A Guide to Developing Literacy Practices in Science

Combining Simulations and Text to Support Scientific Explanations: Gravity and Orbits

Strategy Guide

The Learning Design Group

THE LAWRENCE HALL OF SCIENCE

Earth Science

Grades 6–8

Overview

What's in this guide? This strategy guide introduces how to combine simulations and text to support students in creating scientific explanations, an approach for providing a rich, multimodal learning experience. Students read about orbits and gravitational pull and then collaborate in groups to use a simulation to explain and demonstrate key ideas to other students. This guide includes a plan for combining simulations and text to support students in creating scientific explanations with a set of articles that describes how the orbit of an object in space is affected by various factors, including gravity, mass, velocity, and distance.

Why combine simulations and text? Students can deepen their understanding about key science concepts when they learn about those concepts in different formats (such as texts, diagrams, and physical or computer simulations) and when peer discussion and collaboration is structured so students interact productively to make sense of learning experiences. The approach described in this guide capitalizes on the power of simulations while building on students' interest in collaborating and exchanging ideas with peers.

How This Fits Into Your Science Curriculum

This strategy guide is best used near the end of a unit that emphasizes the gravitational attraction between objects that are in orbit. The activities in the guide are intended as sense-making or reflection activities to help students advance their thinking about orbits by applying ideas about gravity and motion to more complex situations. Before engaging in these activities, students should have a basic understanding of how gravity can cause one object to orbit another. In addition, students should have a qualitative understanding of how the force of attraction is affected by the mass of the object. They should be familiar with the concepts of mass and velocity since these terms are used in the simulation.

Addressing Standards

NEXT GENERATION SCIENCE STANDARDS

Disciplinary Core Ideas

ESS1.B: Earth and the Solar System: The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them.

Crosscutting Concepts

Scale, Proportion, and Quantity: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. The observed function of natural and designed systems may change with scale.

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information: Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).

Developing and Using Models: Develop and/or use a model to predict and/or describe phenomena.

COMMON CORE STATE STANDARDS FOR ELA/LITERACY

Reading Standards for Literacy in Science and Technical Subjects 6–12

RST.6–8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

RST.6–8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

College and Career Readiness Anchor Standards for Speaking and Listening

SL #5: Make strategic use of digital media and visual displays of data to express information and enhance understanding of presentations.

Science Background

Every object attracts every other object with a **gravitational force**. This includes large objects, such a stars, moons, and planets, as well as the everyday objects whose attraction to Earth is very familiar to us. The strength of the force between two objects is greater when the **mass** (how much matter something is made of) of each object is greater. The strength of the force is also greater when the distance between the two objects is less. Without **gravity**, objects in space would move in never-ending straight lines. The force of gravity causes objects to move in curved paths, forming systems of objects that move in regular patterns, such as our Solar System. The way an object responds to the force of gravity depends on the mass of the object and the **velocity** (the speed of the object and the direction in which it is traveling) of the object. A simple example is a a star and a planet. The star, being more massive, hardly moves at all. The motion of the planet is more greatly affected by the force from the star, and its path curves to make an orbit around the star. If the velocity of the planet is just right, the orbit is shaped like a circle. Many systems are more complex than one object simply moving in a circle around another, yet the simple idea that all objects attract one another helps to make sense of this complexity.

Getting Ready: Day 1

1. Make copies of each of the four articles (*Comets*, *Pluto and Charon*, *Moons of Jupiter*, and *The Shape of a Moon's Orbit*). Account for roughly one-fourth of the class reading each article. Students who read the same article will be working together in groups of four as they explore a computer simulation. You can assign students to groups in advance and assign each group an article. Or, you can give students a choice by having them select the article that they would like to read. If you choose the latter option, make one set of all four articles for each student. Make sure you keep a set of the articles for yourself and have a way to project them during class.
2. Make one copy of the Learning More About Orbits copymaster for each student.
3. Arrange to have the use of computers for two class sessions. Students will work with the simulation in groups of four.
4. Test the Gravity and Orbits Simulation (from PhET at the University of Colorado). You will find it at: **http://phet.colorado.edu/en/simulation/gravity-and-orbits**. You may run the simulation over the Internet (from the PhET servers) or download the Java application to your computer and the computers your students will be using. Make sure the correct version of Java is installed on the computers.
5. Place a round object, such as a tennis ball, in a clear plastic bag. Tie the bag closed tightly, using one end of a piece of string that is 1 meter in length. This will serve as the Tennis Ball Model that you will use to demonstrate an orbit.
6. On the board, write ""How can gravity cause one object to orbit another object instead of just making the objects crash into each other?"
7. On the board, write the following key concepts:
   - Gravity from the Sun or a planet can cause a moving object to orbit around it.
   - There are differences among the various orbits of Solar System objects.

Before Beginning the Instructional Sequence

1. Distribute one copy of the article that you assigned to each student (or one set of the four articles to each student if you decided to let students choose their articles).
2. Using methods you have established with your class, have each student read through the assigned or chosen article once. Encourage students to read thoughtfully and carefully and to make a record of their thinking by annotating the text with questions, comments, and connections as they read.
3. Lead students in a discussion of their questions and ideas about the articles. Allow time for students to use the text to try to answer any questions they may have had and to talk to one another about key ideas they read about.
4. For more information about ways to engage students in an initial reading of the articles, see the Engaging with Text Through Active Reading: Wind Currents strategy guide.

Using a Model to Demonstrate an Orbit
(10 minutes)

1. **Review *gravity* and *orbit*.** Make sure that each student has a copy of the article they read. Remind students that gravity from the Sun or a planet can cause a moving object to orbit around it. Refer to the focus question you wrote on the board and ask, **"In the article you read, how did gravity cause one object to orbit another object instead of just making the objects crash into each other?"** Have students turn to a partner and briefly explain their initial ideas.
2. **Demonstrate an orbit.** Explain that you will use a model to show what causes an object to orbit another object. Hold up the plastic bag with the ball inside. Hold the end of the string and swing the bag in a circle above your head, going fast enough so the string is nearly horizontal. Point out that a smaller object (the tennis ball) is orbiting around a larger object (you). Call on a student to describe the trajectory of the bag. [It moved in a nearly circular path around your head, like an orbit.]
3. **Review ideas about gravity.** Ask, **"Why does the ball move in a circle?"** [The string keeps it from flying away/forward.] **"What does the string in this model represent?"** [Gravity pulling on the object and keeping it in orbit.] **"What would happen to the ball if the string broke?"** [The bag would stop moving in a circle and fly away from you. It would also fall to the floor.] Let students know that they will keep thinking about the answer to this last question while they are using a computer simulation.

