Teacher Guide for the Exoplanet Atmospheres Instant Pack

With the discovery of over 5000 exoplanets and counting, the next generation of telescopes will search for signs of habitable conditions by studying their atmospheres. In this Teen Astronomy Cafe — To Go! Instant Pack, students simulate exoplanet systems and determine the relationship between a planet's radius and depth of the lightcurve. Students then identify patterns within the exoplanet atmosphere's spectral data to determine the chemicals present in the atmosphere, or the absence of an atmosphere. This activity is conducted in a Python Notebook, a web-based interactive computational environment that contains code, text, and plots.

Learning Objectives

Students will be able to:

- Determine the relationship between the planet's radius and depth of the lightcurve.
- Compare the size of a planet's atmosphere at different wavelengths.
- Analyze exoplanet transmission spectra models to determine the radius of the exoplanet and the chemicals present in the atmosphere.

NGSS Standards

Building Towards NGSS Performance Expectations

- HS-ESS1-3: Communicate scientific ideas about the way stars, over their life cycle, produce elements.

Disciplinary Core Ideas	**HS-ESS1.A: The Universe and Its Stars** The study of stars' light spectra and brightnesses is used to identify compositional elements of stars, their movements, and their distances from Earth. **HS-PS4.B: Electromagnetic Radiation** Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities.

Science and Engineering Practices	**Developing and Using Models** Students use a computational model to generate data based on exoplanet atmospheric spectra to analyze the composition of exoplanet systems. **Using Mathematics and Computational Thinking** Students test exoplanet system simulations to see if a model "makes sense" by comparing the outcomes with what is known about spectra from real exoplanets.
Cross Cutting Concepts	**Scale, Proportion, and Quantity** Algebraic thinking is used to examine spectral data from exoplanets and predict the effect of a change in one variable, the planet radius, on another, the exoplanet transit light curve. **Systems and System Models** Computer-based models are used to simulate interactions between exoplanet systems and the host star's radiation. **Patterns** Mathematical representations are used to identify patterns within the exoplanet's spectral data to understand their atmospheric composition.

Suggested Timing

- Exoplanet Atmospheres Phenomenon & Presentation (50 minutes)
- Python Notebook intro and how to run a cell (5 minutes)
- Activity 1: Introduction – Planet Lightcurves (5 minutes)
- Activity 2: Planet Radius (10 minutes)
- Activity 3: A Planet Spectrum (15 minutes)
- Activity 4: Example Planet Atmospheres (10 minutes)
- Activity 5: Mystery Planet Atmosphere (20 minutes)

Exoplanet Atmospheres Presentation

The Teen Astronomy Cafe – To Go! Instant Pack includes a slideshow presentation that is accompanied by a recorded presentation video. The purpose of the slideshow is to provide the audience with background information on exoplanet spectra and to excite and motivate learners in the content. A lesson-level phenomenon is suggested to precede the presentation slides and is recommended as a student-driven active learning strategy to initiate curiosity and questioning. Instructions for incorporating the phenomenon are included below.

Exoplanet Spectra Phenomenon:

1. "Is there life beyond Earth?" is the question that has driven humanity throughout history and is currently leading space exploration missions. To begin the lesson, set up a Driving Question Board with the lesson question: "How will we find life on other planets?"
2. To drive student curiosity and questioning, observe the phenomenon of a planetary transit, Mercury Transit 2019, and the animation Distant Exoplanet Transiting Its Star.

3. After viewing the videos, revisit the Driving Question Board and the driving question: "How will we find life on other planets?" Students should develop questions based on the lesson driving question and the observed phenomenon of a transiting planet.
4. Students should share their generated questions as a whole class by posting them visibly to the Driving Question Board. These questions can be organized into similar categories and revisited throughout the slideshow presentation and/or Python Notebook.
5. When referencing back to the Driving Question Board, students should work as a whole class to answer, refine or ask new questions.
6. At the end of the lesson, show the concluding support video How Webb Will Study Exoplanets.

