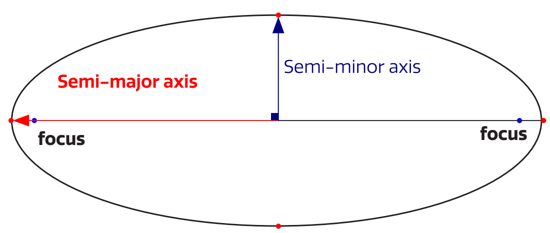
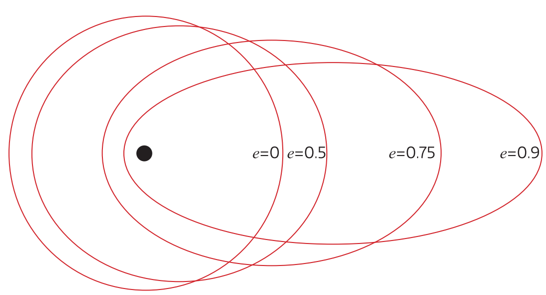
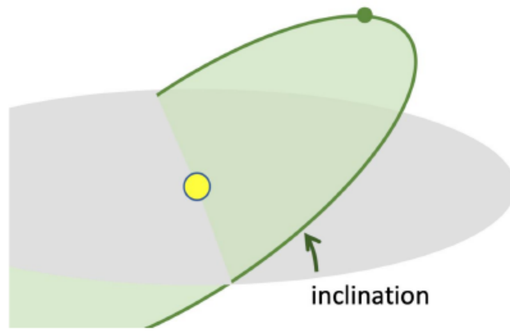
Student Worksheet for the Breaking the Solar System Instant Pack

In this Teen Astronomy Cafe — To Go! Instant Pack we will run simulations of planetary systems in order to understand how stable the Solar System is. Would the Solar System look the same if everything was 10 times more massive? What about if the planets were spaced closer together? Farther apart? This activity is conducted in a Python Notebook, a web-based interactive computational environment that contains code, text, and plots. Follow the directions on the Python Notebook to complete each activity and break the Solar System!

Orbital Parameters

This table can be used as a reference for the orbital parameters and the symbols of the planets.

Parameter	Symbol	Code Name	Description	Range/Units
Mass	*M*	`mass`	Mass of the star/planet	stars: $M_\odot$ planets: M_{Jup}
Semi-major axis	*a*	`a`	Average size of the orbit  	AU
Eccentricity	*e*	`e`	How circular or elliptical the orbit is  	0–1 (no units; 0=circle, 1=line)

Inclination	*i*	`i`	Tilt of the orbit relative to a reference 	0–90 (degrees)
Argument of pericenter, Longitude of ascending node	*ω*, *Ω*	`omega`, `Omega`	Angles that describe the orientation of a planet's orbit	0–360 (degrees)
True anomaly	*f*	`f`	Angle that describes a planet's current position along its orbit	0–360 (degrees)

Activity 1: Simulating a Single Planet
After the Pre-Activity Setup is complete, you are ready to simulate your first solar system. This activity walks you through four steps of running the simulation.

Activity 2: Simulating a Hot Jupiter Exoplanet
A list of hot Jupiters is provided for this activity. You will select one hot Jupiter from the list and add it to your simulation.

1. Which hot Jupiter did you choose?

2. Write down the orbital properties you'll need for your simulation.

3. Sketch the orbit you saw in your simulation below. Be sure to include axis labels and units!

Activity 3: Simulating the Solar System

In this activity you will simulate the Solar System and add orbital properties for the Sun and outer planets. Below is a table of orbital parameters for objects in our Solar System.

Star	Mass ($M_\odot$)	a	e	i	ω	Ω	f
Sun	1	—	—	—	—	—	—
Planet	**Mass (M_{Jup})**	**a**	**e**	**i**	ω	**Ω**	**f**
Mercury	0.00017	0.38	0.22	7.1	30	48	201
Venus	0.0026	0.74	0.02	3.4	91	7	347
Earth	0.0031	1.00	0.01	0.0	335	133	86
Mars	0.00034	1.51	0.09	1.9	292	49	281
Jupiter	1.0	5.2	0.05	1.3	275	101	268
Saturn	0.30	9.5	0.05	2.5	339	114	202
Uranus	0.046	19.2	0.05	0.8	97	74	225
Neptune	0.054	30.1	0.01	1.8	274	132	302
Pluto — Charon	0.000007	39.5	0.25	17.1	114	110	69

4. What do you notice about the properties of the planets in our Solar System?

Activity 4: Break the Solar System

Consider what you have learned so far in the coding activity and answer the following questions in preparation for breaking the Solar System.

5. What does it mean to "break" the Solar System?

6. Which parameters do you think the Solar System's stability is most sensitive to? Think in terms of the orbital elements, time, etc.

7. Evaluate whether the following Solar System objects need to be included in your simulations. Explain your reasoning for each object.

a. Sun

b. Inner planets (Mercury, Venus, Earth, Mars)

c. Outer planets (Jupiter, Saturn, Uranus, Neptune)

d. Pluto-Charon

8. In your groups, decide on the **specific** criteria you will use to determine whether the Solar System "breaks" during a simulation and record the criteria below.

Record what you learn from the simulations in the table below.

Parameter tested. How did you test it (e.g., what values did you use)?	Describe what happens to the Solar System.	Did you break the Solar System? How long did it take?