Exploring the Simulation (20 minutes)

1. **Arrange students into groups.** Arrange students into groups of four based on students who read the same article.
2. **Introduce the simulation.** Project the simulation and explain that it is a computer simulation of the Solar System, which will help students explore how gravity affects orbits. Point out that scientists develop computer models to simulate how something in nature works, especially complex natural systems that are hard to observe directly, such as the Solar System.
3. **Introduce goals.** Explain that today, students will have an opportunity to explore the simulation in groups of four. As they explore, you would like them to note if they learn anything that would help answer the question you raised earlier: *How can gravity cause one object to orbit another object instead of just making the objects crash into each other?* Have students note the factors they manipulate on the simulation that cause changes in the orbit of objects (e.g., objects flying away or crashing into one another).
4. **Orient students to the simulation.** Briefly orient students to the simulation by demonstrating how to change the objects they observe by clicking the buttons in the top section of the box on the right (e.g., to switch from Earth and the Moon to Earth and a satellite). Show students what is different about the two tabs that affect the view (Cartoon vs. To Scale) and that they can shrink or expand what they see by using the vertical slider on the far left.
5. **Briefly review vocabulary.** If needed, review accessible definitions for *mass* (how much matter something is made of) and *velocity* (speed with a direction).
6. **Students explore simulation.** Have students decide how they will take turns leading the exploration of the simulation in their groups. As you circulate, have students tell you what they are finding out about how the simulation works.
7. **Review simulation features and key concepts.** Students may have discovered things about the simulation that will be useful for other students. Have a few students demonstrate these for the class on the projected simulation. If not included in the tips that students share, address the following key features and use this

Allowing Exploration of Simulations

When working with engaging simulations, students may find it challenging to pause and look away to share ideas or receive further directions. Thus, it can be very helpful to limit pre-instruction for the simulation and provide a brief time for students to explore the simulation freely. Allowing students to discover features of the simulation on their own, or from other students, improves their focus and provides an enhanced sense of engagement with the simulation.

as an opportunity to review the key concepts that students have learned related to gravity and orbits.

- **Arrows and lines.** Demonstrate how to click the items in the Show section of the box on the right.
    - When you click the Gravity Force button, the arrows show the direction and strength of the force of gravity on each object due to the other objects.
    - When you click the Velocity button, the arrows show the speed and direction of motion of each object. Demonstrate how students can change the velocity of an object at any time by grabbing the head of the velocity arrow.
    - When you click the Path button, the lines show how the object has moved. The motion of an object is the result of the velocity and the forces on that object. Demonstrate how students can also change an object's path by simply dragging the object.
- **Factors that affect gravity.** As you demonstrate the basic features of the simulation, review the factors that affect gravitational force (e.g., the mass of objects in orbit) by using the features of the simulation.

8. **Discuss initial question.** Ask, **"Did your observations help you answer the question *How can gravity cause one object to orbit another object instead of just making the objects crash into each other?*"** Ask students from a few different groups to share their ideas with the class.

Rereading the Articles (15 minutes)

1. **Review directions for rereading.** Let students know that they will now reread their articles with partners. They will focus on finding and underlining the central ideas in the text. In the next session, they will use the simulation to explain these key ideas to students who read different articles.
2. **Have pairs reread articles.** Assign pairs and have them begin rereading. Circulate to check that students are underlining central ideas. Encourage pairs to share their thinking about the central ideas by reading together and discussing what to underline as they read. Alternatively, they can read independently and stop after each paragraph to share their thinking about what to underline.
3. **Pairs answer questions on student sheet.** Distribute one copy of the Learning More About Orbits student sheet to each student. Let students know that although they will work with their partners to complete the questions, each student should fill out her own student sheet.
4. **Debrief.** Have students share ideas about how there are differences among the various orbits of Solar System objects.
5. **Wrap up session.** Let students know that in the next session, they will use the simulation to explain important ideas from the text before they share with students who read different articles. Point out that they will learn from one another how orbits can vary.

Encouraging Distributed Expertise

Having middle school students read and learn about various examples of orbits across the class gives students a reason to think about, share, and teach what they learned to others who did not read the same article. This creates an authentic purpose for student-to-student talk, which is important in helping students solidify their understanding of science ideas. This sharing of knowledge and listening to others share fosters an environment in which students are truly learning from one another. If students have trouble getting started or explaining their ideas, provide them with sentence starters. Over time, such supports help students collaborate effectively and independently.

Getting Ready: Day 2

1. Make one copy of the Gravity and Motion Simulator Planning Sheet copymaster for each student.
2. Make sure you have access to computers for this session and that the simulation is working properly. Students will continue to work with the simulation in groups of four.

Preparing to Share Expertise (20 minutes)

1. **Review purpose for using simulation.** Let students know that today, they will decide

with their groups how to use the simulation to share the most important ideas from their article with classmates who read different articles.

2. **Project Preparing to Share Expertise.** Review the steps for sharing that students will do first in their groups and then later with other students. Keep this projected during the activity.
3. **Distribute student sheets.** Distribute one copy of the Gravity and Motion Simulator Planning Sheet to each student. Explain that although students will be working in groups, each group member should record on his own student sheet.
4. **Support students in changing the simulation.** Though students may start with a preset scenario in the simulation, encourage them to try adjusting the mass, speed, and distance of objects to illustrate the orbits they read about. Allow students time for trial and error as they try to illustrate ideas. If students become stuck, you might help by providing the following suggestions for each article.
   - ***Comets*:** To make a circular orbit of Earth around the Sun more elliptical, students can try changing the preset distance between the planet and the Sun, the speed of the planet, or the difference in mass between the objects. This may help students see which changes lead to a more elliptical and less circular orbit and how the object speeds up and slows down as it orbits.
   - ***Pluto and Charon*:** Students can try changing the preset masses of Earth and the Moon to make those masses more similar to each other. When the masses become more similar, the movement of the more massive object becomes greater. Students may also try changing the distance between Earth and the Moon to see if they can make orbits that are a good model of the orbits of Pluto and Charon. As students make these changes, they will have to adjust the velocities in order to compensate for the change in the gravitational force between the two objects.
   - ***Moons of Jupiter*:** This scenario poses a particular challenge because there is no preset that includes multiple moons in orbit. However, students can change the distance of the Moon from Earth to mimic how the distance of a moon affects gravity and orbits. You might suggest that students observe what happens when the distance changes. They can also test what else they can change (e.g., velocity) to have the moon that they moved travel in a circular orbit.
   - ***The Shape of a Moon's Orbit*:** Students can observe how the Moon's wavy path is affected when they change the distance between the Moon's orbit and Earth. Or, they might remove Earth altogether by crashing it into the Sun to see what happens. [The Moon's orbit is no longer wavy.]
5. **Groups begin work.** Circulate and make sure students are working together, using the Preparing to Share Expertise guidelines.
6. **Remind students to write notes.** When there are 5–10 minutes remaining, let students know that all group members should help one another record notes on their Gravity and Motion Simulator Planning Sheet. If they have time, they may want to practice explaining the orbit they read about to one another.

Supporting English Language Learners

Allowing ELLs to create annotated diagrams about gravity and orbits provides them with more opportunities to express what they know. By providing ways for them to show their ideas that are not fully dependent on language, you can gain a clearer picture of ELLs' understanding of concepts. Having students demonstrate their understanding through diagrams often reveals understandings and ideas that you may not have otherwise known they had. As students discuss the simulation and create diagrams or drawings, look for their developing understanding related to factors affecting gravity and orbits. You might also review strong and accurate examples of students' diagrams with the whole class and post them in the classroom as examples.