Python Notebook General Information

- Start by going over the operation of a Python notebook: To execute or run a selected cell, click the little play button or hit [Shift + Enter] on your keyboard. Some cells may take a few seconds to render, so be patient!
- If something doesn't seem to be working correctly (e.g., it can't find resources such as tools.ipynb, or the first simulation where students don't have to enter in any values fails), try restarting the notebook (Runtime → Restart).
- To run all the cells at once, go to the "Runtime" menu and select the option to "Run all."
- To reset each simulation, run the corresponding cell again. This helps when exploring the function of each parameter.
- Students can practice interacting with the notebook by moving the slider in the Pre-Activity Setup. Some terms are printed in green. Hovering your cursor over these terms for a few seconds will provide more information for the students in a gray pop-up box.

Activity 1: Introduction — Planet Lightcurves

This activity introduces students to the concept of a lightcurve. When a planet passes in front of a star, it blocks a small portion of the star's light and the star appears slightly dimmer to observers on Earth. Time = 0 is defined as the middle of the lightcurve corresponding to when the planet is in the middle of its transit. Negative time is prior to this point and positive time is after this point.

Notice the scale on the y-axis. This particular planet blocks only 1% of the star's light at most. Many transits block even less than 1% of the star's light! Students can move the slider on the lightcurve and observe the position of the planet in front of the star.

This lightcurve is much smoother than what real astronomical data usually produces!

