Challenge Proposal: Chronicles of Exoplanet Exploration

Title: Exploring Exoplanets: Experimental Models and Graphical Narratives

Abstract:

This educational proposal aims to carry out a series of staged activities designed to engage students with the field of astronomy, particularly in the detection and identification of exoplanets using the transit method. To achieve this, the project intends to **adapt and implement an experimental setup for generating light curves**. Proper interpretation of light curves requires the development of scientific thinking skills[1], paired with the integration of concepts surrounding exoplanetology. This is contrasted with the construction of visual narratives that accurately describe an exoplanetary system based on its corresponding light curve.

In the specific case of interpreting generated light curves, active learning allows students to practically experience scientific concepts, facilitating a deep understanding of the transit method for exoplanet detection. The teaching methodology is structured at different levels to accommodate varying technological access, promoting learning through hands-on activities, sensory exploration, and creative use of digital tools to inspire students to visualize and comprehend the complexity of exoplanetary systems.

It is expected that, upon implementing the proposal, students will connect with the scientific vocation of exoplanetology by applying data processing and analysis methods to generate visual narratives. These narratives will form a model image of the exoplanetary system's correct appearance, in line with scientifically validated criteria.

DETAILED PROJECT DESCRIPTION

General Objective:

To develop a set of **didactic strategies and experimental models** that enable individuals at different educational levels to explore the detection and identification of exoplanets using real and simulated data, combining sensory experiences, graphical narratives, and technological tools in accordance with available resources and access levels.

[1] Inquiry, Observation, Analysis and Interpretation, Exploration

Specific Objectives:

1. Build an experimental setup for generating **light curves** that represent the detection of exoplanets.
2. Create sensory experiences involving the concrete manipulation of experimental models, such as **pendulums, light sources, and observation of physical phenomena**, to illustrate astrophysics concepts related to the field.
3. Construct **graphs** based on real or simulated exoplanet data, using traditional resources (pen and paper) and digital tools (Python).
4. Recreate graphic narratives of exoplanetary environments using artistic representation techniques such as drawing, painting, 3D modeling, as well as **digital tools** and AI.
5. Implement digital resources (light curve databases: TESS) and interactive experiences that promote **dynamic visualization** of exoplanetary systems, using technologies like **augmented reality** or **computational visualizations** for those with the necessary resources.

Description of the Supporting Experimental Setup:

This proposal aims to simulate, under controlled conditions in a room, the measurement of light curves of simple exoplanetary systems: Keplerian systems with zero eccentricity and zero orbital inclination, using the light sensors commonly incorporated in mobile devices. The simulation involves a setup consisting of a white light bulb (representing the star) positioned along the axis of a 50 cm rotating rod, with spheres of different sizes hanging from its ends to represent various exoplanets.

The rotating rod is connected to a small motor with an analog speed variator. On the same plane as the bulb and the sphere hanging from the rod, but slightly distanced, a mobile device with a light sensor is positioned. Using the Arduino Science Journal (ASJ) mobile app, the light sensor can be accessed independently, allowing the recording of the detected light over time.

The amount of light detected is measured as luminous flux in units of lux [lx], equivalent to 1 $\frac{\mathrm{lm}}{\mathrm{m}^2}$. This unit correlates directly with brightness; thus, measuring the variation in light requires considering parameters such as the distance from all light sources, ambient luminance, and the orientation of the detector relative to the sources. The optical detection resolution of light intensity depends on the quality of the mobile device's sensor, generally around $1\mathrm{X}10^{-7}$ lx. This data can be reflected in the table generated by the ASJ App by observing the number of significant figures recorded in the "AmbientLightSensor" column.

The sensor records ambient light data in lx, at non-specific time intervals within a resolution threshold of 1 ms. That is, it takes ambient light measurements at irregular intervals, averaging every 100 ms. This irregularity stems from the random nature of modern smartphone sensors, unlike specialized equipment that incorporates sensors with a specific time resolution.

The experiment is conducted while minimizing disturbances from other light sources besides the bulb in the experimental setup. To achieve this, it is recommended to perform the experiment in a dark room. If conditions differ from those suggested, adjustment measurements should be made to normalize the light intensity curve for further analysis.

As the setup is activated, drops in luminosity on the light curve, produced by the transits or partial eclipses of the simulated exoplanets, can be observed on the ASJ luxometer detector. With ASJ, we can record the entire light curve, obtaining a histogram of the changes in the bulb's brightness over time.

Given the conditions above, the result is a light curve whose analysis allows for the derivation of three properties of the exoplanetary system: the semi-major axis, the orbital period, and the planet/star size ratio. The period of transits is reflected in the periodic frequency of the light curve’s drops, which in the setup depends on the rotation speed of the rod, with a reduction factor based on the weight placed on it, though this factor is negligible for the purposes of this experiment.