Sharing Expertise (25 minutes)

1. **Explain process.** Let students know that they will now be arranged in mixed groups of four students—one student to represent each of the articles. Each group member will have about 3–4 minutes to explain their article, using the simulation and any diagrams they drew on the Gravity and Motion Simulator Planning Sheet to demonstrate the main ideas.

2. **Arrange mixed groups and have students share.** Once mixed groups have been formed, have students quickly decide an order in which they will share and then prompt them to begin. After each 3–4 minute interval, let groups know that they should switch to the next group member. Circulate as groups work and encourage students to return to the articles and to use any diagrams and notes from their two student sheets. You might have students who are not presenting write brief notes or make a sketch while they listen.
3. **Discuss key ideas with the class.** Lead a brief discussion in which a few students share what they learned from their peers. Then, conclude the session by asking students to think about what they have learned about mass, velocity, and orbits. Below are some key ideas to listen for and to draw out in students' responses.
   - The mass of the two objects involved in an orbit affects the orbit.
   - The distance between the two objects involved in an orbit affects the orbit.
   - The speed at which an object orbits another object can vary.
   - Orbit systems may involve more than two objects.
4. **Reflect on learning.** As a class, review and debrief the task. Alternatively, have students reflect and write about what they learned from completing the task. Encourage students to include not just the examples or topics about which they are experts, but those they heard about from others as well.

Connecting to Standards

Using simulations to explain concepts from text is an approach that capitalizes on the overlap between the science practices in the Next Generation Science Standards (NGSS) and the Common Core State Standards (CCSS) for English Language Arts. One way that using simulations to explain concepts from text meets these standards is that students use information in text and a computer model to build explanatory accounts about how the world works and then apply those explanatory accounts to new contexts. This provides an authentic reason for students to critically read scientific text to determine central ideas (NGSS Science Practice 8: Obtaining, Evaluating, and Communicating Information). As students connect the simulation to what they have read, they are connecting and linking information presented visually with information presented in words in a text (CCSS.ELA-Literacy.RST.6–8.7). Through this process of integrating the visual information in the simulation with the information presented in the text, students are using the simulation as a model to explain natural phenomena (NGSS Science Practice 6: Constructing Explanations and Designing Solutions).

Generalizing This Practice

Combining simulations and text to support students in creating scientific explanations is an approach that can be used throughout your science curriculum with a variety of texts, topics, and computer or physical simulations. Students explain to their peers specific concepts that are illustrated in both texts and simulations before they use their shared knowledge for a collaborative task that applies those concepts. This approach makes learning science content a student-centered rather than a teacher-driven experience, allowing students' genuine understandings, misunderstandings, and questions about the topic to emerge and to prompt further discussion of science ideas. It also helps students learn that scientists collaborate and discuss their ideas and use information from different sources (e.g., texts and models) to develop understanding. This approach aids in the creation of a class community in which students see themselves as active participants in knowledge development and view one another as resources. Use the following steps to use simulations to explain concepts from text throughout your curriculum.

Preparing to Combine Simulations and Text to Support Students in Creating Scientific Explanations

1. **Select a simulation that illustrates a concept you are teaching.** Many simulations are available online for classroom use. Choose one that clearly illustrates a concept your class is studying.
2. **Identify texts that provide examples of the concept.** Find 2–5 texts that illustrate different examples of the selected concept (e.g., if you are studying ecosystems, find a few examples of different organisms interacting in different ecosystems). The texts should be at a level that students can access more or less independently. Examples could also be in the form of visual representations (e.g., maps, diagrams, charts, tables), or multimedia.
3. **Identify a collaborative application activity.** Create a task that requires students to apply the ideas they learn from the text and simulation. For instance, students might need to pool knowledge and apply concepts to solve a mystery or figure out a problem; make and test predictions about a new example; create a visual representation or model; or demonstrate and understand new cases in the simulation. It is helpful if a group of students completing the activity clearly benefit from sharing expertise and are able to complete the task even if one example or part is missing or not well explained.
4. **Plan groupings.** Plan for students to work in pairs or in groups and then share their methods for illustrating their examples with a new group of students. If students learn about different examples of the same concept, they should begin in pairs or in groups whose members learned about the same example and then share their methods for illustrating the concepts with a new group of students who learned about different examples.
5. **Develop discussion supports.** You may wish to provide students with guidelines to help them structure their discussions. Another helpful support is to provide sentence starters that prompt students to ask one another questions, provide evidence, and explain their thinking.

Combining Simulations and Text to Support Students in Creating Scientific Explanations

1. **Activate background knowledge.** Provide a prompt or question that helps students activate their background knowledge about the topic. Have students respond either orally or in writing.
2. **Students select their examples.** Preview each example with the class and point out interesting features or questions about each. If possible, let students choose what they will study rather than assigning the examples to them.

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Generalizing This Practice (continued)

3. **Preview the activity.** Explain that students will participate in multiple stages of talk to learn about, explain, and apply the key concepts. Let students know that they will work with their peers to identify key ideas in the text and ways to illustrate those ideas in a simulation. They will then share their expertise and pool their knowledge for a final application activity related to a focus question. Underscore that collaborative discussion will be essential to develop their understandings and complete their challenge application task.
4. **Provide a model for students.** If students will be using a new skill or encountering a challenging task, show how you, as an expert, would complete the task. For example, if students will be reading a text, demonstrate strategies that you would use to closely read the text or use text features and diagrams to identify key ideas.
5. **Students read.** Provide time and resources for students to learn about science concepts through text.
6. **Provide free exploration time with a simulation.** Allowing students time to explore the simulation will help increase their focus and confidence when they use the simulation later for a specific task. (See the Allowing Exploration of Simulations note on page 3 for information about the benefits of providing free exploration time with a simulation.)
7. **Set expectations.** To support and focus students, provide a list of criteria and/or sentence starters that will guide their discussions. These supports should prompt students to collaborate effectively by identifying questions and confusions, seeking and building on one another's ideas, and supporting their ideas with evidence and reason.
8. **Have groups discuss text and simulation.** Remind students that they will need to identify key ideas in the text and then identify ways to use the simulation to explain the important concepts to other students.
9. **Share expertise in mixed groups.** Arrange students into mixed groups or pairs comprised of students who learned about different examples. Direct students to briefly explain the examples they studied. Consider providing a graphic organizer or note taker that can help students identify and record key concepts from their examples.
10. **Groups apply learning.** Present the application activity to students. Remind them that they will need to share their expertise and collaborate with the rest of the class. Redirect students to any collaboration guidelines you created and posted. Circulate to support and monitor discussions.
11. **Reflect on learning.** As a class, review and debrief the task. Alternatively, have students reflect and write about what they learned from completing the task. Encourage students to include not just the examples or topics about which they are experts, but those they heard about from others as well.