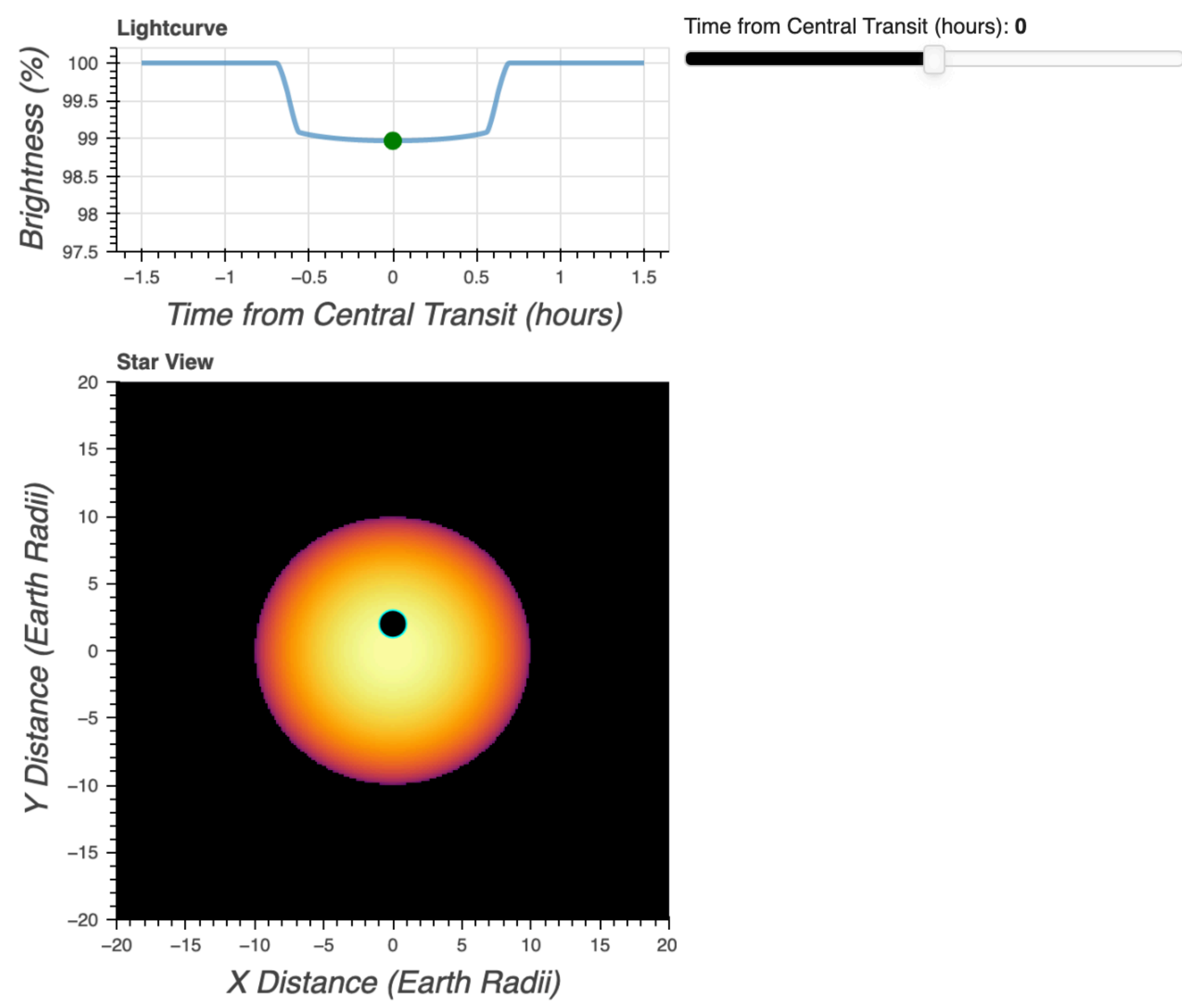


Figure 1: Students are introduced to lightcurves in Activity 1.

Activity 2: Planet Radius

This activity is similar to the first with the addition of the ability to change the planet's radius. Encourage students to explore the relationship between the planet's radius and the depth of the lightcurve as well as the length of the transit and the shape of the lightcurve.

You may need to remind students that the area of a circle is proportional to the square of the radius!

