Exoplanets at School – an educational program about hunting and analyzing exoplanets – meets the FREI-project

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***Abstract*— Since 2015, pupils (secondary level, grades 7-10) are able to conduct analogy experiments to explore at the school laboratory of the University of Cologne how to detect and analyze exoplanets. The experiments deal with various methods for the search for exoplanets (transit-method, direct imaging and astrometry), spectral analysis, the temperature of a star and the habitable zone, the greenhouse effect, the atmospheric pressure, the albedo, the influence of the solar wind and ultraviolet radiation on the probability of the existence of life. The experience gained has led to a continuous development of the experiments and the entire project, e.g by taking into account preconceptions of the pupils. In particular, the experiment about the transit-method was revised in the so-called FREI-project. The FREI-project is a remote-controlled laboratory (RCL) which allows to perform various physics experiments via the Internet. As a consequence, the exoplanet experiment – located at the University of Cologne – can be integrated into regular lessons by teachers around the world, since live streams and light curves are transmitted over the Internet. This article gives a brief overview of the individual experiments at the school laboratory and the experiences gained. In addition, the extension of the original transit-method experiment in the student laboratory to a FREI-experiment is described.**

Keywords—exoplanets, analogy experiments, transit method, FREI-project, physics teaching

I. Introduction

Physics is not a very popular subject at school in Germany and most of the pupils – especially girls – are not interested in the contents specified in the curriculum [1, 2]. In response to this fact, physics education in Germany should be context-oriented [3]. The results of the Relevance of Science Education (ROSE) study [2] show that female and male pupils are usually interested in different contexts: For example, only boys are interested in "technical contexts", while girls are much more interested in "Body and Health" [2]. If physics education wants to become more suitable for both boys and girls, it has to take into account the interests of both sexes. As the ROSE study [2] shows, the context "The possibility of life outside earth" is the most popular one for girls and boys. In order to motivate both girls and boys for physics, this context should be explicitly included in the school-lessons. How this can succeed, the authors of this article examine in a first step in the school laboratory "Our Spacecraft Earth" at the University of Cologne.

II. The Exoplanet Project at the School Laboratory "Our Spacecraft Earth"

In 2015, the first version of the exoplanet project for the school laboratory was developed [4,5]. In this project, pupils come to the university for a day to conduct analogy experiments on finding and examining exoplanets. In particular, the state variables density, composition of the atmosphere and the temperature at the exoplanet are considered in more detail. In order to determine the density, information about the radius and the mass of the exoplanet is needed. Information about the radius is obtained from the transit method [6]. An upper limit for the mass is obtained from the radial-velocity method [6] which has been added in an improved version of the original project.

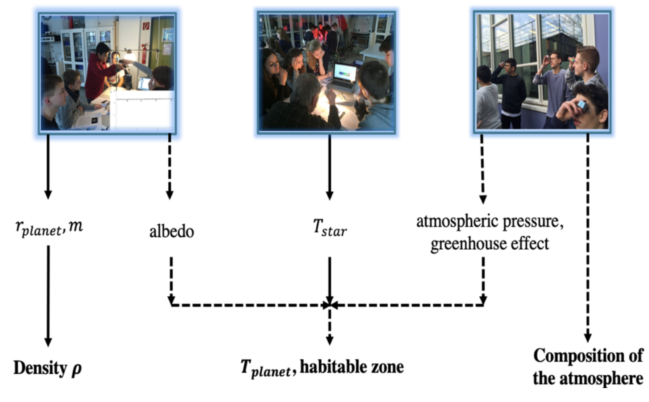

Fig. 1: Important state variables of exoplanets.

The composition of the exoplanets' atmosphere can be measured by the spectrum of the star within the primary and secondary transit [6].

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The location of the habitable zone is particularly influenced by the temperature of the star and the distance between the exoplanet and the star. Furthermore, the temperature at the exoplanet is influenced by the albedo of the planet, the atmospheric pressure and the greenhouse effect [6]. The temperature of the star can be determined by observations, for example from the spectrum and Wien's displacement law. The albedo results from the light curve which is measured by the transit method [8]. An experiment on the albedo has not been part of the first version of the project.
In addition to this other experiments deal with dangerous radiation like the solar wind and ultraviolet-radiation.
This article focusses on the transit method. Further information about the other experiments can be found in [4,5].

