Activity 2 – MODELING LAB

PURPOSE. This activity sets up the rest of the ExoLab investigation, and is intended to help your students predict what the "signal" of an alien world might look like. They use the model to:

Visualize an alien solar system oriented so that a planetary transit takes place.

Plan their investigation [which involves obtaining a series of star brightness measurements over time]

Predict how a graph of the star's brightness versus time (a *light-curve)* can be used to:

- provide *evidence* that they have detected a planet, and
- quantitatively determine the size of the planet compared its star

NGSS EDUCATIONAL OBJECTIVES. This lab gives students experience with the following scientific practices, while they apply and consolidate their disciplinary core understandings of what makes a solar system a system:

Reasoning from a model, including using the Cross-Cutting Concept of Size, Scale, and Proportion to understand how the size of an exoplanet influences the proportion of starlight blocked during a transit.

Translating from one representation of a system (the visual model) to another representation (a graph of brightness vs. time).

Students will use this predictive model later on to help them interpret their findings with the telescopes.

Core Concept Underpinning this Lesson:
Models are important tools used by scientists working at the frontiers of science. A model – physical, visual, or theoretical – captures important features of the world, and helps us analyze and predict its behavior. It's important to evaluate both the merits and limitations of a model in using it to make predictions or interpret real data.

BACKGROUND SCIENCE
Detecting extrasolar planets via the "transit method"
Astronomers have been hunting for planets that orbit stars similar to our own Sun. To date, they have confirmed detections of nearly 2000 of these new worlds, with 3000 more good candidates awaiting confirmation by further observation and analysis (for the latest numbers, go to planetquest.jpl.nasa.gov). Because planets do not shine with visible light of their own, and are so dim and small compared to the stars they orbit, it is only in very rare circumstances can astronomers use current telescopes to detect these planets directly. Instead, they primarily use indirect methods. One such method, used here in the ExoLab, involves detecting a planetary

transit.

In a few cases, the orbit of an alien planet happens to be oriented so that the planet passes through our line of sight with the star. That is, the planet eclipses, or blocks, part of the star's light once during each orbit. These are called transiting planets, because if we were closer we would see the planet transit across the face of the star.

How can a telescope be used to detect planetary transits?

Telescopes do more than take pictures – their electronic detectors gather light; and the digital images derived from this electronic data contain valuable information about the amount of light reaching the telescope from each star. It turns out that even a small telescope, such as the MicroObservatory telescope students will be using, is sensitive enough to detect a 2-3% drop in the amount of light reaching the telescope when the image is taken. In fact, many of large exoplanets students will be observing were originally discovered by small telescopes similar to the ones they use in the ExoLab. To detect a transiting planet, you must take a series of images that span the timeframe of the entire transit; measure the brightness of the star in each of those images; plot it on a graph of time versus brightness; and look for the telltale dip in brightness that is the signal of the alien world.

SUGGESTIONS FOR LEADING THE LESSON.
If you haven't already, you may wish to begin this lesson with a discussion of student's own ideas about what methods astronomers might use to detect planets around other stars. Some teachers may want to first use a physical model (a ball and light bulb) to demonstrate the "transit method." (A nice review of detection methods can be found at this URL: http://planetquest.jpl.nasa.gov/page/methods)

