Students in search of an Earth 2.0

Teaching materials

Front image source: pixabay.com

Image sources in this workbook:

Figure 1 (pixabay.com), Figure 2 (pixabay.com), Figure 3 (A. Küpper), Figure 4 (A. Küpper), Figure 5 (Screenshot from the App of Hissel et al.), Pc 6 (A. Küpper), Figure 7 (A. Küpper), Figure 8 (A. Küpper), Figure 9 (A. Küpper), Figure 10 (A. Küpper), Figure 11 (A. Küpper), Figure 12 (A. Küpper), Figure 13 (A. Küpper), Figure 14 (pixabay.com), Figure 15 (Collage from Pictures of pixabay.com), Figure 16 (Collage A. Küpper, Background: Mars surface of NASA), Figure 17 (A. Küpper), Figure 18 (A. Küpper), Figure 19 (A. Küpper), Figure 20 (A. Küpper), Figure 21 (A. Küpper), Figure 22 (A. Küpper), Figure Certificate (pixabay.com)

Back image source: pixabay.com

Development & Design:
Alexander Küpper
University of Cologne
Institute of Physics Education
Gronewaldstr. 2
50931 Cologne – GERMANY

E-Mail: alexkuepper@yahoo.de

Translated for astro-lab.app by: Sebastian J. Spicker

Version: April 2021

„Students in search of an Earth 2.0“ – Station 1

The transit method

Station 1 in a nutshell:

The search for exoplanets is not so easy. In this station, you will develop or learn about one way astrophysicists search for exoplanets.

Research assignment 1:

The two images show a solar eclipse on Earth (left) and an exoplanet passing in front of its star (right).

Figure 1: Solar eclipse.

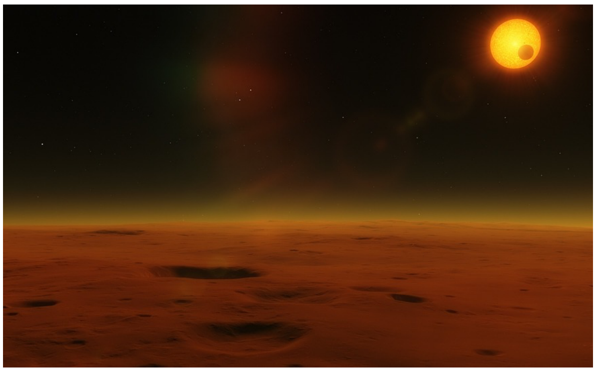


Figure 2: Exoplanet in front of its star (seen from the surface of another exoplanet).

Explain how a solar eclipse occurs on Earth.

List similarities and differences in the two pictures.

Research assignment 2:

Develops a way to find exoplanets orbiting other stars using Research assignment 1.

Research assignment 3:

Now you are a real astrophysicist. With the help of a special computer program you can measure the brightness of two "stars" as a function of time. The program will draw you a diagram directly. The curve in the diagram is also called "light curve".

Measure the brightness of the star 1. Sketch the measured diagram.

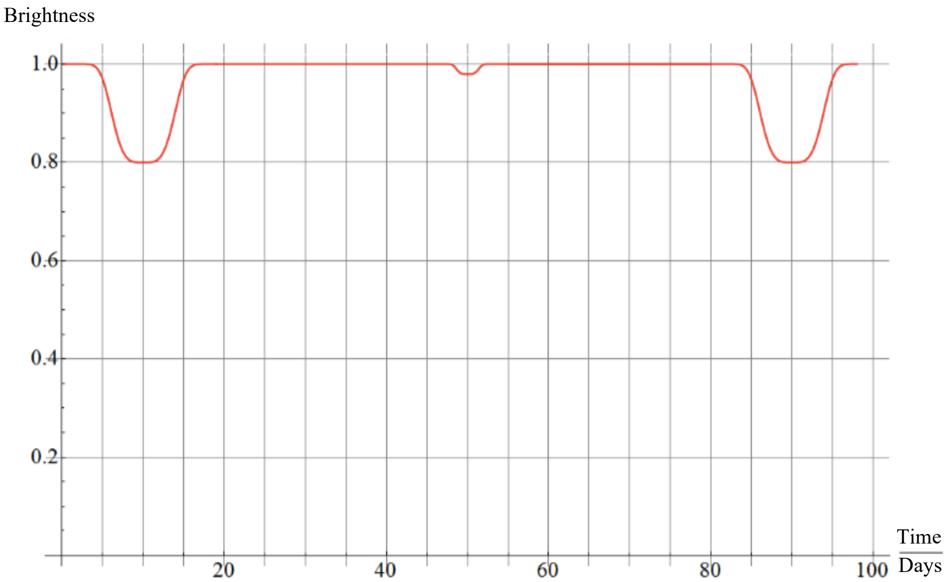
Measure the brightness of the star 2. Sketch the measured diagram.