III. The Transit-Method in an Analogy-Experiment

When an exoplanet moves around the star, it temporarily covers a portion of the star for an observer on earth. By measuring the intensity of the star over time, many exoplanets have already been discovered [7].

A. The first version of the experiment

The aim of the experiment is the development of the transit method by the pupils. In addition, the pupils should test the method in an analogy experiment. As especially the development of the method is not easy, the pupils are supported by a bachelor-student. The setup of the experiment is shown in figure 2.

Fig. 2: Setup of the first version.

A motor is used to move a ball – the "exoplanet" – around a lamp – the "star". The intensity of the "star" can be measured with a solar cell. Using a computer program, the voltage generated by the solar cell can be plotted against time. The experiment is limited by the fact, that pupils get to know the transit method but not the limits of the method. Therefore, a second version of the experiment has been developed.

B. The second version of the experiment

As part of a seminar at the University of Cologne, the setup of the transit experiment has been expanded by students of the University of Cologne and the authors of this article. The reason for this expansion was the desire to show the pupils that not every exoplanet can be detected with the transit method. Therefore, a second lamp was added to the setup (compare figure 3).

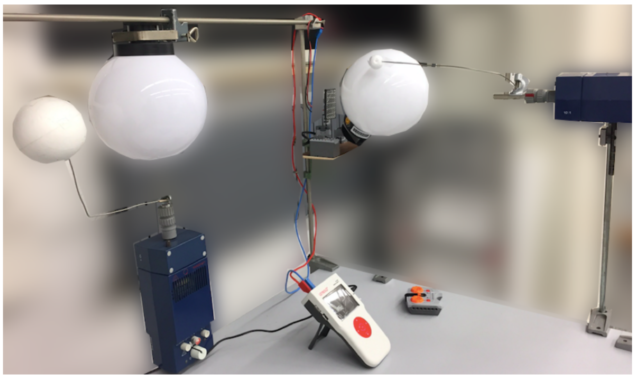

Fig. 3: Setup of the second version.

The intensity is measured by a solar cell, which can be directed by a motor on the respective lamp. The difference between these two „stars" in the inclination of the „exoplanet". While the „exoplanet" of „star" A (left lamp in figure 2) moves between „star" and solar cell, the „exoplanet" of „star B" (right lamp in figure 2) has an inclination of 90° and it does not darken the lamp from the solar cell's point of view. The experimental setup allows to compare the lightcurves of both situations (see figure 4 and 5)

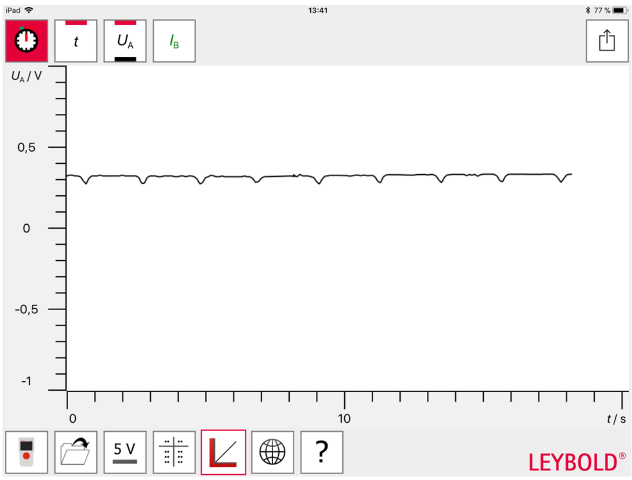

Fig. 4: Light curve of "star" A measured with CASSY Lab by LD Didactic.

Compared to the first version, the pupils do not see the structure of the second version at the beginning of the experiment, as this setup is placed in a different room. They only get information from the measured light curves. Typically, the pupils say that there is only an "exoplanet" moving around "star" A, as the intensity gets lower at regular intervals. At the next step a

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cognitive conflict is used when the pupils go to the room where the experiment is located and see that both "stars" have an "exoplanet" moving around it. Furthermore, they are able to observe why the "exoplanet" of "star B" can't be detected with the transit method. The current setup has some advantages over the old construction, like the possibility to understand the limits of the method.

