

Gravity and Orbital Motion



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION/JET PROPULSION LABORATORY

*What keeps a satellite orbiting in space? Gravity!
Gravity also helps planets like Earth orbit the Sun.*

INTRODUCTION

How does a manmade satellite get into orbit? A satellite is launched by a rocket to a height (or altitude) at which Earth's gravitational force keeps the satellite in orbit around Earth. A satellite, like the Moon, must travel at just the right speed to stay in Earth's orbit. If the satellite moves too slowly, gravity might pull it back down to Earth. If the satellite moves too fast, it might escape Earth's gravitational pull and zoom out into space.

In Lesson 14, you investigated the effects of surface gravity on weight. In this lesson, you will conduct four inquiries that focus on gravity and its effects on the orbits of moons and planets. What part does gravity play in keeping the planets in orbit around the Sun? How do the moons stay in orbit around each planet? In this lesson, you will investigate these and other questions. You will also read to learn more about missions to Saturn, Uranus, and Neptune.

OBJECTIVES FOR THIS LESSON

- Analyze patterns in planetary motion.**
- Observe the motion of a marble when acted upon by different forces.**
- Investigate the effect of a pulling force on the orbital period of a sphere.**
- Relate the observed behavior of a marble and sphere to the motion of moons and planets.**
- Summarize, organize, and compare information about Saturn, Uranus, and Neptune.**

Getting Started

- 1.** Review the Introduction section of the software *Explore the Planets* with your class.
- 2.** Use what you learned from *Explore the Planets* to make general observations about the planets' motion around the Sun. Record your ideas in your notebooks if instructed to do so by your teacher. Discuss your ideas with the class.
- 3.** To get a better sense of how the planets' orbits differ from each other, use the software *Starry Night Backyard*. Observe the orbits of the inner planets. Then observe the orbits of the outer planets. Record or discuss your observations as instructed.
- 4.** Review the objectives of this lesson with your teacher. Discuss the Procedures and Safety Tips listed in each inquiry. A summary of each procedure will be posted at each station.
- 5.** Divide your notebook page into quadrants. Label the quadrants 15.1, 15.2, 15.3, and 15.4.
- 6.** Complete all four inquiries in the order given to you by your teacher. Remember to return all of your equipment and its inquiry master to the plastic box or bag before moving on to the next station.

MATERIALS FOR LESSON 15

For you

- 1 working copy of Student Sheet 10.1c: Planetary Chart

MATERIALS FOR INQUIRY 15.1**For you**

- 1 pair of goggles

For your group

- 1 copy of Inquiry Master 15.1: Gravity's Effect on Objects in Motion
- 1 plastic box from Lesson 12 (filled with sand, flour, and cocoa)
- 1 large resealable bag containing the following:
 - 1 metric ruler, 30 cm (12")
 - 1 marble
 - 1 metric measuring tape

Inquiry 15.1

Gravity's Effect on Objects in Motion

PROCEDURE

1. Hold the marble 40 cm above the plastic box. With the marble in your hand, decide what two forces are acting on the marble. Are the forces balanced (both pulling equally) or unbalanced (one is pulling more than the other)? Discuss your ideas with your group.
2. What will happen if you release the marble from your hand into the box? Discuss your predictions with your group.

SAFETY TIPS

Wear safety goggles at all times.

Work in a well-ventilated area to minimize the level of dust in the air.

3. Let go of the marble. Discuss your observations of the marble's motion with your group. (Do not be concerned about the crater that the marble makes. The sand and flour keep the marble from moving once it lands in the box.) Compare your observations to your predictions.
4. Repeat Procedure Steps 1–3. Does the marble move the same way each time? Discuss your observations and record them in quadrant 15.1 in your notebook.
5. Use the ruler as a ramp to gently roll the marble into the plastic box, as shown in Figure 15.1. Keep the ruler nearly flat. Discuss your observations. How did the marble move once it left the ruler?



Figure 15.1 Roll the marble down the ruler into the plastic box.

- 6.** Experiment by rolling the marble down the ruler at different speeds. Keep the ruler nearly flat. How does the marble move each time it leaves the ruler? If possible, measure the distance that your marble travels each time. Record your observations in your notebook.
- 7.** Answer these questions in your notebook:
- What pulling force acts on the marble at all times?
 - When you rolled the marble slowly, how did it move once it left the ruler?
 - How does the forward speed of the marble affect the motion of the marble once it leaves the ruler?
 - All planets that orbit the Sun are traveling forward due to inertia and falling toward the Sun due to gravity. Describe the path of something that has forward motion (like your marble) but is also being pulled down by gravity.
- 8.** Clean up. Return all materials to their original condition.