Decide if a "planet" is moving around the "star" by looking at the light curve.
If a "planet" moves around the "star": Determine the orbital period T.

The corresponding experiment is in the next room. Check your answers from the last part of the task by looking at the experiment. Describe your observations.

Research assignment 4:
Can you detect any exoplanet using the method you developed? Give reasons for your answer!

Bonus assignment:
A group of astrophysicists measured the following light curve of a star:



Analyze the light curve and make a guess about possible exoplanets around the star.

„Students in search of an Earth 2.0“ – Station 2

Atmospheric composition

Station 2 in a nutshell:

It is of very special importance to know the composition of the atmosphere. But how to find out if there is e.g. oxygen in the atmosphere of an exoplanet.

At the beginning you will deal with the light spectrum of stars. You will look at a star whose spectrum you can observe without a telescope: the sun.

Research assignment 1:
Point your spectroscope at the sky and observe the solar spectrum with your spectroscope. Describe the spectrum.

Safety note: Never look directly into the sun with the spectroscope!

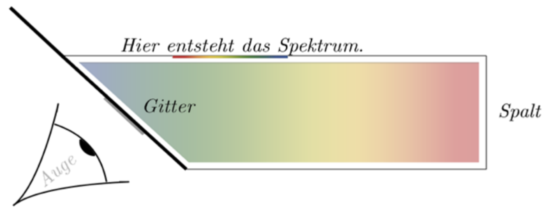


Figure 3: Where the spectrum is created.

Research assignment 2:
When the light is emitted from the surface of the sun, the spectrum still looks like the spectrum of an ordinary light bulb. The light then passes through the sun's atmosphere on its way and then passes through the space between the sun and the earth. It passes through the earth's atmosphere and enters your spectroscope.

Figure 4: The system sun/earth.

Write the terms: solar surface, solar atmosphere, Earth's atmosphere, and Earth's surface in the correct places in the figure above.

Make a guess: At which points on the path of light from the surface of the sun to the surface of the earth do the dark lines (they are called absorption lines) appear in the spectrum? Give reasons for your answer!

Bonus assignment:

A classmate of yours claims that the absorption lines in the solar spectrum do not originate in the Earth's atmosphere. Propose a mission to your national space agency to verify this statement.

Research assignment 3:

A classmate of yours (also) made the assumption in Research Assignment 2 that the absorption line(s) in the solar spectrum are caused by the sun's and Earth's atmosphere. But is that true?

In our app, you're standing in a lab (pictured right). Observe what happens when you fill different gases into the glass bell jar. Write down your observations.

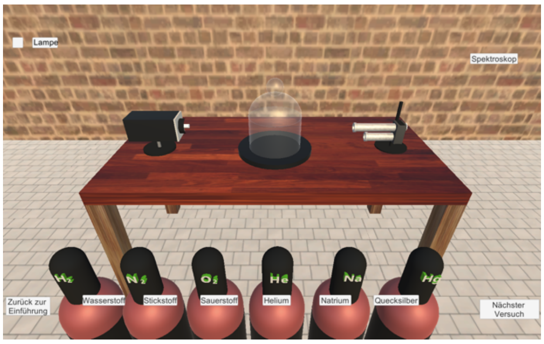


Figure 5: A look inside our virtual lab.

What does the spectrum look like when you fill sodium into the glass bell jar. Complete the figure below so that it looks like the spectrum in the experiment.

Figure 6: The spectrum of an ordinary light bulb to complete.

Research assignment 4:
Using the dark absorption lines in the spectrum, you can even determine the composition of stars and exoplanets. This research assignment shows you how to do this:

In a sodium vapor lamp, sodium gas is heated to a temperature of +1000°C so that it emits light by itself. Observe this light with your spectroscope and describe your observations.

In a newspaper article in 1860, Kirchhoff and Bunsen wrote the following text:

It can be concluded from this that the solar spectrum with its dark lines is nothing else than the inversion of the spectrum which the atmosphere of the sun would show for itself. According to this, the chemical analysis of the solar atmosphere requires only the search for those substances which, brought into a flame, cause bright lines to appear which coincide with the dark lines of the solar spectrum (Kirchhoff & Bunsen, 1860)[1].

Explain in your own words how to determine the chemical composition of the solar atmosphere from the solar spectrum.

[1] Text source: Kirchoff & Bunsen (1860): Chemische Analyse durch Spectralbeobachtungen, Analen der Physik und Chemie. Translated by the authors.

A physicist has recorded the spectrum of a star.