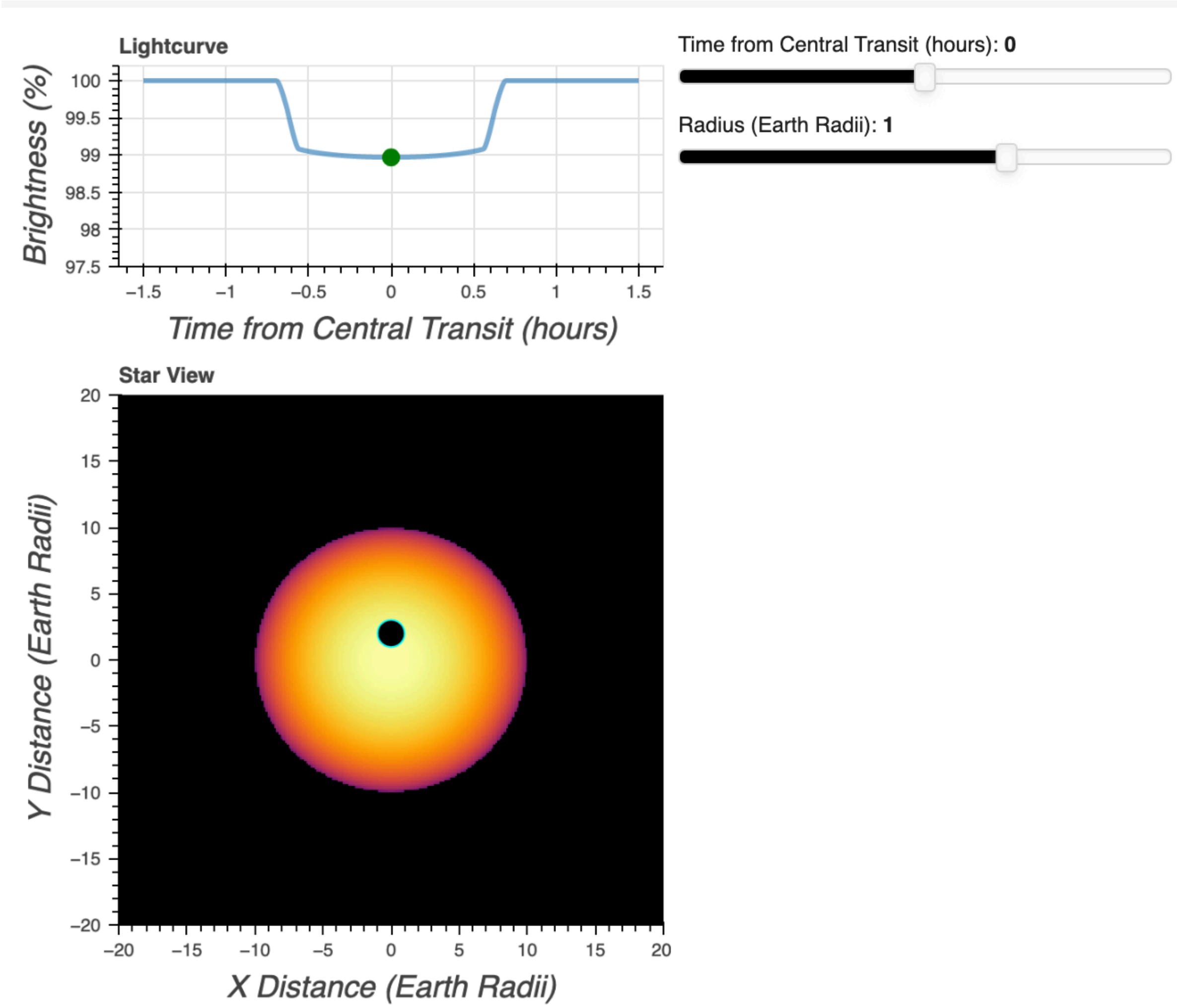


Figure 2: Students see the relationship between radius of a planet and a lightcurve in Activity 2.

Activity 3: A Planet Spectrum

3.a. Planet Sizes in Different Colors

This activity introduces the effects of a planetary atmosphere. Since blue light is scattered more than red light, the planet appears larger when you observe it in the blue wavelengths. Students can experiment with how dense the planetary atmosphere is and observe the changes in the measured size at different wavelengths.

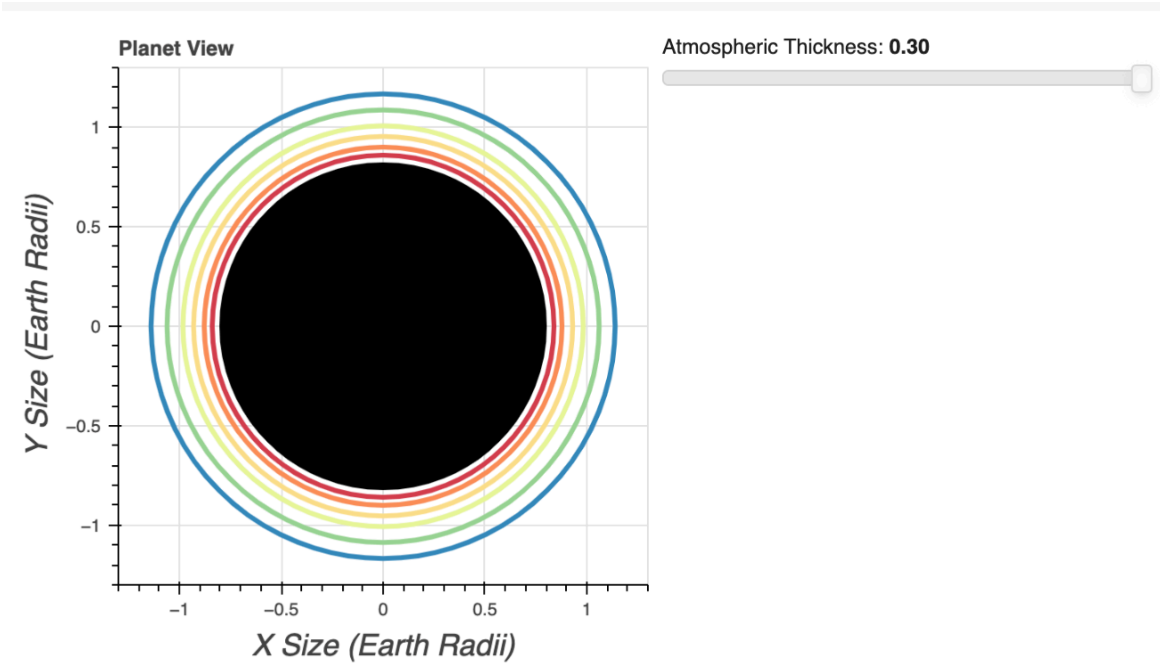


Figure 3: Students can change the thickness of the planet's atmosphere in Activity 3.a.

3.b. A Spectrum Plot

This section introduces the concept of a transmission spectrum. A transmission spectrum plots the size of the planet (in Earth radii) on the y-axis vs the wavelength of the observation (in microns) on the x-axis. A micron is one-millionth of a meter (abbreviated as . Visible light has wavelengths from about 0.4 (blue) to 0.7 (red). Students may be more familiar with units such as nanometers or Ångstroms.

Students use the slider to explore the shape of the transmission spectrum as the thickness of the atmosphere changes. In this case, the thickness of the atmosphere is measured as the number of Earth radii the atmosphere extends above the planet's surface.