Name: ______________________________ Date: ______________

Learning More About Orbits

1. From the article you read, choose one of the diagrams to observe carefully. What did you learn about the orbit shown in the diagram? Describe the orbit, in words or in a drawing (in the space below), including the objects that are orbiting, the shape of the orbit, etc.

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2. Think of the Tennis Ball Model and the orbit of the object in that model. Explain how the orbit you learned about in your article is different from the orbit in the model?

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3. Explain why the orbit you read about is different than the orbit in the Tennis Ball Model.

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4. Using only one or two sentences, explain the most important ideas from your article. (Hint: You should include something about orbits.)

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Preparing to Share Expertise

1. Look at the last question on your Learning More About Orbits sheet to see the important ideas from the article you read.

2. With your group, discuss the most important ideas and what you want to show other groups.

3. Decide how to use the simulation to illustrate the ideas in your article.

4. Practice explaining what the simulator shows.

5. Use the Gravity and Motion Simulator Planning Sheet to write notes to help you remember what you want to say to other groups.

Name: ______________________________ Date: ______________

Gravity and Motion Simulator Planning Sheet

1. Describe the orbit you read about.

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2. Explain and draw a diagram to indicate how you could change the settings in the simulator to demonstrate important ideas about your orbit. (Hint: You might change the mass, velocity, or number or position of objects.)

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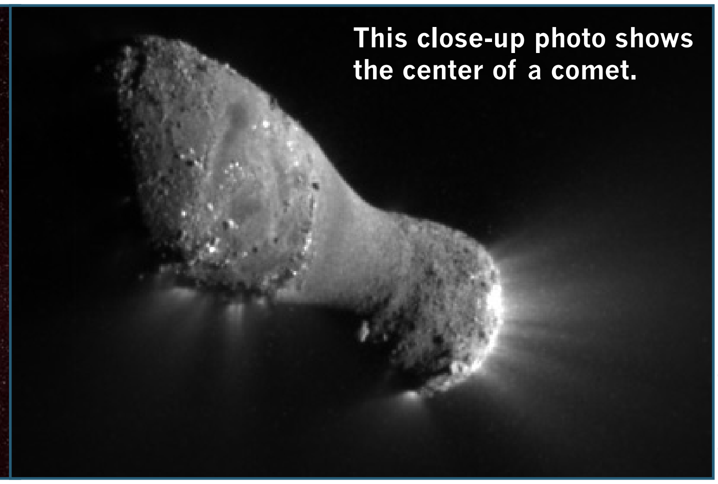
Wikimedia/Hans Bernhard (Schnobby)



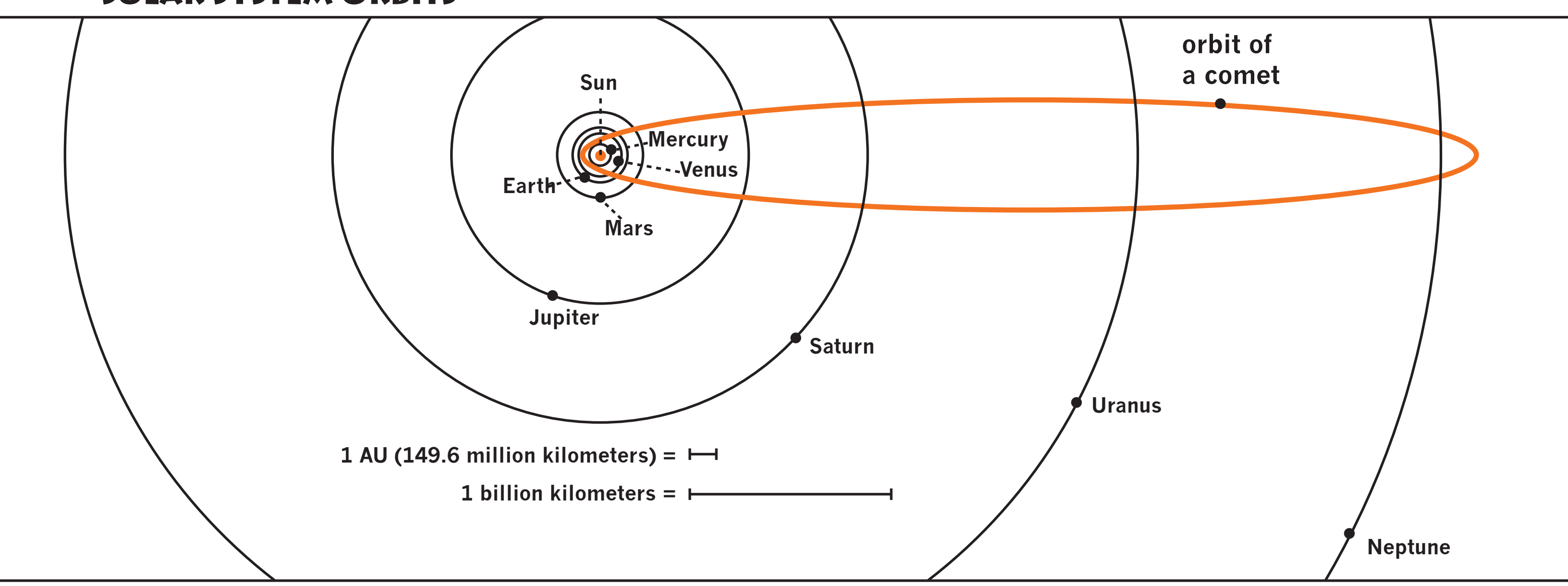
NASA/JPL-Caltech/UMD

Comets

With their bright glow and long, streaming tails of light, comets look beautiful from Earth. However, at its heart a comet is a dirty snowball that orbits the Sun. Comets are mostly composed of frozen water, frozen carbon dioxide, and other frozen matter. They also contain dust and small chunks of rock. The solid part of a comet is usually only about 16 kilometers (10 miles) across, but its tail of gas and dust may stretch as far as 250 million kilometers! Comets only have tails some of the time, and the reason why has to do with the way comets orbit.

Comets orbit differently than planets. The planets in our Solar System have orbits that are nearly circular, with the Sun in the center. Unlike the planets, comets have orbits that are highly elliptical: their orbits are long and narrow instead of circular. Comets come close to the Sun and then swing out very far away from it—farther from the Sun than the farthest planets. It takes some comets millions of years to orbit the Sun.