Figure 7: The spectrum of a star.

Determine the chemical composition of the stellar atmosphere with the spectral table. Describe your procedure.

At a later time, an exoplanet is in front of the star. Meanwhile, a physicist has recorded the star's spectrum.

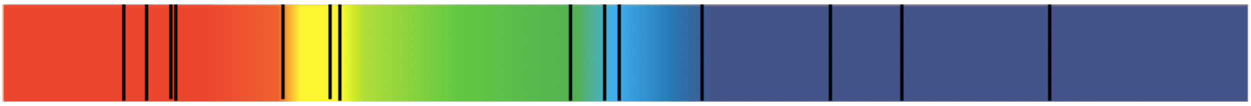


Figure 8: Spectrum of stellar and exoplanet atmospheres together..

Determine the chemical composition of the exoplanet atmosphere with the spectral table. Describe your procedure.

„Students in search of an Earth 2.0“ – Station 3

Surface temperature

Station 3 in a nutshell:

For life as we know it to develop, water in liquid form is necessary. For this, the temperature should be between 0°C and 100°C (assuming an Earth-like atmosphere). For this, the temperature of the star plays a decisive role.

Research assignment 1:
First, you need to find out how astrophysicists can determine the temperature of a star. For an analogy experiment, you need a light source with a variable temperature. How can such a light source be realized in an experiment? Write down your ideas.

Research assignment 2:
Observe the light source from Research Assignment 1 at low and high temperatures using your spectroscope.

Make a sketch of each of the spectra.

Sketch of the spectrum at low temperature.	Sketch of the spectrum at high temperature.

Describe the differences in the two spectra.

Research assignment 3:
Transfer the results from research assignment 2 to a star and complete the mnemonic:

The higher the temperature of a star, the ________________________________.

Research assignment 4:
A group of astrophysicists used a spectroscope to record various stellar spectra at night.

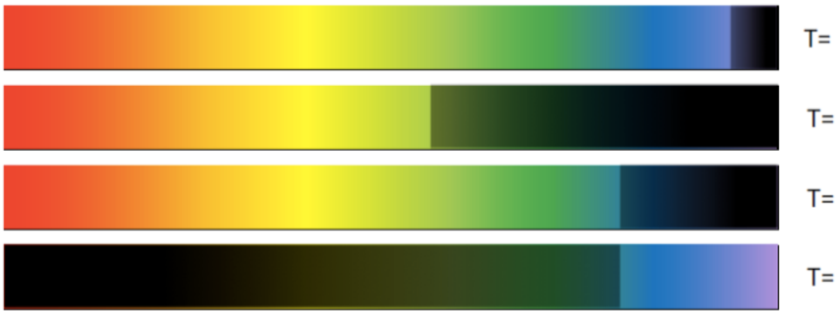


Figure 9: Different star spectra.

Assign the following temperatures to the spectra:

3.500°C, 6.000°C, 10.000°C, 50.000°C

Write the temperatures in the boxes to the right of the spectrum.

Research assignment 5:
The "Habitable Zone" is an area around a star where water can exist in liquid form. Physicists have determined the inner boundary (blue measurement points) and the outer boundary (orange measurement points) of the Habitable Zone for different stellar temperatures.

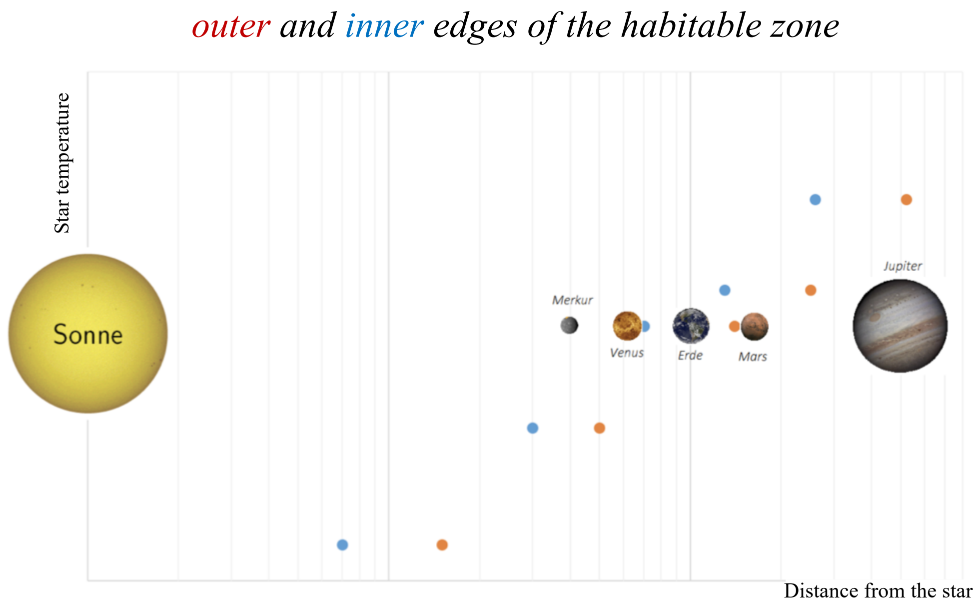


Figure 10: A diagram of the Habitable Zone.