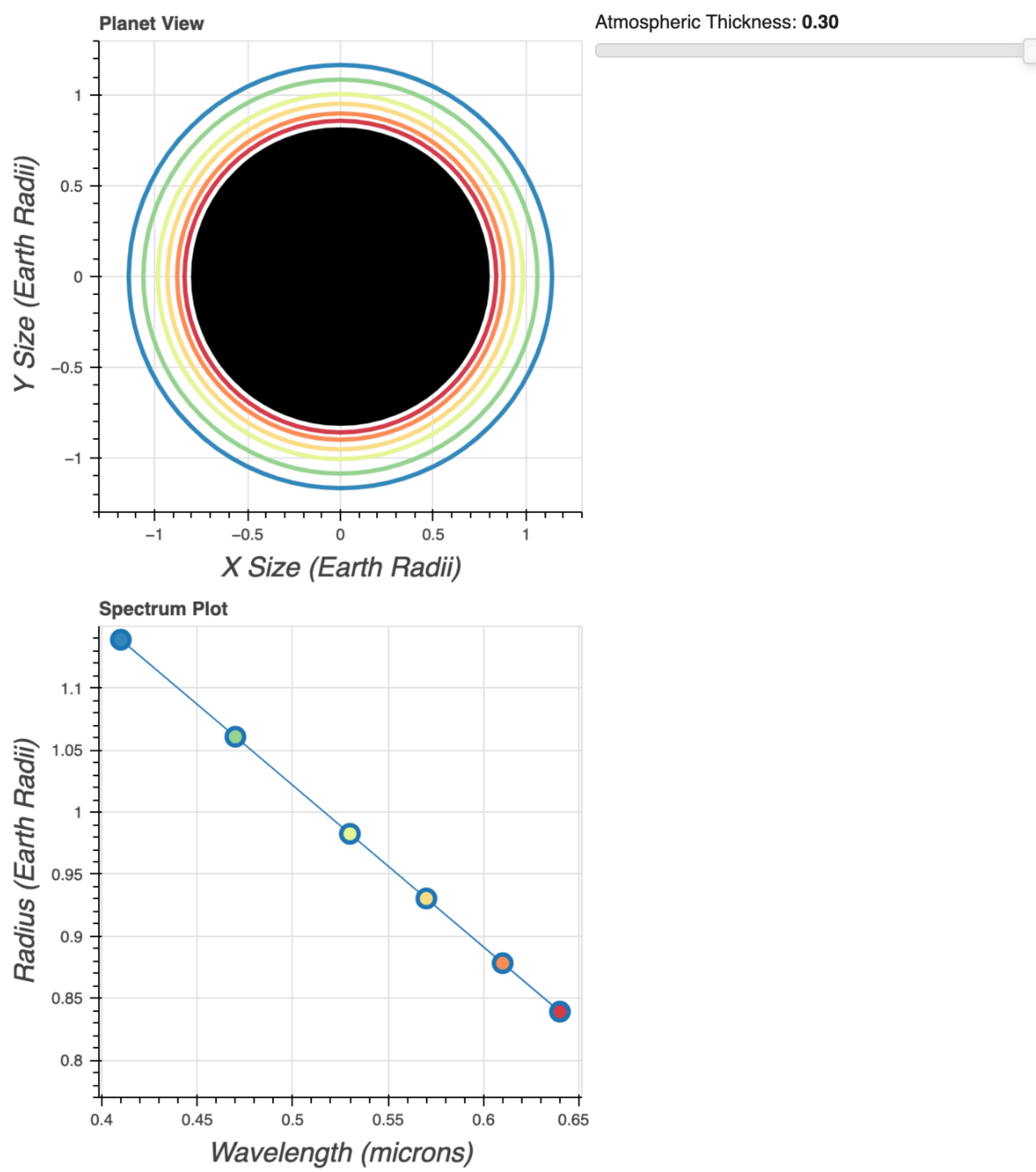


Figure 4: A spectrum plot is generate in Activity 3.b.

3.c. A Multi-Colored Lightcurve

The multi-colored lightcurve is very similar to the spectrum plot. This section adds a lightcurve plot for students to explore the depth of the lightcurve at different wavelengths (colors). The transmission curve behaves the same as in 3.b.

It should be noted that the atmospheres are much larger relative to the planet than in reality. The larger atmospheres make it easier to see the effects.