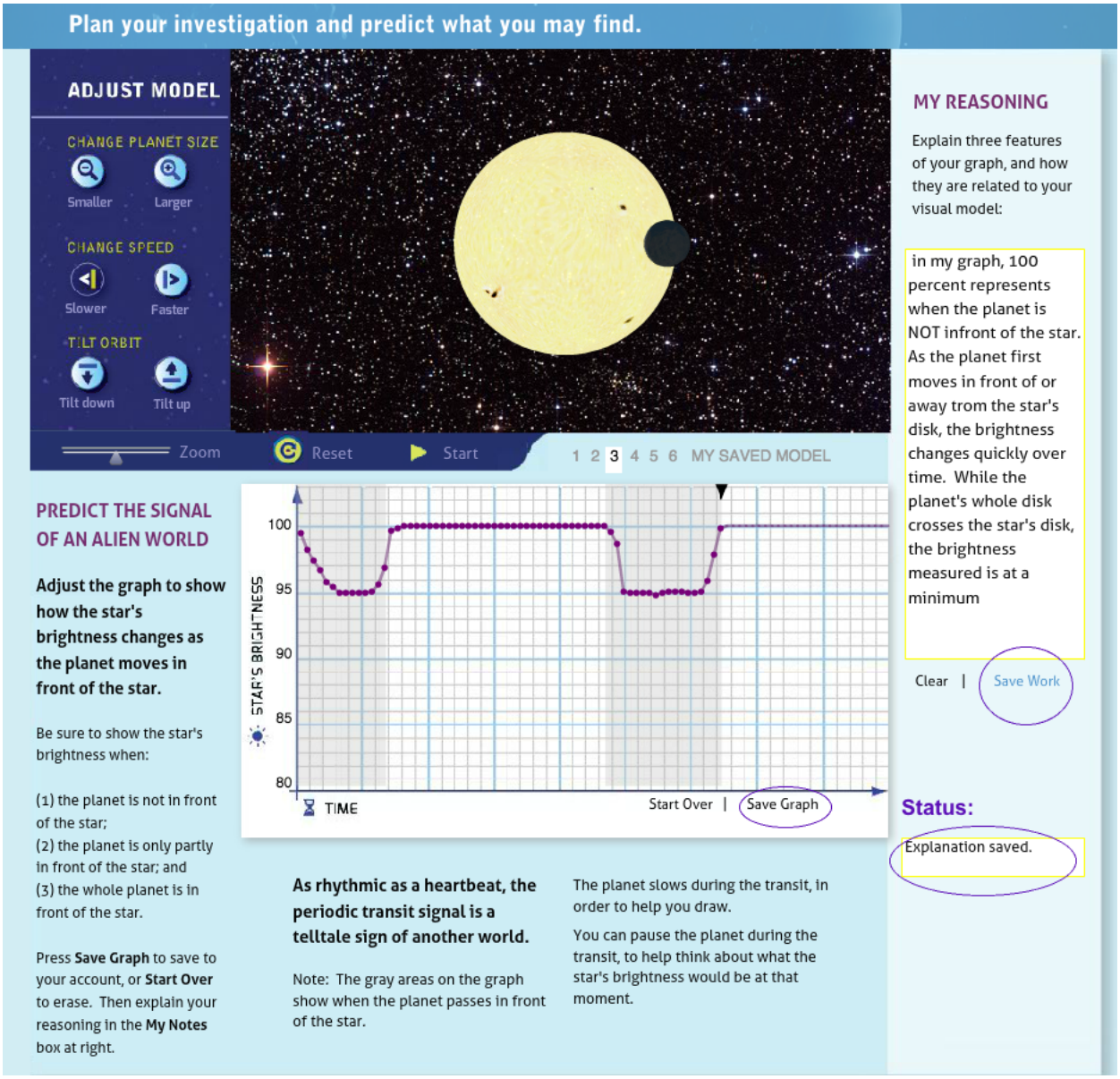
*Students may understand models as simply **representing** or **explaining** real phenomena, but often don't appreciate the importance of a model's ability to **predict** what could be observed, and its usefulness in **interpreting** and drawing inferences from observational data.*

In the online Modeling Lab, student will use a computer-based model of a solar system to predict how the brightness of their star varies as a planet transits across (eclipses) the star. Later, after they have made their actual observations, they will use the same model to interpret specific features of their data that reveal what their alien solar system might look like.

Remind students that we can't see an alien world directly, but we can see its effect on light from the star that it orbits. As students interact with the Modeling Lab, they should <u>use the numbered buttons to consider the model in **6 stages**</u>.

Starting with Stages 1 and 2, the text at the bottom of the Lab provides instructions and tips for thinking about how the Modeling Lab can help students interpret the results of their investigation. (They may want to put their web browser in "Presentation" mode to be able to see more of the Lab screen at once).

Stage 3 asks students to make a graphical prediction of what the star's brightness over time would look like, and then to enter a verbal explanation describing at least 3 feature of their graph that relate to the model. Point out that they can pause and restart the movement of the planet in this model. Students should be sure to click "Save Graph" and "Save Work" and check the "Status" bar to insure that their graph and text gets saved to their ExoLab account.



