

## First Law Screen

Explore and analyze the geometric properties of the planet's orbit by changing its position and velocity.

**ANALYZE** the different eccentricities

**DRAG** the planet or velocity vector to change the orbit

**PAUSE** and go **STEP BY STEP** for a better analysis

**CHOOSE** a real planet's orbit to imitate

**OBSERVE** geometrical properties of ellipses

**MEASURE** time and distances

## Second Law Screen

Observe how the movement of the body around the orbit results in sweeping multiple equal areas over the same intervals of time, even if the areas are different in shape.

**CHANGE** the number of divisions

**RECOGNIZE** the total area of each region and the time it takes to fill them

**COMPARE** the time and total area of each section

**OBSERVE** the planet's behavior on the furthest and closest distances

**PLAY** the simulation to see how the areas are drawn

## Third Law Screen

Relate the size of the orbit and the time it takes to complete a full revolution. More specifically, explore how by changing the powers of the semi-major axis of the orbit and its period you can reach a linear relationship.

**EXPLORE** the numeric relation of period ( $T$ ) and semi-major axis ( $a$ )

**DISCOVER** the different graph shapes by changing the orbit and powers of  $a$  and  $T$

**ALTER** the orbit by changing the star's mass

**BUILD** the target orbit and **ANALYZE** it with the  $T$  vs  $a$  graph.

**MEASURE** the period of the orbit

## All Laws Screen

Combine what you have learned and analyze a single orbit through each of Kepler's Laws.

**GET** more orbital data by selecting this option in the preferences panel

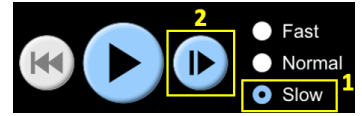
**CHANGE** the scene between the different laws

**PRESERVES** the same orbit in each law

**MEASURE** time and distances even changing to another law

## Insights into Student Use

- For a quantitative analysis of the changes in velocity and position throughout the orbits, students may want to slow down or stop the bodies' movement in a specific position. To improve accuracy, use "Slow" (1) and pause and step forward (2) to incrementally analyze. (Note that the step size is smallest when "Slow" is selected.)
- At first, the way the orbit changes will seem unintuitive and arbitrary. Try to get the students to identify how changes in position and velocity (magnitude and direction) alone will affect the shape. Invite students to match the "Target orbit", where they will need to modify all variables that affect an orbit size and shape.
- Students want to build "perfect orbits" (elliptical orbits with a centered axis), and it is hard for them to discover that they need to play with the velocity direction.
- Encourage students to find many of the different possible shapes: small orbits, big ones, highly elliptical, circular, or even forbidden orbits (escape and crash).



## Complex Controls

- Each time that the planet's position or velocity is modified, a new state is saved. This state can be restored with the Restart Button.
- When the planet is in a position or velocity that generates a crashing or escape trajectory, the play buttons are deactivated to prevent the reproduction of the planet's movement.
- Once the user reaches an escape trajectory by dragging the planet, it is not possible to continue moving it farther away from the sun. It is necessary first to change the velocity to return to an elliptical orbit and after that, it is possible to continue moving the planet farther from the sun.



## Model Simplifications

### Size of Bodies

The size of the bodies are greatly exaggerated, as using the same scale for distances and sizes would render all bodies as invisible points. For example, the real solar radius is about 0.004 AU, but in the sim it is displayed as 0.15 AU. Additionally, typical gravitational systems usually have enormous distances between bodies, even when measured in AUs, but most of the sim pre-sets show them in the same range of ~5AU in size.

### Areas

The elliptical areas are calculated and displayed as  $AU^2$  to demonstrate the equality of those areas. In real-life examples of Kepler's Laws, the areas are rarely calculated, and when they are,  $AU^2$  is not really the best unit to use.

### Parabolic Trajectories

When bodies reach escape speed in real life, their orbit becomes an escape parabola (or hyperbola if the velocity is higher). However, in the sim, the velocity will stop exactly before escape speed, thus displaying a highly elliptical trajectory, almost a parabola. This is done to avoid the orbit calculations from breaking down and having to smoothly change shapes from ellipse to parabola.