Solar System Orbits

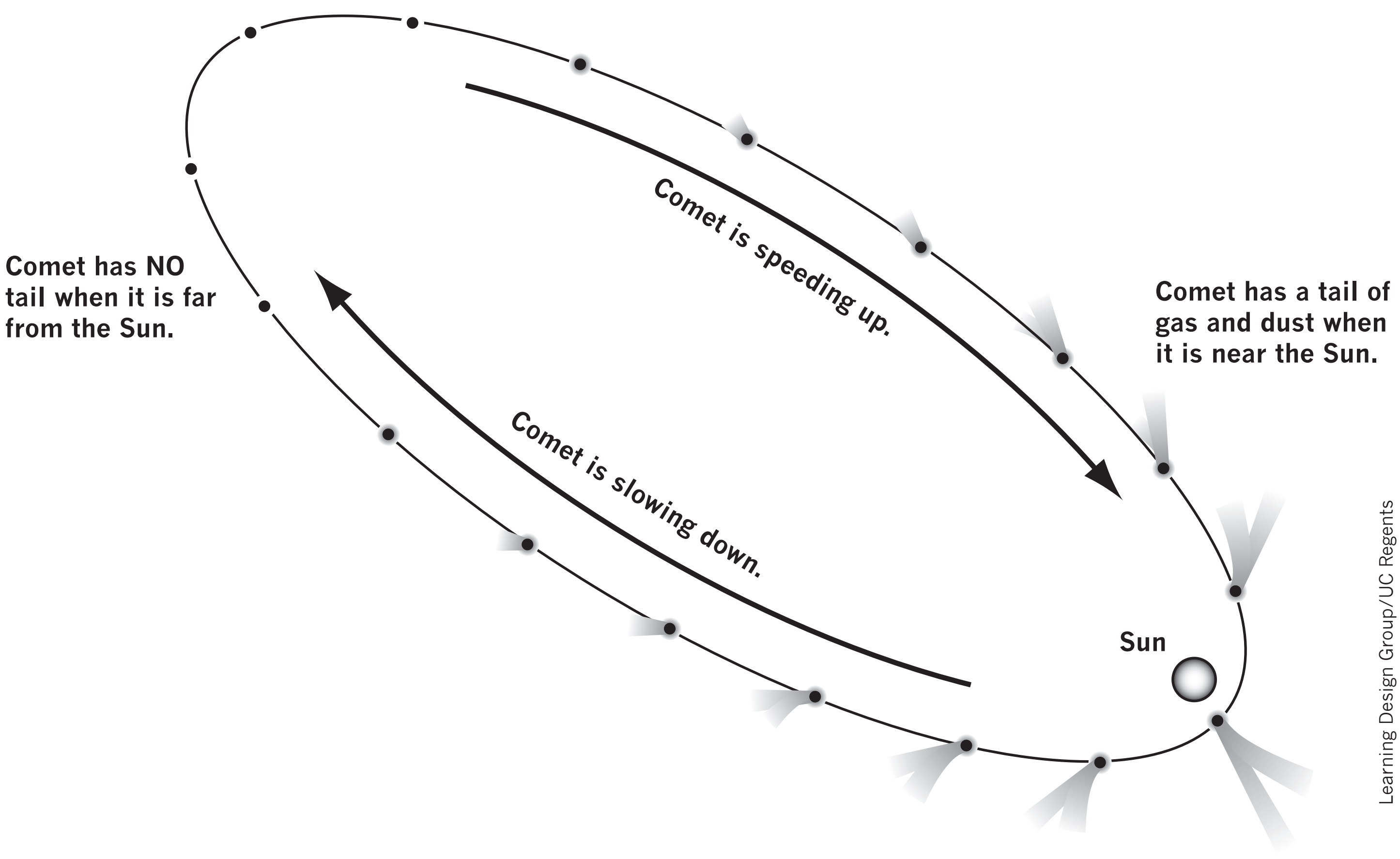


Learning Design Group/UC Regents

The Sun pulls on a comet with a gravitational force, just as it does to every other object in the Solar System. An object such as a planet moves fast enough so that the pull of gravity makes it curve around the Sun, without moving closer to the Sun or farther from the Sun. A comet is different. When it is far from the Sun, it is moving slowly, and it falls toward the Sun. As it moves toward the Sun, the gravitational pull of the Sun makes the comet get faster and faster. At a certain point, the comet swoops around the Sun and starts to move away. During this time, the gravitational pull of the Sun is against the motion of the comet, and the comet gets slower and slower. When it has slowed down enough, the comet starts moving toward the Sun again, following its elliptical path.

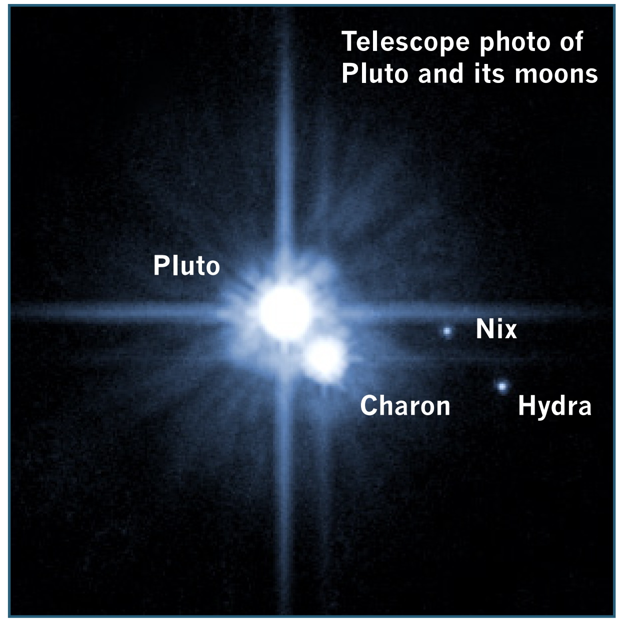
Because of their elliptical orbits, comets experience big changes in temperature as they orbit. When they are far from the Sun, comets are extremely cold. As a comet approaches the Sun, sunlight warms up the comet. The warmed-up comet gives off lots of gas and dust, which can be seen from Earth as a glowing tail.

Orbit of a Comet



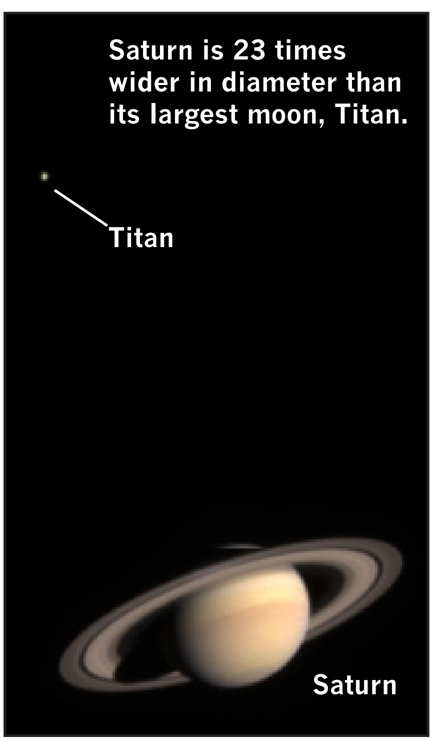
Pluto and Charon

Pluto is not classified as a planet anymore. Some call it a dwarf planet, but it has one thing in common with most of the true planets in the Solar System: it has moons. Scientist have observed five moons, but there may be more. Pluto's largest Moon, Charon, is different from other moons in the Solar System in a few important ways. In fact, it is so different that some scientists say that Pluto and Charon are more like a double-dwarf planet instead a dwarf planet with a moon.