MODELING LAB Stage 3: You can have students save a screen shot, like the one above, to hand in to you for assessment

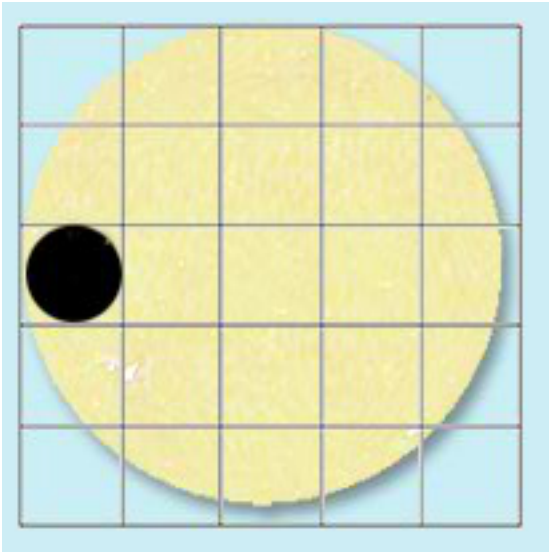
After your students have completed and saved their Stage 3 work on their own, you may wish to facilitate a class discussion about how the details of a light-curve graph match (or provide evidence for) the visual model. Gaining fluency in going back and forth between a graphical and visual model is an important scientific skill, and there are many nuances to the model that your

students may not notice at first. **Stages 4 and 5** call students' attention to some of these details and prompt them to think more quantitatively about the model. [PLEASE NOTE: Some teachers prefer to have students move on to get the data in the **Telescope Lab** and generate light curves in the **Image Lab** before coming back to **Modeling Lab Stages 4, 5 and 6** to help them interpret the data. This is a perfectly valid alternate pathway through the ExoLab investigation.]

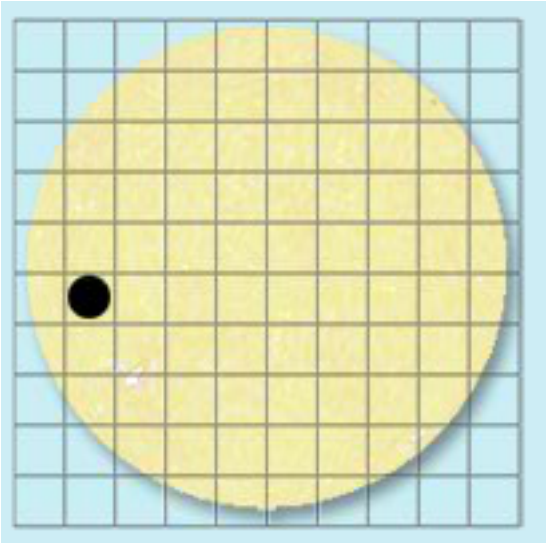
Stage 4—Use Math to Predict. This stage asks students to think quantitatively about how the *amount* (percentage) of dimming in the star's brightness is related to the size of the transiting planet.

*MATH ALERT! Most students will naively assume a **direct** proportion between the linear size (width or radius) of a planet and the percentage of starlight it blocks (e.g., they would predict a planet 1/5 or 0.2 times the diameter of a star will block 1/5 of its light (20%!). They also predict that if you double (or halve) a planet's width it will double (or halve) the amount of light blocked.) But it is the planet's projected **area (πr^2)** against the area of the star's disk (πR^2) that matters. You may need to explicitly call out to students that for the purposes of a transit investigation, when thinking about the "**size**" of a planet, they should be thinking not just about its width, but rather its "**radius-squared**" – because that affects the **area** of light blockage.*

Facilitate a class discussion of the two scenarios in Stage 4, which ask students to consider the *fraction* of the amount of starlight blocked by the "default" model planet, which is 0.2 times (or 1/5th) the radius of its star; and of a Jupiter-like planet, which would be 0.1 times, or 1/10 the radius of a sun-like star. If students naively predict the default model planet would block 1/5 of its star's light, have them examine the diagrams on the page more closely:



1/5th radius = 1/25th area (.04)
(Star will dim from 100% to 96% brightness)



1/10th radius = 1/100th area (.01)
(Star will dim from 100% to 99% brightness)

In all cases, the amount of dimming (ΔB) caused by a transiting planet of radius *r* equals:

$$\Delta B = \frac{\pi r^2}{\pi R^2}$$ (and here we're setting R, the Radius of the star, equal to 1)

You may wish to go over this math with students to help them become more facile with going back and forth between the size of a transiting planet and the fractional dimming of its star. Remember, when you and students create a light curve from your data, you will NOT know r/R. Instead, you will have a record of the percentage drop in the star's light and will have to work backwards: if you were to measure a 3 percent drop from 100% to 97% of the star's baseline brightness, what would such a planet's size be? It would be the ***square root*** of 0.03, or .17 times its star's radius!