More information about the Model of the simulation can be found [here](#).

## Customization Options

Query parameters allow for customization of the simulation, and can be added by appending a '?' to the sim URL, and separating each query parameter with an '&'. The general URL pattern is:

```
...html?queryParameter1&queryParameter2&queryParameter3
```

For example, if you only want to show the 2nd screen (`screens=2`), and disable pan and zoom (`supportsPanAndZoom=false`) use:

[https://phet.colorado.edu/sims/html/keplers-laws/latest/keplers-laws\\_all.html?screens=2&supportsPanAndZoom=false](https://phet.colorado.edu/sims/html/keplers-laws/latest/keplers-laws_all.html?screens=2&supportsPanAndZoom=false)

To run this in Spanish (`locale=es`), the URL would become:

[https://phet.colorado.edu/sims/html/keplers-laws/latest/keplers-laws\\_all.html?locale=es&screens=2&supportsPanAndZoom=false](https://phet.colorado.edu/sims/html/keplers-laws/latest/keplers-laws_all.html?locale=es&screens=2&supportsPanAndZoom=false)

☞ Indicates this customization can be accessed from the Preferences menu within the simulation.

Query Parameter and Description	Example Links
<code>screens</code> - specifies which screens are included in the sim and their order. Each screen should be separated by a comma. For more information, visit the <a href="#">Help Center</a> .	<code>screens=1</code> <code>screens=2,1</code>
<code>initialScreen</code> - opens the sim directly to the specified screen, bypassing the home screen.	<code>initialScreen=1</code> <code>initialScreen=2</code>
☞ <code>moreOrbitalDate</code> - display a panel with more information about the planet's positioning and velocity vectors.	<code>moreOrbitalData=true</code>
☞ <code>locale</code> - specify the language of the simulation using <a href="#">ISO 639-1</a> codes. Available locales can be found on the simulation page on the <a href="#">Translations tab</a> . Note: this only works if the simulation URL ends in "_all.html".	<code>locale=es</code> (Spanish) <code>locale=fr</code> (French)
☞ <code>colorProfile</code> - changes simulation colors for easier projection.	<code>colorProfile=projector</code>
<code>audio</code> - if muted, audio is muted by default. If disabled, all audio is permanently turned off.	<code>audio=muted</code> <code>audio=disabled</code>
<code>allowLinks</code> - when <code>false</code> , disables links that take students to an external URL. Default is <code>true</code> .	<code>allowLinks=false</code>
<code>supportsPanAndZoom</code> - when <code>false</code> , disables panning and zooming using pinch-to-zoom or browser zoom controls. Default is <code>true</code> .	<code>supportsPanAndZoom=false</code>

## Suggestions for Use

### Sample Challenge Prompts

- Identify all the variables that affect the shape and size of an orbit.

- With the Target Orbit selector, try to mimic real-life orbits. What combination of position and velocity achieves those trajectories?
- Try to reach the highest eccentricity possible without reaching an escape orbit (dashed line). What does eccentricity mean?
- Measure the speed at which the body would escape. Is it the same for every position?
- In the Third Law Screen, what combination of powers will make the graph a straight line? You have to create multiple orbits first to see the line.
- In the Third Law Screen, build three different orbits with  $a=2$  AU. What is the period of each orbit? What do you observe?

## Inclusive Features

### Sound and Sonification

- The acceleration of the orbiting planet is mapped to its volume.
- When changing the shape of the orbit, there is a sound related to the size of the semi-major axis, and a vibrato tone related to the eccentricity.
- In the Second Law Screen, to better indicate that the areas are covered in equal time intervals, a metronome sound plays when a new area is reached.

See the [simulation page](#) for all supported inclusive features.

See all published activities for Kepler's Law [here](#).

For more tips on using PhET sims with your students, see [Tips for Using PhET](#).