Connect the related points with a curve.
In addition, some planets of our solar system have been plotted in the diagram in Figure 10.
Name all planets that are located in the Habitable Zone.

In a second diagram - for the outer and inner boundary the measuring points were already connected - the planets around the star Kepler 90 were drawn.

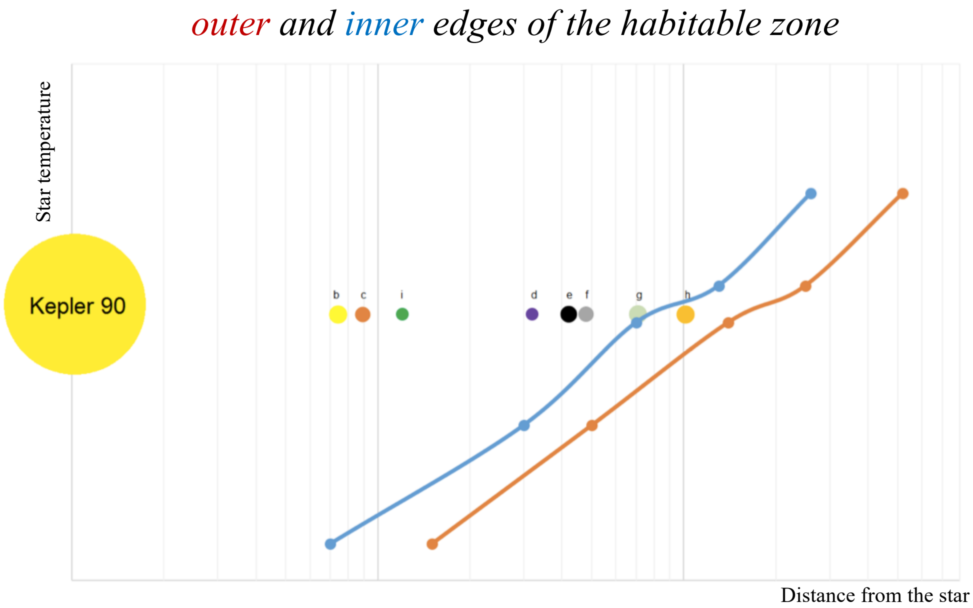


Figure 11: A diagram of the Habitable Zone with exoplanets around Kepler 90.

Name the number of planets orbiting the star Kepler 90.

Name the exoplanets around Kepler 90 that are in the Habitable Zone.

„Students in search of an Earth 2.0" – Station 4

Dangerous UV radiation

Station 4 in a nutshell:

For life as we know it to develop, water in liquid form is necessary. For this, the temperature should be between 0°C and 100°C (assuming an Earth-like atmosphere). The temperature on an exoplanet is therefore determined to a large extent by the temperature of the star.

Research assignment 1:
Make a sketch of the spectrum of an ordinary light bulb.

Spectrum of an ordinary light bulb.

Research assignment 2:
In an experiment, light is split into its spectral colors. The spectrum is collected on a so-called zinc sulfite screen. Wait about one minute.

Compare the light bulb spectrum from research assignment 1 with the spectrum on the zinc sulfite screen. If necessary, supplement the sketch in research assignment 1.

Explain that there are areas in the spectrum of an incandescent lamp that the human eye cannot perceive. What do you call the radiation you have detected?

Replace the zinc sulfite screen in the experiment with a "Sun Doll". Decide (with justification) whether the radiation you have detected is dangerous for living beings.

Research assignment 3:
An astrophysicist recorded the spectra of two stars at night.

Figure 12: Star Spectrum No. 1.

Figure 13: Star Spectrum No. 2.

Both stars are orbited by an exoplanet. Decide (with reasoning) on which of the two exoplanets life is more likely to have evolved.

Research assignment 4:
Can you actually tell if a star emits a lot of UV radiation when observing the night sky with the naked eye? Find out!

The photo on the right shows the constellation "Orion". Describe what you can see in the photo.

Figure 14: The "Orion" constellation.

Make a guess as to which of the stars in the constellation Orion emits the most UV radiation.

Check your assumption in the experiment. Describe how you proceeded.