What about an Earth-sized planet compared to a Sun-sized star? At 1/100th the radius of its star, an alien Earth would only block 1/10,000th, 0.0001 or 0.01% of its star's light! This is why astronomers are using space-based telescopes, like NASA's Kepler Mission, that can get above the distortions of our atmosphere to detect such tiny variations in the brightness of distant stars as earth-sized planets transit.

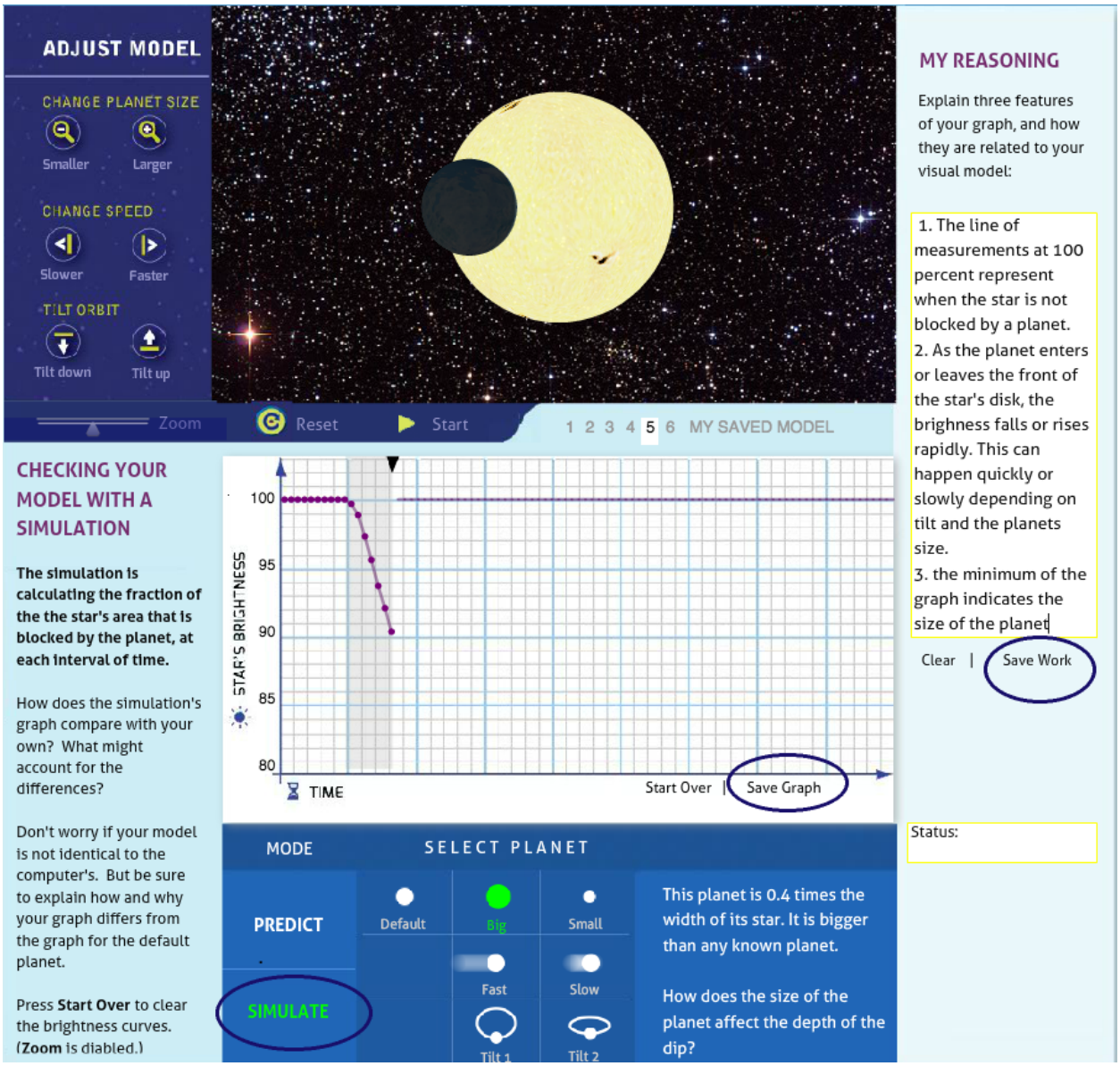
Stage 5 of the **Modeling Lab** encourages students to think more deeply about how the model predicts *variations* in the signal (the brightness graph or light curve), depending upon assumptions about 3 key features of any exoplanet they might observe: its **size**, its orbital **speed**, and its orbital **tilt.**

When students first click on Stage 5, the Graph is in the PREDICT Mode, where they can select a Big, Small, Fast, Slow, or Tilted planet, and then click and drag the graph to predict how this planet's signal would differ from the Default, Medium size and speed, Edge-on planet.