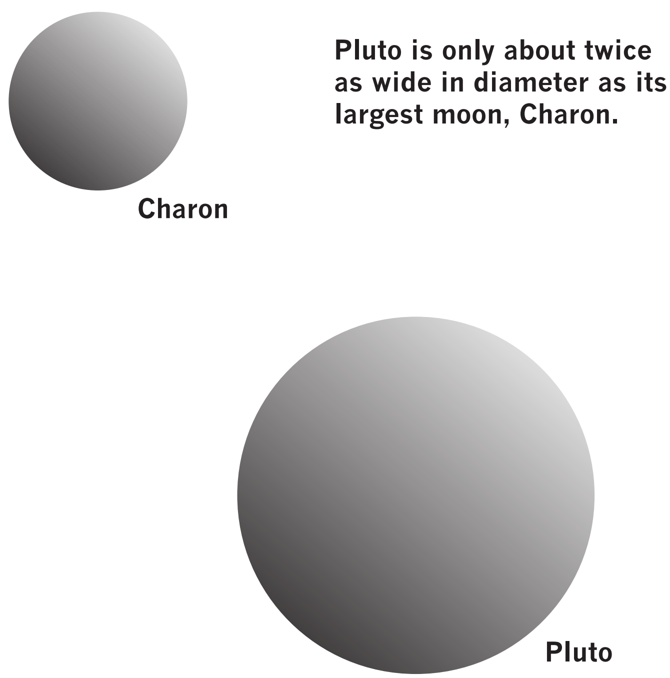


NASA, ESA, H. Weaver (JHUAPL), A. Stern (SwRI), and the HST Pluto Companion Search Team

Charon's size and mass, in comparison with Pluto, make it special. The diameter of Charon is just over half the diameter of Pluto. Even though that makes it smaller than Pluto, it means that Charon is big for a moon. No other moon in the Solar System is so similar in size to the planet that it orbits. For example, Saturn's largest moon, Titan, is only about 1/23rd the diameter of Saturn itself. Charon's mass is about 1/8th of the mass of Pluto. That is a much smaller mass, but the masses of Pluto and Charon are more similar to each other than the masses of any other pair of planets and moons. Saturn is about 4,300 times more massive than Titan.

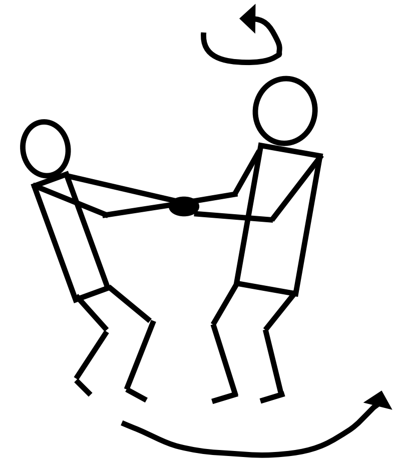


NASA/JPL/Southwest Research Institute



The similarity of the masses of Charon and Pluto make them orbit in an unusual way. You could say that Charon does not really orbit Pluto—they orbit around each other! The center of the Pluto–Charon system is somewhere between the two.

Think of Pluto and Charon as two people, a heavier one and a lighter one, holding their hands and turning. Their arms and hands are like the gravity that hold Pluto and Charon in orbit around each other. The lighter person will move around the heavier person, but the heavier person will move around, too. They will both orbit a spot near where their hands meet, but closer to the heavier person.



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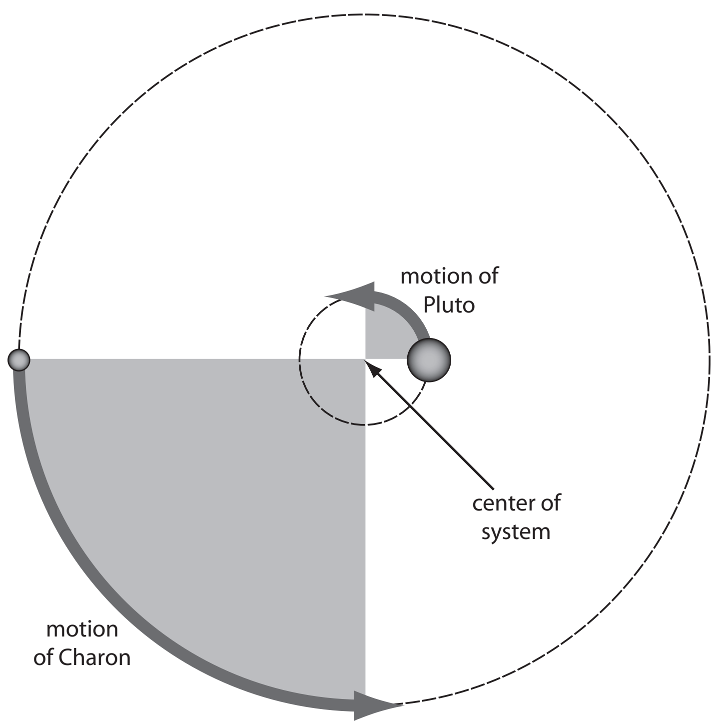
It's the same with Pluto and Charon. They are always pulling toward each other with the force of gravity, and they orbit a spot that is between them that is about 2,000 kilometers from the center of Pluto.

Other objects and their moons affect each other in a similar way, but with an important difference. For instance, Earth and the Moon both orbit a spot that is between the center of the Moon and the center of Earth, but that spot is actually inside Earth. That is the way with all other moons and planets in the Solar System. They orbit a spot between their centers, but that spot is always inside the planet because the planet is much bigger and heavier.



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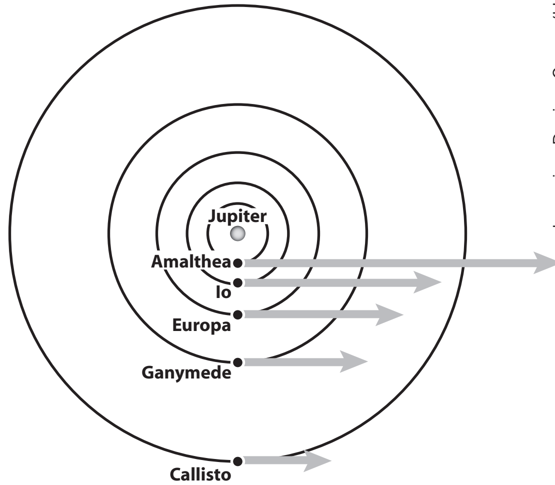
Moons of Jupiter

If you look at the planet Jupiter through a telescope, you can see what looks like a little Solar System model. At the center is Jupiter, just as the Sun is at the center of the Solar System. Four large moons are visible orbiting around Jupiter, just as the Solar System planets orbit the Sun. There are also many smaller moons of Jupiter that are harder to see from Earth—at least 60 have been discovered so far. Jupiter's moons orbit the planet at different distances. The moons that are farther from Jupiter take longer to orbit than the moons that are closer. That might seem obvious, because the moons that are farther away have a longer trip to get all the way around Jupiter. However, that's not the only reason the farther moons take longer to orbit.The closer a moon is to Jupiter, the faster it moves. The closer moons not only have a shorter distance to travel around Jupiter, they also travel at greater speeds than the moons that are farther away.