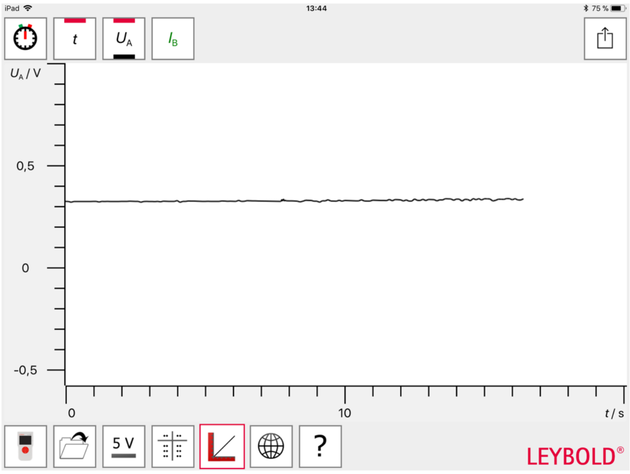

Fig. 5: Light curve of "star" B measured with CASSY Lab by LD Didactic.

A disadvantage is that a supervisor has to move the solar cell to generate the cognitive conflict. As a result of this aspect, a third version has been developed as a FREI-experiment.

IV. The FREI-project

A. *General information about the FREI-project*

FREI is an abbreviation for "**F**ernsteuerung von **r**ealen **E**xperimenten über das **I**nternet" [Remote control of real experiments via the Internet]. The project was developed at the Institute of Physics at the University of Applied Sciences Cologne (TH Cologne) as a way of giving rising numbers of Bachelor-students in Engineering the opportunity to perform a decent number of experiments in practical-work-classes, while reducing the time and manpower needed at the same time [10]. [11]. Remote-controlled experiments have a good learning effect when the experiment does not require a hands-on approach [10]. More technical details specifically for a remotely-controlled forced mechanic oscillation experiment can be found in [11].

The FREI-experiments can be controlled via the Internet. The user needs to register and log in to the FREI-Website www.frei-web-th-koeln.de using his E-Mail. Afterwards the user can join one of the setup courses with a password to get access to the experiments required for the practical-work-class and book a timeslot to perform the experiment. In this time the user gains exclusive access to a website that contains the input controls and output data of the chosen experiment. Many experiments also provide live data from a webcam.

The user's inputs are sent to a server that checks the request and forwards it to the lab-computer at the TH Cologne. There the data is used by a LabView-VI to set the required parameters in the experiment or perform certain actions. Furthermore, the website can request measurements in the same way. The measurement data is recorded by digital multimeters which the LabView-VI can read out directly. All those steps are necessary to make sure that no input sent by a student leads to an error in the controlling VI. Also, it prevents the student from having direct access to the computer at the TH Cologne.

For an experiment to be built for the FREI-project it needs to have an actor for any adjustment you want to set and a sensor for any data you want to get. The controlling VI needs to be accessible via the Internet all day with a fixed IP address so that the server can route data between the website and the lab-computer.

B. *The third version of the transit-experiment as a FREI-experiment*

The analogy-experiment for the transit-method is especially suited for remote control [9]. The pupils are not supposed to see the set-up before the measurements are completed and they have made a presumption if there is a "planet" orbiting the "star". Only after that they are supposed to control their guess.

For this reason, the third version of the transit experiment is built in three boxes. Each box contains a diffuse spherical lamp that is orbited by a plastic ball using an electro-motor. A solar panel is placed on the wall of the box to provide data for the lamp's intensity. The webcam is positioned directly next to the solar panel so that the image transmitted to the website is synchronized with the data gained by the solar panel.