General Methodology

The project will be developed in three levels of complexity, organized according to students' access to technology and available resources:

Level 1: Sensory Experiences and Concrete Manipulation

- **Context:** Populations with limited resources or no access to advanced technology.
- **Approach:** Use of simple materials and manipulatives such as pendulums, flashlights, candles, and reflective surfaces to represent planetary transits and stellar oscillation.
- **Final Product:** Creation of manual graphs and visual representation of light curves, followed by hand-drawn visual narratives.

Level 2: Analytical Activities with Basic Technological Resources

- **Context:** Students with access to basic technological tools such as computers and graphing software.
- **Approach:** Use of software (Excel, Geogebra) to construct radial velocity graphs and light curves based on simulated or real data.
- **Final Product:** Creation of digital models and graphical representation of exoplanetary physical characteristics, accompanied by digital narratives explaining the results.

Level 3: AI-based Visualizations and Narratives

- **Context:** Populations with access to advanced tools like Artificial Intelligence and augmented reality.
- **Approach:** Use of AI to generate images of exoplanets and their characteristics based on real data and descriptions, as well as creating interactive narratives using dynamic visualization tools.
- **Final Product:** Graphic narratives, interactive visualizations of exoplanetary systems, and simulations that allow exploration of the obtained results.

Teaching Sequence by Stages:

First Activity: Introduction and Motivation

- **Description:** Motivational reading or multimedia presentation on the search for exoplanets and the history of astrobiology.
- **Purpose:** To spark curiosity and contextualize the importance of exoplanet research.
- **Resources:** Short readings, introductory videos, and illustrative graphics.

Second Activity: Interaction with the Light Curve Prototype

- **Description:** Introduction to the existing prototype, adjusted to demonstrate how a planet passing in front of a star affects the observed light curve. At this stage, manual experiments with flashlights can be conducted, or the digital prototype can be used.
- **Purpose:** To understand the concept of transits and how a star's light is affected by the presence of an exoplanet.
- **Resources:** Experimental prototype (light and sensors) or digital simulations.

Third Activity: Graph Construction and Analysis

- **Description:** Construct light curves from observed or simulated data.
  - **Level 1:** Manually constructed graphs.
  - **Level 2:** Use of graphing software to obtain Kepler's constant and orbital parameters.
- **Purpose:** To facilitate understanding of how exoplanets are detected and how their physical characteristics are determined.
- **Resources:** notebooks, pencils, basic software to graphic representations (python, excel, etc.).

Fourth Activity: Construction of Experimental Models

- **Description:** Set up different configurations to simulate planetary oscillations and transits, using pendulums, flashlights, and other materials.
- **Purpose:** To promote direct manipulation and observation of the physical phenomenon being represented.
- **Resources:** Conical pendulum, simple pendulum, flashlights, stopwatches.

Fifth Activity: Creation of Graphic Narratives

- **Description:** Create stories that represent the history of an exoplanet based on the data and observations.
  - **Level 1:** Hand-drawn illustrations.
  - **Level 2:** Digital comics with editing software.
  - **Level 3:** AI-based visualizations.
- **Purpose:** To consolidate knowledge through visual creation, integrating art and science.
- **Resources:** Paper and pencil, Canva, DALL-E, and other digital illustration tools.

Final Activity: Presentation and Sharing of Results

- **Description:** Presentation of graphic narratives and experimental results to the educational community.
- **Purpose:** To value the work done and share the learning with others, fostering interest and curiosity in exoplanet research.

DATA

The Transiting Exoplanet Survey Satellite (TESS) is designed to discover thousands of exoplanets orbiting the brightest dwarf stars in the sky. TESS is detecting exoplanets ranging from small, rocky worlds to giant planets, showcasing the diversity of planets in the galaxy. In this project, TESS light curves are used by students to qualitatively and quantitatively characterize the physical properties of some exoplanets, such as size, distance from the star, and rotational period. Students will apply their imagination for qualitative analysis and use quantitative methods, such as Kepler's laws, for precise calculations.

- **TESS Database:** https://exoplanetarchive.ipac.caltech.edu/cgi-bin/TblView/nph-tblView?app=ExoTbls&config=TOI
- **Cellphone app:** https://www.arduino.cc/education/science-journal
- **Digital tool used to extract light curves from TESS database:** https://www.tessextractor.app/

The last tool refers before, was developed by Javier Serna, a very good researcher from our country: Colombia, and other interesting investigators.

Conclusion: The project aims to create an inclusive and adaptable learning environment, promoting interest in scientific exploration and curiosity about the universe, particularly the world of exoplanetology, through sensory experiences and visual narratives supported by emerging technologies.

Possibilities for future improvement: given the versatility of the assembly, we could then implement an entire methodology based on the radial velocity detection method, adding to the rotating sphere around the bulb, some sound source (it could be a small speaker), which is manifest in a receiver with tone changes associated with the sound Doppler effect, analogous to the light Doppler effect with which exoplanets are detected through this method.