„Students in search of an Earth 2.0" – Station 5

Atmospheric pressure

Station 5 in a nutshell:

Liquid water is important for life on an (exo)planet. But what does the state of water depend on besides temperature? For this, you will first take a closer look at the planet Mars in our solar system.

Research assignment 1:
You probably already know the three states of water: gaseous, liquid and solid.
In the following overview graphic, label the arrows with the terms sublimate, re-sublimate, melt, boil, solidify and condense.

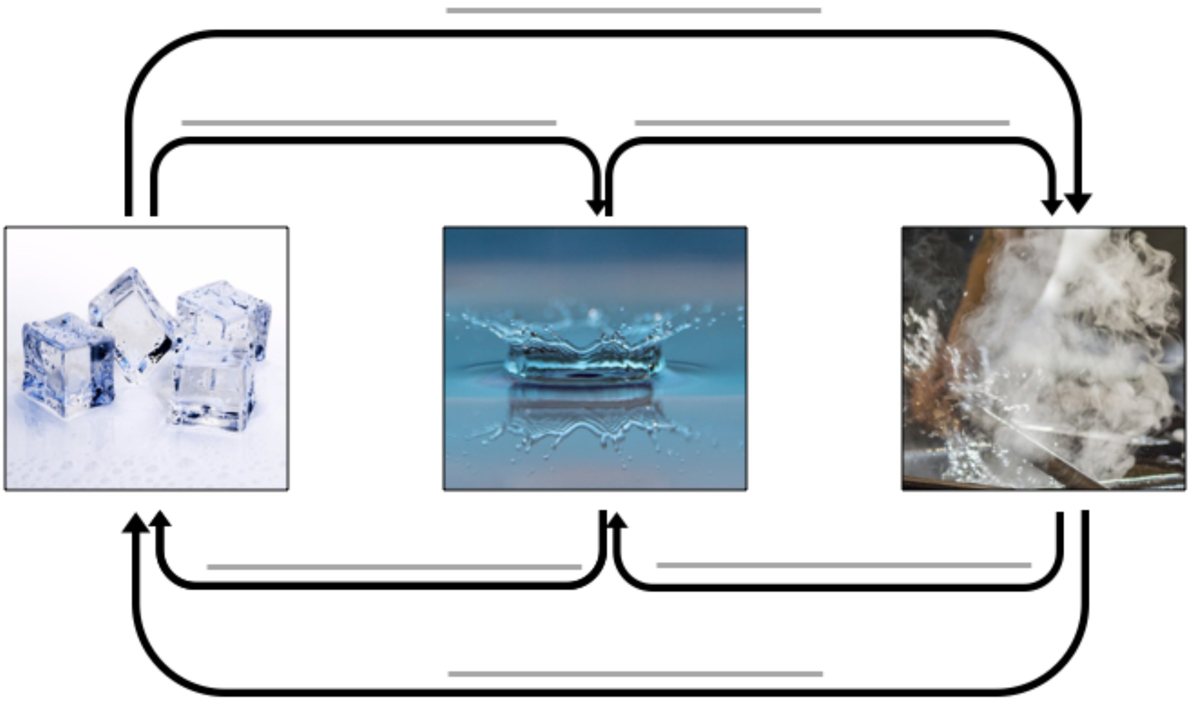


Figure 15: State forms of water.

Research assignment 2:
Temperatures on Mars near the equator sometimes climb to +20°C during the day and drop to about -80°C at night. Make a guess whether water can exist in liquid form on Mars. Write down your guess.

Research assignment 3:
Despite suitable temperatures, there is actually no liquid water on Mars.
Since the formation of the planet Mars, the Martian atmosphere has been eroded over time due to several physical effects. The atmospheric pressure decreased more and more, so that today there is only a very low air pressure of 0.006 bar on Mars. For comparison: On Earth, the atmospheric pressure is about 1.013 bar.

To recreate the conditions on Mars, you need to reduce the air pressure in an experiment. The Martian atmosphere is to be recreated in a syringe. How do you proceed to reduce the air pressure in the syringe? Describe your procedure!

Investigate and describe (using technical language) how liquid water behaves under low atmospheric pressure.

Explain what happened to the originally existing (liquid) water on Mars.