The trajectories of the "planets" on "stars" 1 and 2 both have no inclination from the observer's perspective, but the setups are different regarding their scale. "Starsystem" 2 is 1.5 times bigger than "starsystem" 1. The difference can be seen in the intensity

Fig. 6: Third version of the transit-method-experiment

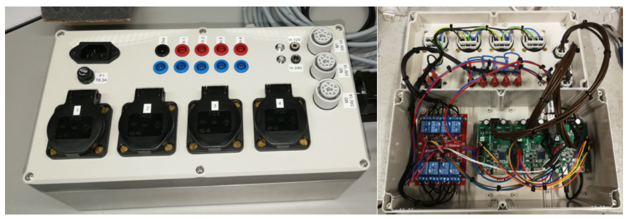

Fig. 7: central controlling unit

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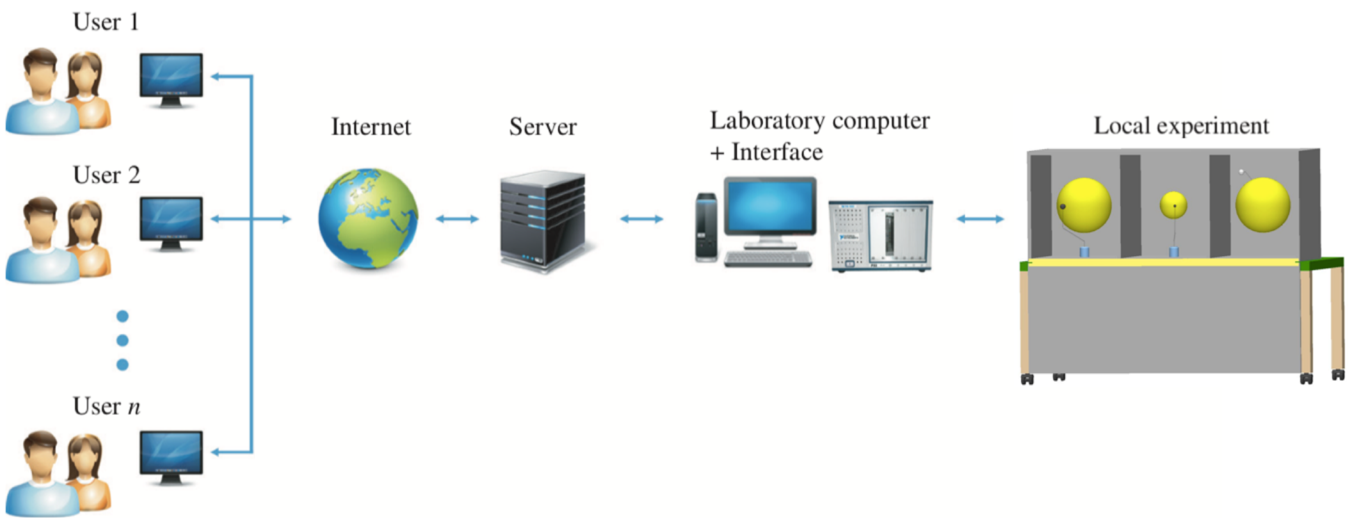

Fig. 8: Functional principle of the Exoplanet-FREI-Experiment. Reproduced and modified with permission of [10].

graph by a lower dip during the transit in system 2. The inclination on “star” 3 is 90°. This is achieved by placing the observing units (solar panel and webcam) on the lid of the box.

To activate the correct inputs and output, a LabView-VI sends requests to a Central Controlling Unit (CCU) via USB. This unit contains three driver modules – one for each of the motors – which can be accessed by the driver module’s software via USB. The lamps’ and the solar panels’ circuits are broken by a relay so that they can be activated on the switch of the maker. Each relay’s maker is therefore connected to one of the driver module’s outputs. At last the output of the CCU is connected to the digital multimeter that is linked to LabView (compare Fig. 8).

On the FREI website the pupils can choose one of the three “stars” to direct their “telescope” at. After starting the measurement, a diagram visualizes the intensity data. After stopping the measurement, the users are able to activate the webcam and thereby look directly at the set-up.