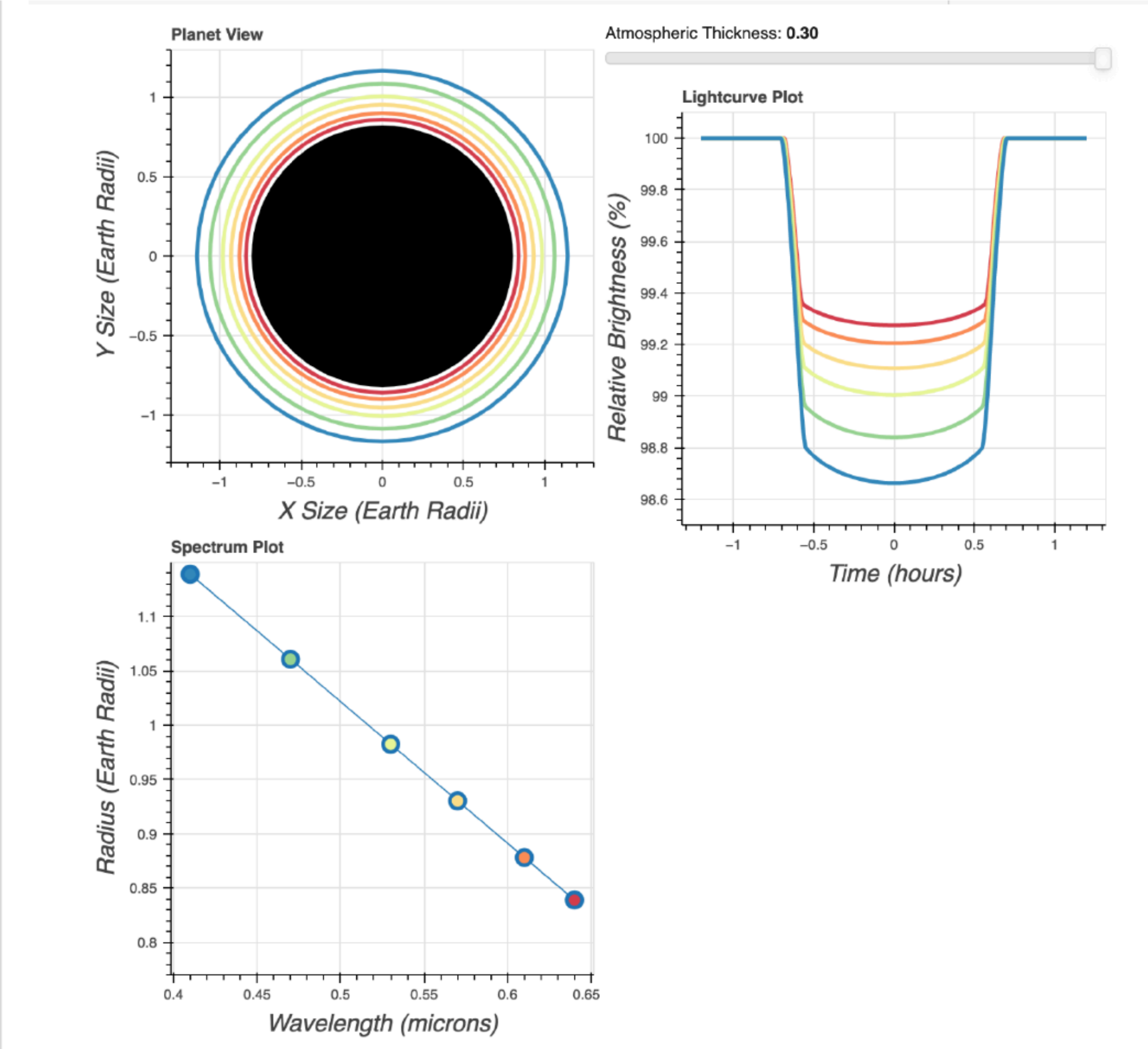


Figure 5: A lightcurve plot is generated in Activity 3.c.

Activity 4. Example Planet Atmospheres

This section looks at adding different substances to the atmosphere of the exoplanet. Different substances absorb and transmit different wavelengths of light. Water vapor absorbs more light between 2.5 and 3 so the planet would appear to have a larger radius when observed at those wavelengths. Water vapor transmits more light between 3.5 and 4 so the planet would appear larger when observed at those wavelengths.