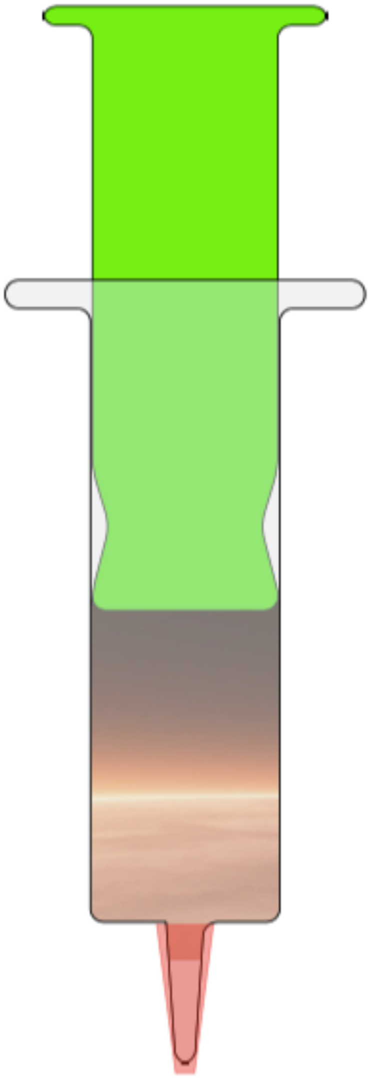


Figure 16: Syringe for simulation of the Martian atmosphere.

Research assignment 4:
You have already found out that the state forms of water depend not only on the temperature, but also on the atmospheric pressure. A physicist has recorded the following state diagram of water in an experiment.

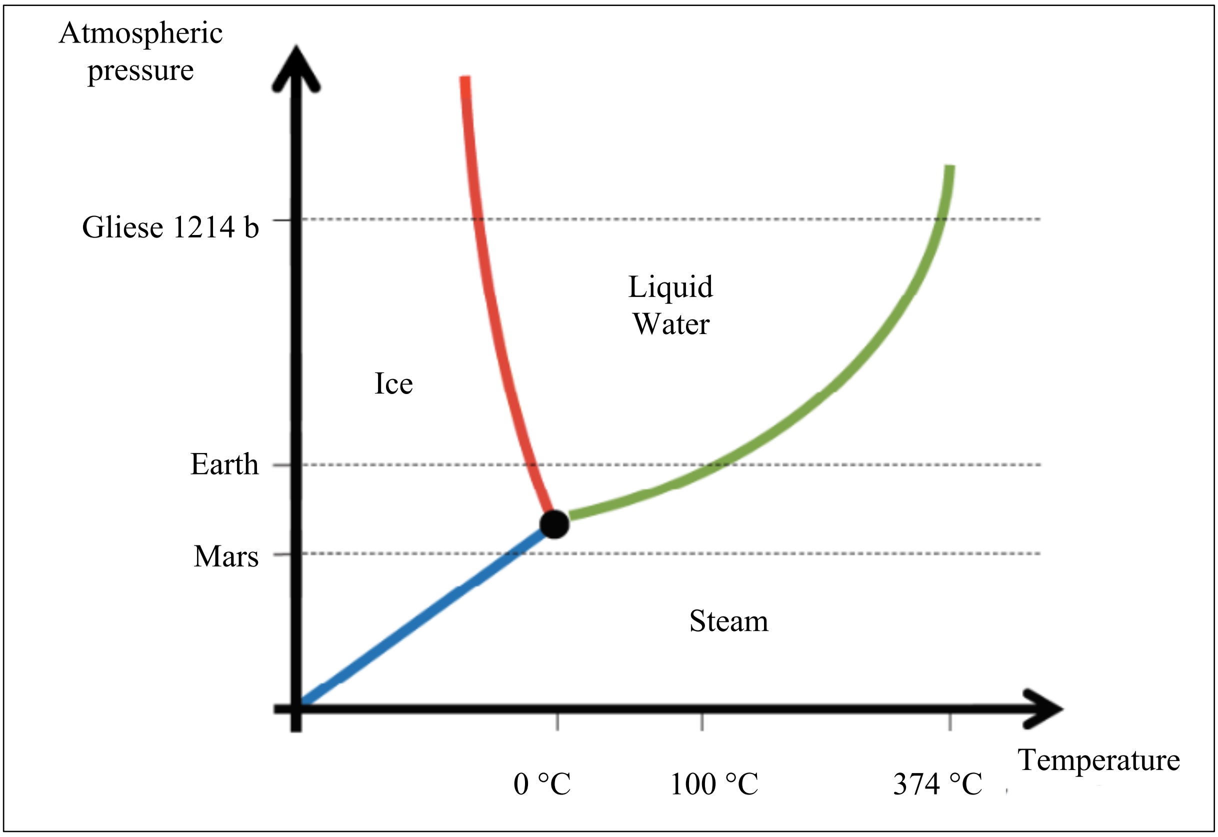


Figure 17: The phase diagram of water.

Describe the diagram as accurately as possible.

The temperatures at the equator of the planet Mars change in the course of a day partly from -80°C at night to +20°C during the day. Explain whether water can exist in liquid form on Mars.