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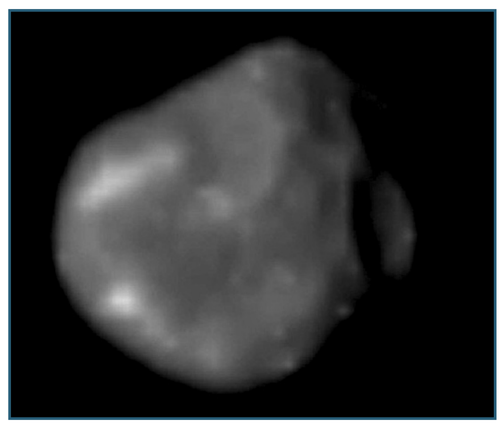
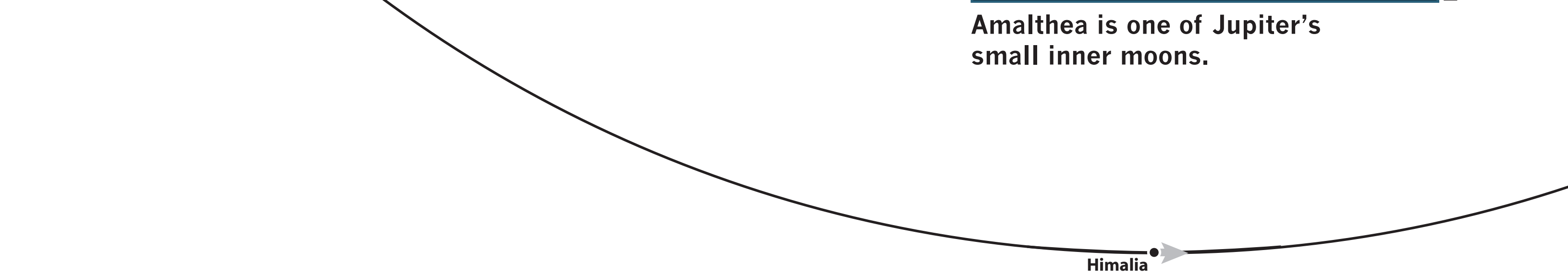
The diagram above shows the orbits of six of Jupiter's moons. The arrows show how fast the moons are orbiting: the longer the arrow, the faster the moon.

The distances are shown to scale. To find the orbit of Himalia, the most distant moon, look at the very bottom of the page.



NASA/JPL/Cornell University

Amalthea is one of Jupiter's small inner moons.



Orbit Data for Jupiter's Six Largest Moons

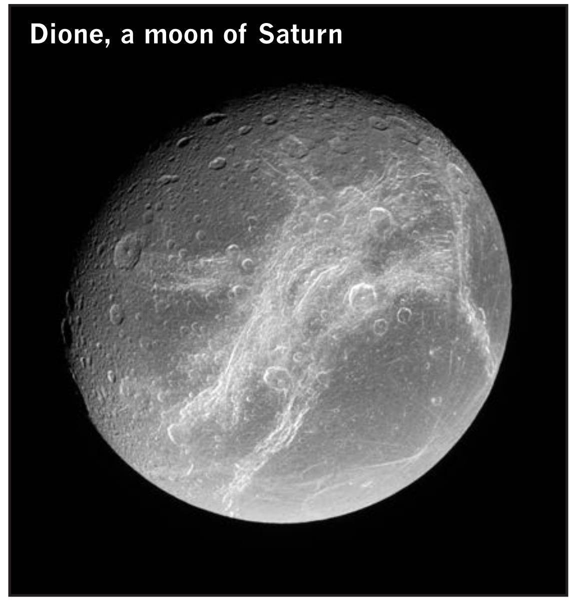
Moon	Average distance from Jupiter	Orbital period (how long it takes to orbit Jupiter)	Average speed of orbit
Amalthea	181,400 km	12 hours	27 km per second
Io	421,800 km	43 hours	17 km per second
Europa	671,100 km	85 hours	14 km per second
Ganymede	1,070,400 km	172 hours	11 km per second
Callisto	1,882,700 km	401 hours	8 km per second
Himalia	11,461,000 km	6,013 hours	3 km per second

Why do closer moons orbit faster than faraway moons? The closer a moon is to Jupiter, the stronger the pull of gravity between Jupiter and that moon. In order to keep orbiting around instead of crashing into Jupiter, a nearby moon has to be traveling very fast. The pull of gravity between Jupiter and faraway moons is weaker, so the outer moons do not have to travel as fast to stay in orbit. In fact, if they were traveling faster, the outer moons would fly off into space instead of orbiting Jupiter.

The closer an object is to the thing it is orbiting, the faster that object has to be traveling to stay in orbit. The farther an object is from the thing it is orbiting, the slower that object has to be traveling to stay in orbit. These rules are not only true for Jupiter's moons, they are true for all objects that orbit. If you look at a data table showing the Solar System planets and their orbits around the Sun, you'll see that the closest planet orbits the Sun fastest, and the farthest planet orbits slowest. Jupiter and its moons really are like a little model of the Solar System.