MATERIALS FOR INQUIRY 15.2

For you

- 1 pair of goggles

For your group

- 1 copy of Inquiry Master 15.2: Testing Balanced and Unbalanced Forces
- 1 plastic box (empty)
- 1 metal canning jar ring
- 1 marble
- 1 sheet of white paper

Inquiry 15.2 Testing Balanced and Unbalanced Forces

PROCEDURE

- Place the white paper in the bottom of the plastic box. Put the metal ring on top of the paper with the lip up, as if you were putting the metal ring on a jar.
- Trace an outline of the ring onto the paper. Remove the metal ring from the paper. Mark four points at equal distances around the circle. Number the marks 1 to 4 going clockwise, as shown in Figure 15.2.

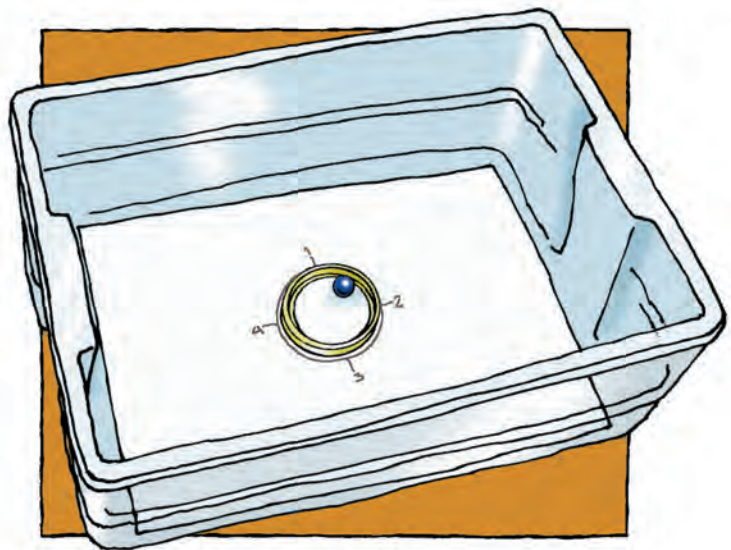


Figure 15.2 Mark the outline of the circle with 1, 2, 3, and 4 at quarter intervals.

SAFETY TIP

Wear safety goggles at all times.

3. Place the metal ring on the circle, again with the lip up. Place the marble inside the metal ring. Without moving the metal ring, describe the motion of the marble. Record your observations in quadrant 15.2 in your notebook.
4. Use the ring to move the marble in circles. Keep the ring on the paper at all times. Record your observations. Discuss with your group how the ring creates a force (called an “unbalanced force”) that influences the marble’s motion.
5. Make a prediction about what will happen if you lift the ring (remove the unbalanced force).
6. Move the marble in circles again, then lift the ring. What happens? In quadrant 15.2 in your notebook, describe the motion of the marble without the unbalanced force of the ring. Try this several times. Record your observations in both words and pictures. Use your numbered markings to pinpoint the motion of the marble each time.
7. Answer these questions in your notebook:
 - A. Describe the motion of the marble when an unbalanced force (the metal ring) influences it.
 - B. Describe the motion of the marble when the unbalanced force is removed.
 - C. Suppose you lifted the ring when the clockwise orbiting marble was at the “1.” Draw the path the marble would take.

D. Suppose you lifted the ring when the clockwise orbiting marble was at the “4.” Draw the path the marble would take.

E. Like the marble, the planets move forward due to inertia and inward due to an unbalanced force. Together, these forces cause the planets’ paths to curve. What is the unbalanced force that keeps the planets in orbit? What would happen to the planets without this unbalanced force?

8. Clean up. Return all materials to their original condition.

MATERIALS FOR INQUIRY 15.3

For you

- 1 pair of goggles

For your group

- 1 copy of Inquiry Master 15.3: Observing Planetary Motion
- 1 Planetary Motion Model™
- 4 plastic boxes or boxes of the same height
- 1 large resealable plastic bag containing the following:
 - 1 yellow balloon, filled with water
 - 1 metric ruler, 30 cm (12")
 - 1 marble

Inquiry 15.3

Observing Planetary Motion

PROCEDURE

1. Check the setup of the Planetary Motion Model™. The lip of the hoop should be facing up to prevent the marble from falling off the latex sheet, as shown in Figure 15.3. Allow any extra sheeting to hang down under the hoop. Make sure the hoop rests on the edges of the boxes so they do not interfere with the marble once it is on the sheet.
2. You will use your ruler as a ramp to roll the marble onto the latex sheet. Before you do, make a prediction about the path the marble will take on the sheet. Discuss your predictions with your group.
3. Hold the ruler as shown in Figure 15.3 so that it faces the edge of the hoop. Roll the marble onto the flat sheet. Observe the marble. Repeat this several times. Discuss your observations with your group. Record your results in quadrant 15.3 in your notebook.
4. Place the balloon in the center of the sheet. Let go of the balloon. Discuss what the balloon does to the sheet. Then roll the marble onto the sheet toward the edge of the hoop. Watch the balloon and marble carefully. What do you observe about the motion of the marble? What do you observe about the behavior of the balloon? Discuss and record your observations with your group.