By clicking on SIMULATE, the computer will actually calculate and graph an accurate representation of the fraction of the star's area that is blocked by the visual model planet as it changes. Have students use the "ADJUST MODEL" panel to actively change the planets' size, speed and tilt while they observe the resulting graph. Here, for example, they can actually test how *doubling* the planet's size would *quadruple* the depth of the dip in brightness during the transit.

Assessment. The goal of **Stage 5** is for students to save a final graph for a particular model planet, and to refine and save their verbal reasoning that explains in detail how at least 3 features of that graph are related to specific aspects of their model planet. The "MY SAVED MODEL" tab will save to their ExoLab account the *last* Graph and the *last* verbal Reasoning explanation that students enter in the Modeling Lab. If they log out of the ExoLab and return, the MY SAVED MODEL will still have their graph and explanation. You may wish to have students capture a screen shot of their Saved Model so that you can assess their understanding of what the model predicts.

Stage 5 *Simulation Mode – Students can click on SIMULATE to see the graph respond accurately as they change the size, speed or tilt of the model exoplanet. Be sure students click "Save Graph" and "Save Work" to enter the final graph and explanation they want recorded in the "MY SAVED MODEL" tab.*



Stage 6 – Summary of the Model, and its strengths and limitations.

This is a good time to facilitate a class discussion of the merits and weaknesses of the model being used for this project – by doing such an evaluation, students are participating in the

scientific practice of using models in the same way that professional planet hunters do (and as called for by the NGSS standards).

1. What is "the model" being used here?

In this project, the "model" refers to:

a. Our visualization of an alien planet orbiting a star, edge-on or nearly edge-on, so it "transits" its star
b. Our understanding of the physics of the transit; and
c. The graphical representation of that understanding, in the form of a brightness curve.

The model embodies this understanding: The star's brightness is constant before and after the transit. The brightness dims at the start and end of the transit (on- and off-ramps). The brightness is lowest when the planet is entirely in front of the star. In this simple model, the brightness curve is completely symmetric.

2. What are the strengths of this model?

This simple model can be used to make predictions about the signal we would observe if we took a series of measurements of a star's brightness over time, that had a transiting planet. For example, the model predicts:

a. The quantitative relationship between the <u>depth</u> of a transit brightness graph and the <u>relative size</u> of the exoplanet compared to its star
b. That there is a relationship between the <u>orbital speed</u> of an orbiting planet and the <u>duration</u> of the transit, and the <u>period</u> between consecutive transits. (For physics students, the model also can include the mathematical relationships of Kepler's Laws to predict the <u>distance</u> of the planet from its star, although the computer model does not include this)
c. The differences in the pattern, or shape, of a light curve resulting from a planet orbiting edge-on with respect to us here on Earth, vs. a tilted orbit that causes the planet's disk to cross over just the top or bottom part of the star's disk. (The model also predicts the case of NO transit if the orbit is tilted too far away from edge-on).

3. What are the model's limitations?

The simplified Modeling Lab visualization represents some things accurately, but other things it misrepresents, or omits, for example:

a. A star is MUCH brighter that a planet (and is not transparent, like the star in this model!)
b. In this visual model, the speed of the planet is not linked to its distance from the star (there is no gravitational physics engine to this computer model)
c. The on- and off-ramps will not be straight lines, since the planet and star are disks.
d. A star is not uniformly bright across its width – the edges of the disk are typically darker.
e. The star may have "sunspots" that cause its brightness to vary (especially if the planet passes over one).
f. The planet reflects a small amount of starlight before and after the transit (especially when it is just about to go behind the star).

g. Other planets nearby may affect the period of the planet's orbit, etc.

The model also does not take into account ANY effects on the ground, such as weather, moonlight, city lights, the atmosphere effect of rising or setting, etc. These are all things that will effect the observations and brightness measurements you and your students will make. You will learn how to account for them and try to minimize them in the Image Lab.

After the Modeling Lab, you will want to discuss how this model might inform the overall strategy for collecting telescope data for the investigation. How long is a transit? How many images will be needed? How closely spaced? Do you need to have images that are before or after the predicted transit as well as those that might be during the transit?