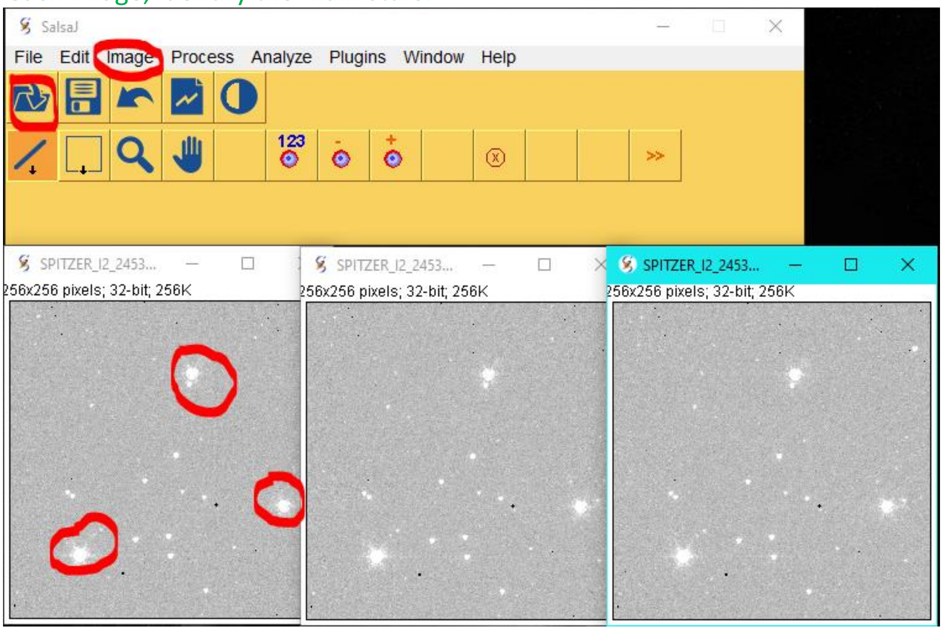
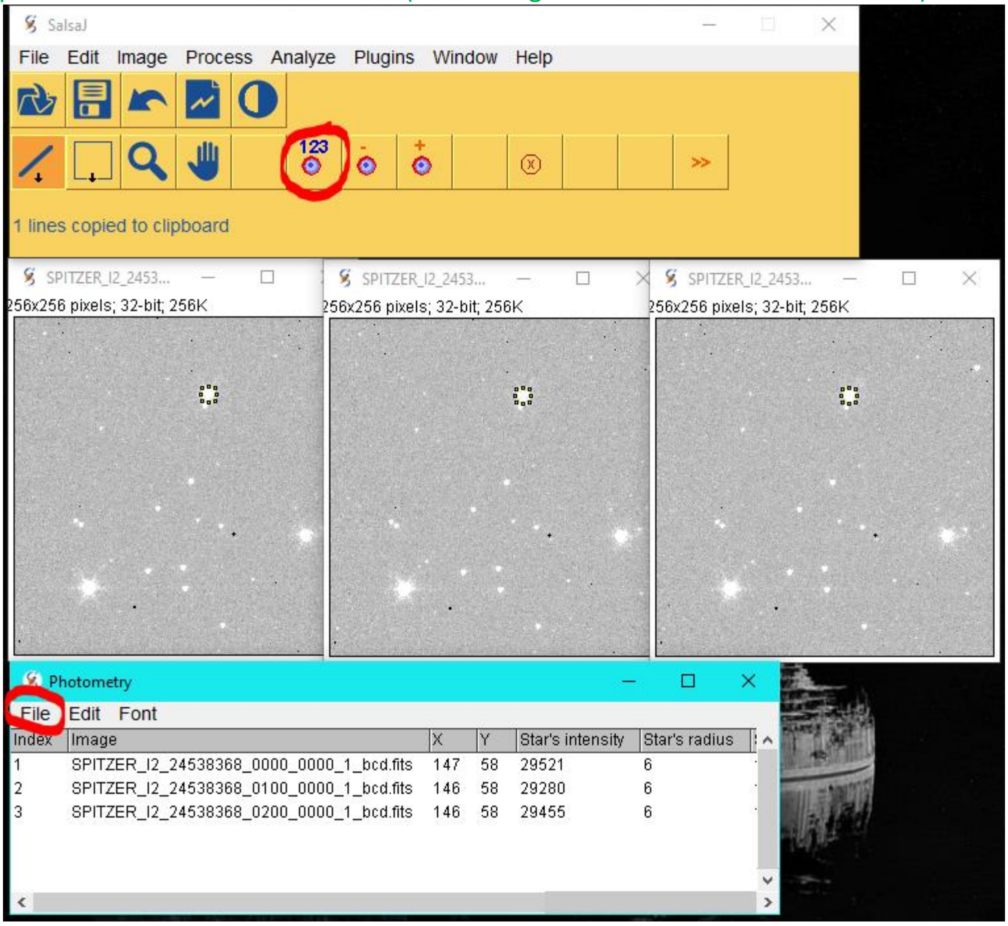
For the first (more theoretical) part of the **detection** session, *SalsaJ* will be used. Show students how an exoplanet can be spotted using images of stars taken by robotic telescopes. The following steps outline the idea:

1) Open SalsaJ and at least 3 images of stars (that you downloaded from e.g. the Faulkes Archive).
2) You might need to adjust the Brightness/Contrast: click on “Image” – “Adjust” – “Brightness/Contrast…” & change the colors and brightness to get a grey image; you can apply the same setting to all open images by clicking on “set” and then click the box “Propagate to all open images”.
3) On each image, identify the main stars:



4) Click on the Photometry icon; a photometry window will appear and your pointer will become a brightness sensor. If you now click on some point of the image, the light intensity (in computer units) at that point will be stored in the photometry window.

5) Measure the intensity of one star in all the pictures you have opened. All the data will be saved in the photometry window.
6) Once you are done, copy the data into an Excel sheet and repeat the intensity measure process with the other main stars (also saving each dataset to the Excel sheet).



7) This is how you can create the datasheets the you can then hand out to your students

For the second part, the students will need to get active. What they have to do will be further explained in “Plan investigation” and “Perform investigation”. The teacher has to prepare the following materials (before the activity starts):

- Data sets of different stars gained from *SalsaJ* (printed out – see process above)
- Calculations of light intensity averages & normalizations to check with the students’ results (e.g. Excel) (see “Perform Investigation”)
- Graphs based on those calculations (e.g. Excel) for further analysis (see “Perform Investigation”)
- Schedule a live telescope session for that day/ time (if possible)

Plan Investigation

Now that students know the basic principles of how to spot an exoplanet using images of stars, let them think about how they can actually do some calculations. Ask them the following questions to provide guidance:

- How do you know which light intensity value is useful if you have that many different ones?
- Do you randomly choose a value or is there a way you could calculate one?
- The values are time-dependent. How can you account for that? What do you need to consider? How can you put different values into relation?

- Which information would you need if you want to create graphs out of the data? Can you imagine how the graph would look like? Where could the “drop” of light intensity be?

Perform Investigation

Each image has been taken at a different time and conditions. Hence, we need to normalize the data. Do you have an idea on how to do that?

- Calculate the mean intensity of your data
- Subtract the mean value from each intensity value

With the gained normalized data, you can plot the intensity of each star against the time (the observational date & time can be found under “Image” – “Show Info…”

ANALYSIS & INTERPRETATION

With the normalized data, can you already spot an exoplanet? Can you already suspect a drop in brightness of one of the main stars?
If not, it will be useful for you to plot the intensity vs. the time. In the graph you should then be able to see a drop in brightness.
What else can you tell from this graph?
What can you say about the exoplanet that you found?
Is there anything else you might be able to calculate? For instance, physical parameters of the planet?

CONCLUSION & EVALUATION

Conclude and communicate result/explanation

A major part of an astronomers’/ astrophysicists’ work is presentations of their results, for example at conferences, in workshops or in research papers. Put together a presentation or a poster that includes the following sections:

- Methodology (What did you do? How did you do it? Which tools did you use?)
- Results (What did you find? Show images, graphs, data, …)
- Conclusion (Summarize your activity. What would that mean for the future?)

When each group has presented their work, come together and discuss open questions or “wrong” results. A group might have got stuck at some point. What advices would other groups give? How can they help each other?
Science is a lot about team work!

Evaluation/Reflection

Keep discussing about the activity and reflect: Comment on how well your investigation went.
Were there major problems or limitations? How did you solve them?
How would you improve the activity?
Is there something you would have like to learn more of?
What was easy to do?
How do your results differ/ match and why?