Figure 15.3 The Planetary Motion Model™ should be set up as shown. (A) Face the lip of the hoop up. (B) Hang the extra sheeting under the hoop. (C) Place the hoop on the edge of each box.

SAFETY TIPS

Wear safety goggles at all times.

Be careful working with the balloon. It can be a choking hazard.

The latex in the rubber sheeting may cause either an immediate or delayed allergic reaction in certain sensitive individuals.

- 5.** Now push down on the balloon as shown in Figure 15.4. Keep a constant pressure on the balloon.



Figure 15.4 Press down continuously on the water-filled balloon.

- 6.** Predict how the marble will move now that the center of the sheet has more mass. Have one of your partners roll the marble onto the sheet as you keep pressure on the balloon. Discuss your observations. Record your observations in words and pictures in your notebook.

- 7.** Test the motion of the marble several times and observe its motion carefully. Let everyone take a turn. How does the motion of the marble change as it nears the balloon?
- 8.** Now wobble the balloon very slightly as the marble orbits it. What happens? Try to use a gentle wobble on the balloon to keep the marble in motion. Discuss your observations. Then let go of the balloon. Does the balloon wobble on its own as the marble orbits it?

- 9.** Answer these questions in your notebook:

A. Describe how the marble moved when the mass in the center (the balloon) was not present.

B. Describe how the marble moved when the mass in the center was present.

C. As the distance between the balloon and marble decreased, what happened to the marble's speed?

D. Based on your observations, which planet do you think would have the fastest orbital speed? What evidence do you have to support your answer?

E. What force keeps the planets in their orbital paths around the Sun?

F. Read "Stars Wobble." Why does a star's "wobble" indicate that a planet is nearby?

- 10.** Clean up. Return all materials to their original condition.

STARS WOBBLE

There are many stars like our Sun. Some of these other stars also may have planets that orbit them. Even though Earth-based astronomers may not have yet seen a planet orbiting another star, they know such orbiting planets exist. How do they know? Because when a planet orbits a star, it makes the star wobble. Astronomers can examine a star's wobble and figure out how big, how massive, and how far away from its star the planet is. At the start of the new millennium, nearly 60 planets had been discovered by using the “wobble” method.

It all begins with gravity. Because of gravity, the Sun pulls on the planets, but it also means

that the planets pull on the Sun. (And moons and planets tug at each other.) An orbiting planet exerts a gravitational force that makes the star wobble in a tiny circular or oval path. The star's wobbly path mirrors in miniature the planet's orbit. It's like two twirling dancers tugging each other in circles.

Scientists use powerful space-based telescopes that orbit Earth to look for wobbling stars. Since they are outside of Earth's atmosphere, these telescopes can see the stars more clearly than telescopes on Earth's surface. Who knows? Someday scientists may use the wobble method to discover another solar system just like ours.

MATERIALS FOR INQUIRY 15.4**For you**

- 1 pair of goggles

For your group

- 1 copy of Inquiry Master 15.4: Investigating the Effect of Planetary Mass on a Moon's Orbit
- 1 plastic box or large resealable plastic bag containing the following:
 - 1 pre-assembled Moon Orbiter™
 - 25 large steel washers
 - 1 student timer

Inquiry 15.4

Investigating the Effect of Planetary Mass on a Moon's Orbit

PROCEDURE

- 1.** Examine the Moon Orbiter™. Discuss with your group how you think the Moon Orbiter might work.
- 2.** Move to an area in the classroom where no other groups are working. Check to see that all nylon knots are secured to the large white sphere.

SAFETY TIPS

Wear safety goggles at all times.