NASA/JPL/DLR

The Shape of a Moon's Orbit

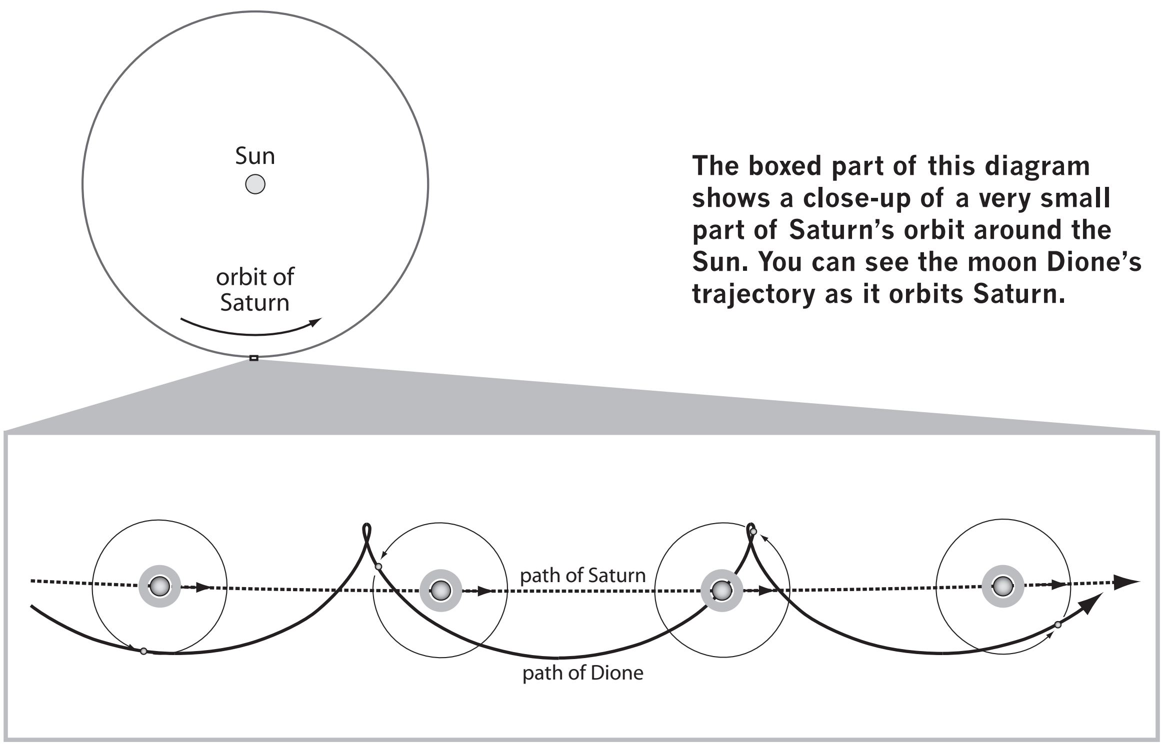


NASA/JPL/Space Science Institute

When is a circle not a circle? Many objects in the Solar System move in orbits that are very circular. For instance, Dione is a moon that moves around the planet Saturn in an orbit that is almost a perfect circle. It seems perfectly logical to say that the trajectory of Dione is circular. But is it really?

While Dione is circling around Saturn, Saturn is not sitting still. Saturn is moving around the Sun. The gravitational pull of the Sun affects Saturn and all its moons, so they all move around the Sun together. Saturn moves in an orbit that is almost a perfect circle, but what kind of trajectory does a moon such as Dione follow?

The path of a moon around the Sun can be quite complicated. It depends on how fast the planet is moving, how fast the moon is orbiting, and how far away the moon is from the planet. Dione moves around the Sun in a wavy path that makes a little loop every time it orbits around Saturn. Every time Saturn orbits the Sun once, Dione orbits Saturn about 3,931 times, so the trajectory that Dione follows is an intricate path with thousands of waves and loops.



The boxed part of this diagram shows a close-up of a very small part of Saturn's orbit around the Sun. You can see the moon Dione's trajectory as it orbits Saturn.

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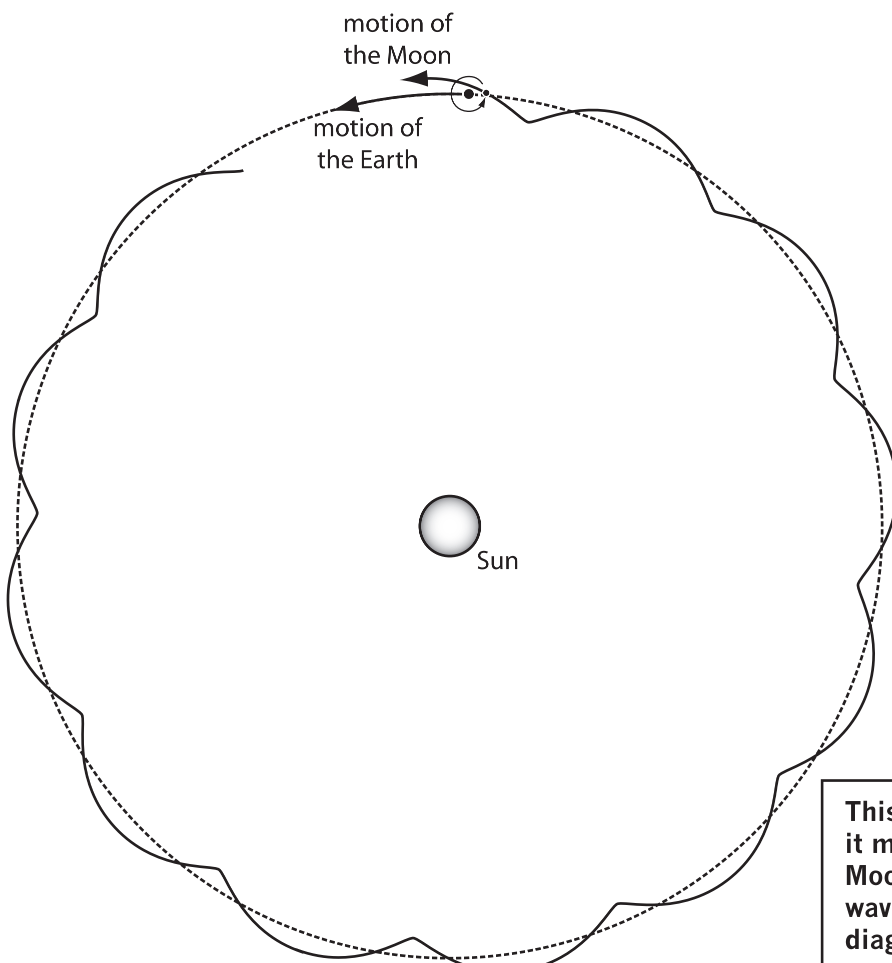
Earth's Moon is like Dione in some ways and different in some ways. Our Moon orbits Earth in very much the same way that Dione orbits Saturn. The orbits are even about the same size.What is different are the speeds. Earth orbits the Sun much more quickly than Saturn does, and the Moon orbits Earth much more slowly than Dione orbits Saturn. While Dione orbits Saturn thousands of times on each orbit around the Sun, the Moon orbits Earth only about a dozen times. The Moon does follow a slightly wavy path around the Sun, but the waves are very stretched out, and they do not have loops in them.

NASA/JPL/USGS



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This diagram is exaggerated: it makes the path of the Moon around the Sun look wavier than it really is. If the diagram were more accurate, you wouldn't be able to tell that the Moon's path around the Sun is wavy at all!

About Disciplinary Literacy

Literacy is an integral part of science. Practicing scientists read, write, and talk, using specialized language as they conduct research, explain findings, connect to the work of other scientists, and communicate ideas to a variety of audiences. Thus, the Next Generation Science Standards (NGSS) and the Common Core State Standards (CCSS) alike call for engaging students in these authentic practices of science. Through analyzing data, evaluating evidence, making arguments, constructing explanations, and similar work, students engage in the same communicative practices that scientists employ in their profession. Through supporting and engaging students in science-focused literacy and inquiry activities that parallel those of scientists, students master discipline-specific ways of thinking and communicating—the disciplinary literacy of science. Strategy guides are intended to help teachers integrate these disciplinary literacy strategies into the science classroom.

About Us

The Learning Design Group, led by Jacqueline Barber, is a curriculum design and research project at the Lawrence Hall of Science at the University of California, Berkeley. Our mission is to create high-quality, next-generation science curriculum with explicit emphasis on disciplinary literacy and to bring these programs to schools nationwide. Our collaborative team includes researchers, curriculum designers, and former teachers as well as science, literacy, and assessment experts.

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