According to estimations, the temperature on the exoplanet Gliese 1214b is between +121°C and +282°C. Nevertheless, physicists assume that the exoplanet is a water world with liquid water. Explain how this is possible.

„Students in search of an Earth 2.0“ – Station 6

Greenhouse effect

Station 6 in a nutshell:

On Earth, the average temperature is currently rising due to so-called greenhouse gases. Do greenhouse gases also play a role on other planets? To answer this question, first consider the planet Venus in our solar system.

Research assignment 1:
Using a thermal imaging camera, explain: "Every warm body emits 'thermal radiation'".

Note: If your school does not have a thermal imaging camera, you can use the photo.

Abbildung 18: Thermal image.

Research assignment 2:
If you compare the surface of Venus with the surface of the Earth, you can see that there are thousands of volcanoes spread across Venus. A single volcanic eruption on Venus releases huge amounts of carbon dioxide (CO_2). Therefore, the Venusian atmosphere today consists of 97% CO_2.
Venus also emits thermal radiation. Plan an experiment to investigate how CO_2 behaves compared to "air" when irradiated with thermal radiation. Write down your procedure. CO_2

Hint: Use the materials in the photo on the right.

Figure 19: Materials for the Experiment

Research assignment 3:
Perform your experiment from research assignment 2. Measure the temperature in the vessels every 60 seconds and record the results in the table below.

TIME IN SECONDS	TEMPERATURE AIR IN °C	TEMPERATURE CO_2 IN °C
0		
60		
120		
180		
240		

Determine the difference between the initial and final values (in °C) and the temperature difference between air and CO_2 after 240 seconds.

How did air and CO_2 behave when irradiated with light? List the differences and similarities.

Research assignment 4:
The sun's rays heat the surface of Venus. The surface of Venus emits thermal radiation as a result of this heating.

What happens to the thermal radiation in the Venus atmosphere? Complete the drawing on the right.

Explain why Venus today has a temperature of about 460°C.

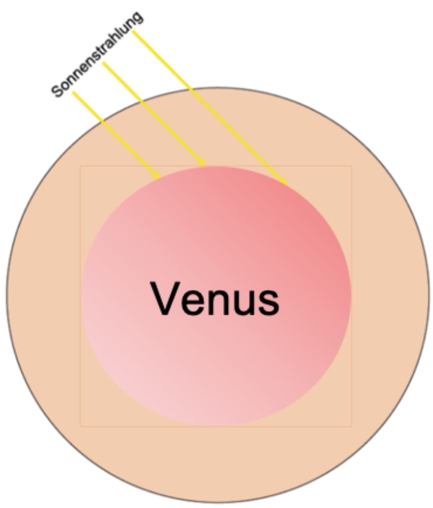


Figure 20: Solar radiation hits the venus.

Research assignment 5:
Greenhouse gases are gases that absorb the thermal radiation emitted by the planet's surface and do not allow it to escape into space. An example of such a greenhouse gas is CO_2.

Why is it necessary to know exactly the fraction of greenhouse gases in exoplanet atmospheres in order to infer the existence of liquid water? Give reasons for your answer!

Bonus assignment:
The Habitable Zone is the area around a star in which the exoplanet moves around its star at the correct distance for the presence of liquid water. In the diagram, the Habitable Zone is bounded by the blue and orange curves.