In contrast to the first two versions of the experiment the pupils’ perspective is limited to the webcam’s point of view. Because of that it is easier for them to understand why the “planet” orbiting “star” 3 can’t be found using the transit-method. On the other hand, the pupils don’t see the set-up with

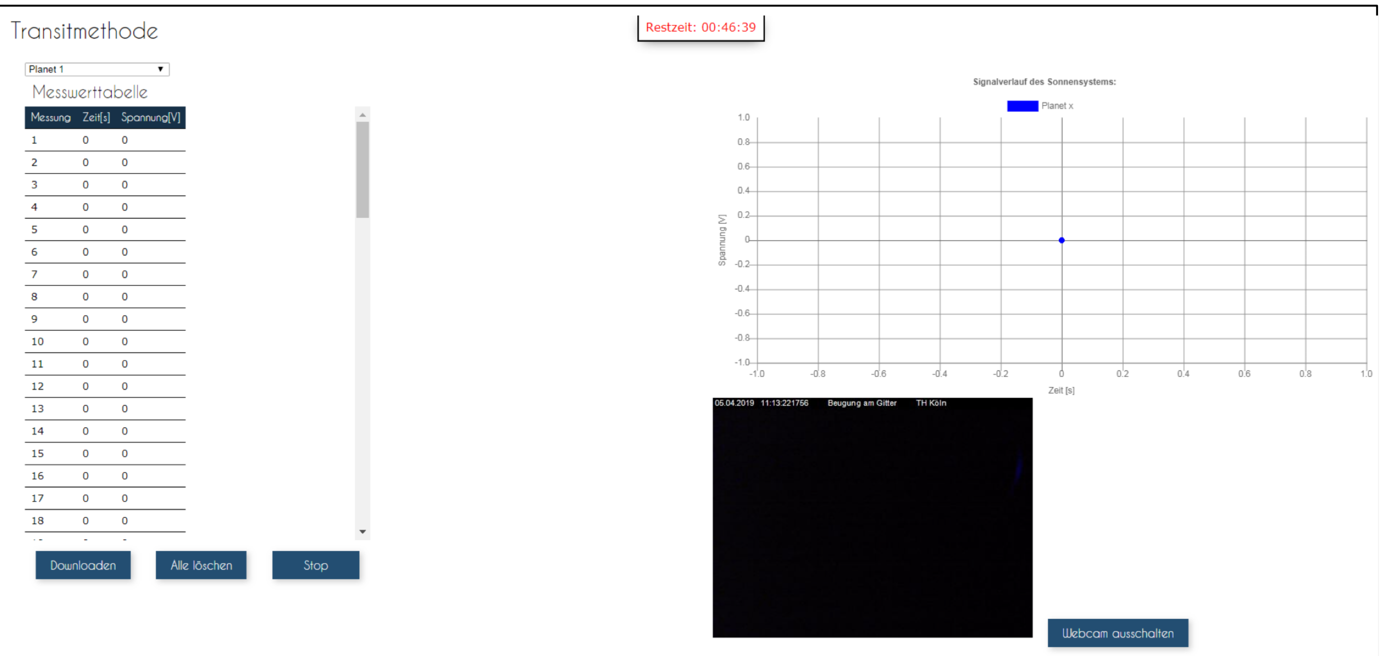

Fig. 9: FREI-Exoplanet-Website during the experiment

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their own eyes if the experiment is performed via the internet. They also do not have the opportunity to touch it or point at certain things.

First experiences with the third version have shown that it works pretty well and the biggest factors in pupils' learning success is the support by the supervisor and the concepts the pupils already know.

C. *Notes on the use of the third version in the school laboratory and in regular lessons at school*

In a first step, the FREI experiment will be further tested and improved in the school laboratory. It will initially replace the second version of the transit experiment and form its own station in the experiment cycle at the school laboratory. Following the testing and further development, the experiment will also be made available to teachers via the Internet for their regular lessons. The experiment can be used as a demonstration experiment as well as a student experiment. It should be noted that only one user at a time can perform the experiment. The method "student experiment" can be realized as part of a learning cycle or as homework. Worksheets are developed for all these options.

V. Outlook

The current version of the FREI experiment consists of three different setups which deal with different aspects of the transit method and the light curve. In a next step, the experimental setup will be further supplemented so that additional aspects can be taken into account. For example, with the help of the FREI experiment, the search for exomoons should be considered more closely. In addition, the experimental setup can be extended so that the phase effect of exoplanets can be considered.

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