Students can make similar observations for planets with methane and carbon dioxide atmospheres. It is important students understand these three graphs as they will be used to identify the atmospheres of mystery planets in the next section.

Activity 5: Mystery Planet Atmospheres

This activity puts students in the role of an astronomer examining the atmospheres of exoplanets. Students see the lightcurves of planets taken at multiple wavelengths ranging from 2.5 to 5. The sliders are used to change the effective radii at different wavelengths to match the data collected. These data are used to create a transmission curve. Students then compare that transmission curve to the different compounds to determine what they are observing in the exoplanet's atmosphere.

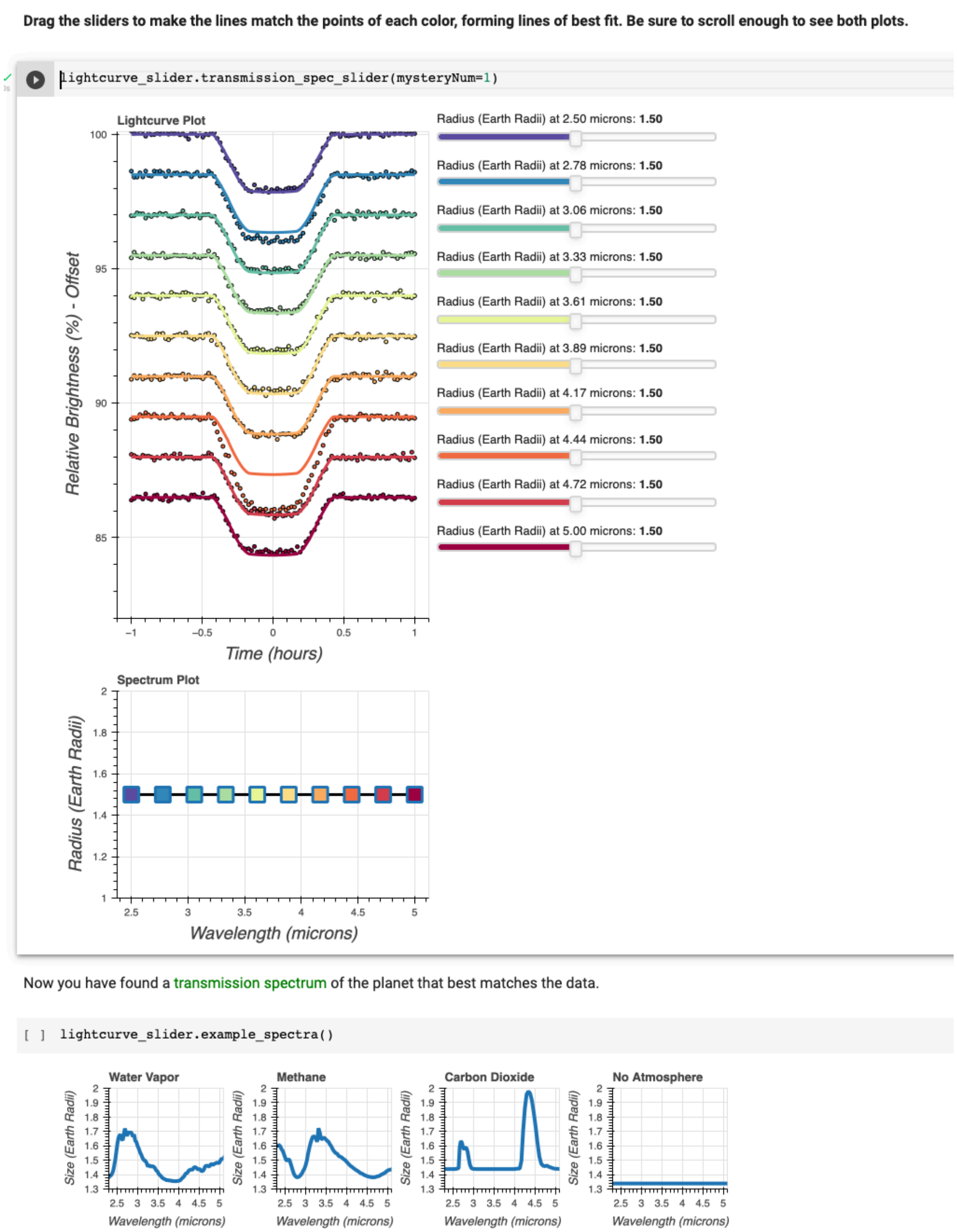
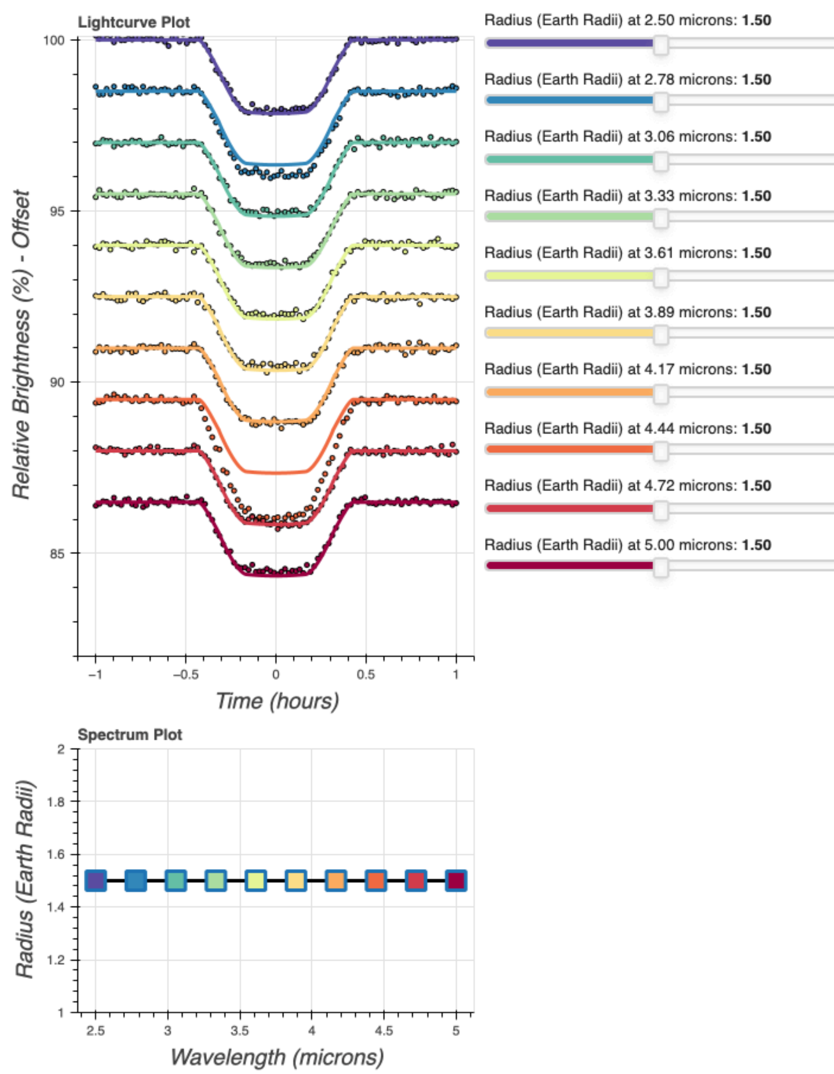


Figure 6: Students examine the atmosphere of a mystery planet in Activity 5.

Drag the sliders to make the lines match the points of each color, forming lines of best fit. Be sure to scroll enough to see both plots.

```
lightcurve_slider.transmission_spec_slider(mysteryNum=1)
```



Now you have found a transmission spectrum of the planet that best matches the data.

```
[ ] lightcurve_slider.example_spectra()
```

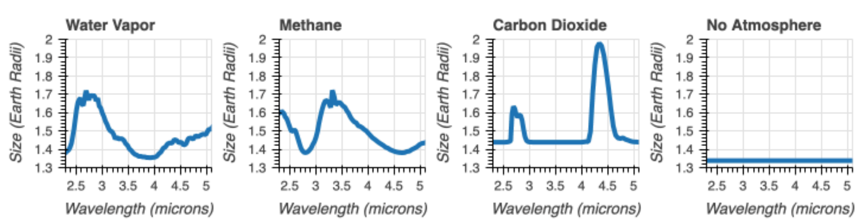


Figure 7: There are four different exoplanet atmospheres for students to explore.