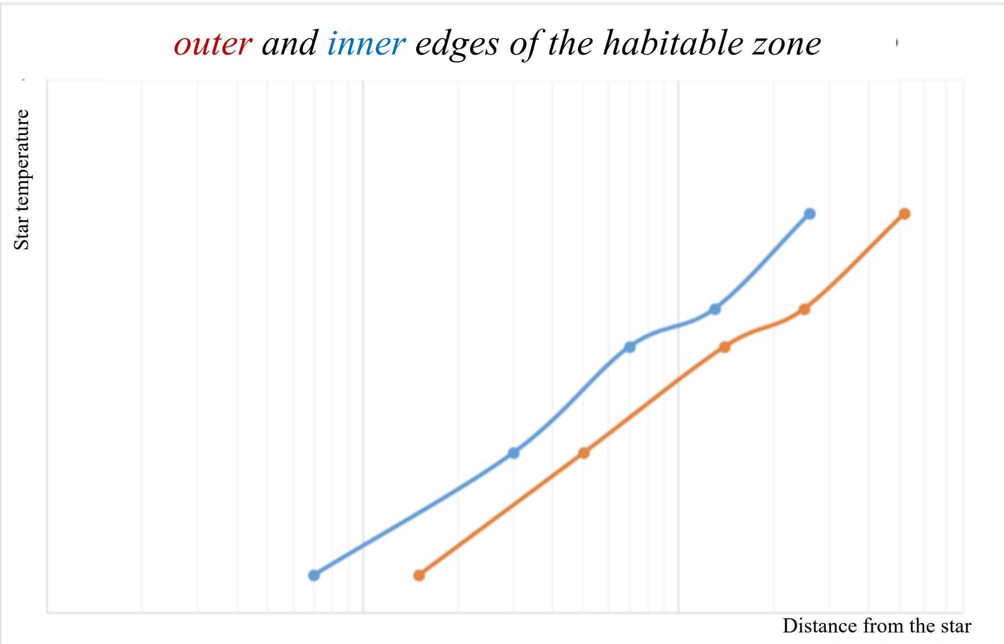


Figure 21: The Habitable Zone.

How does the position of the habitable zone change when the greenhouse effect is taken into account? Give reasons for your answer!

„Students in search of an Earth 2.0“ – Station 7

Reflectivity

Station 7 in a nutshell:

The reflectivity of an exoplanet also has an influence on the surface temperature of the planet. But what is the reflectivity and how is it determined?

Research assignment 1:
Design an experiment to investigate what happens to light when it hits planets with white and black surfaces. Describe your procedure and perform the experiment afterwards. State (using technical language) your observations.

Research assignment 2:
An important physical quantity for planets is the so-called "reflectivity". Physicists use this term to describe the amount of light that is not absorbed by a planet. Which of the planetary surfaces used in Research Assignment 1 has the greatest reflectivity? Give reasons for your answer!

Research assignment 3:
In this subtask, you will learn how to determine the reflectivity of exoplanets.
In the experiment, an exoplanet moves around a star. Draw the shape of the <u>shadow</u> on the exoplanet at the different observation periods.

Time 1	Time 2	Time 3	Time 4
			not applicable
Time 5	**Time 6**	**Time 7**	**Time 8**
			not applicable

Through more accurate measurements, physicists were able to record the following light curve of an exoplanet. Match the marked positions in the diagram with the positions of the exoplanet in the experiment.

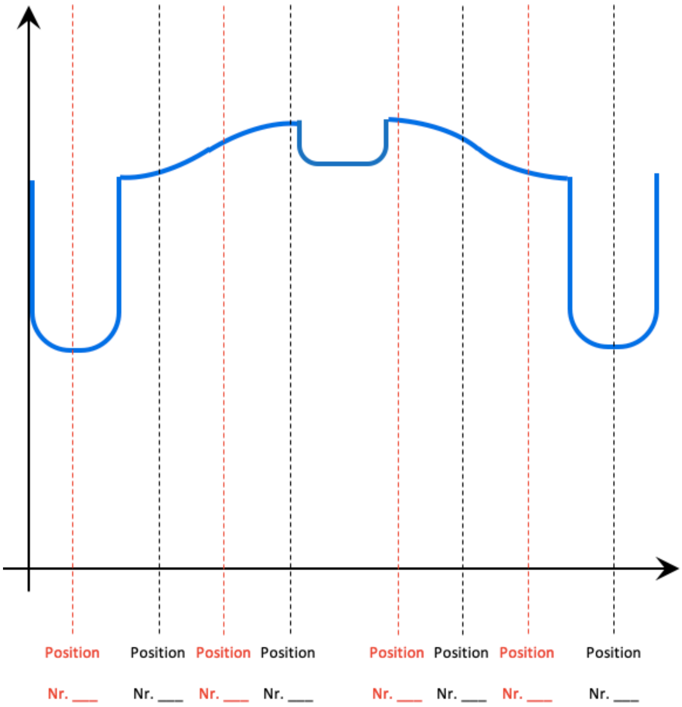


Figure 22: Light curve taking into account the reflectivity.

Explain why a decrease in brightness is measurable in the middle of the diagram. For which of the following exoplanet surfaces is this brightness decrease the largest?

"Snowball exoplanet", exoplanet with dark surface, exoplanet with green surface.

Give reasons for your answer!

Explain how the diagram can be used to determine the exoplanet's reflectivity.

Bonus Assignment:
635 million years ago the earth was like a huge ice ball whose ice could not melt even the intense solar radiation. State conjectures why the ice nevertheless disappeared after 15 million years and life could develop.

Hint: Think of the greenhouse effect.

With the teaching materials in this workbook, students use analogy experiments to work out how physicists go on the exciting search for life in the vastness of outer space.

Contents: Transit method, atmosphere of an exoplanet, temperature on an exoplanet (including consideration of greenhouse effect, atmospheric pressure and reflectivity), dangerous radiation.

The materials were originally developed for the student laboratory at the University of Cologne. However, they can also be used in regular lessons, e.g. as part of a station learning program.