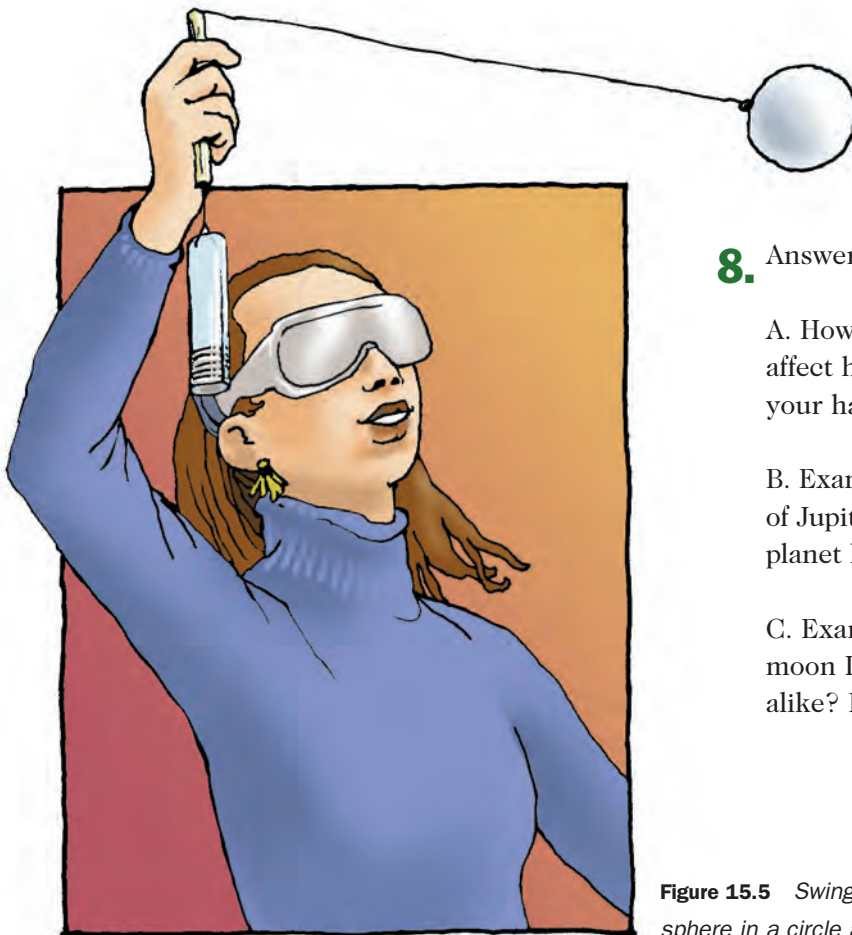
Do not swing the Moon Orbiter at other students.

Make sure that

other students are not nearby when you swing the white sphere.

Always swing the Moon Orbiter above your head.

3. Hold the narrow plastic tubing of the Moon Orbiter in your hand like a handle. Practice holding the Moon Orbiter over your head and moving your hand in circles to get the white sphere to orbit your hand. Use a steady and regular motion. When the sphere is in full orbit, the bottom of the tube should nearly touch the cylinder.
4. Increase the mass of the Moon Orbiter by adding five washers to the cylinder. Move your hand in circles over your head to get the white sphere to orbit your hand, as shown in Figure 15.5. Describe how fast the sphere has to move to stay in orbit around your hand with a mass of five washers pulling on it. (If possible, calculate its orbital period—the time it takes the sphere to orbit your hand. For



example, count the number of seconds it takes the sphere to orbit your hand 10 times. To get the orbital period, divide the number of seconds by 10.) Record your observations and data in quadrant 15.4 in your notebook.

5. Let everyone in your group try to swing the Moon Orbiter. Remember, when the sphere is in full orbit, the tube should nearly touch the cylinder.
6. Predict what will happen if you increase the mass of the Moon Orbiter's cylinder to 25 washers.
7. Fill the cylinder of the Moon Orbiter with 25 washers. Repeat Procedure Step 4 and discuss your observations. Let everyone in your group have a turn. Describe how fast the sphere has to move to stay in orbit around your hand with 25 washers pulling on it. (Try calculating the sphere's orbital period.) Record your observations.
8. Answer these questions in your notebook:
 - A. How does the mass of the cylinder affect how fast or slow the sphere orbits your hand?
 - B. Examine Table 15.1. Compare the mass of Jupiter with the mass of Earth. Which planet has more mass?
 - C. Examine Table 15.1. Compare Jupiter's moon Io with Earth's Moon. How are they alike? How are they different?

Figure 15.5 Swing the white sphere in a circle above your head.

Table 15.1 Planetary Mass Versus Moon's Orbital Period

Solar System Body	Approximate Mass (kg)	Diameter (km)	Distance From Planet (km)	Orbital Speed (km/sec)	Orbital Period (days)
Jupiter	$189,900 \times 10^{22}$	142,984			
Earth	597×10^{22}	12,756			
Io	9×10^{22}	3643	421,600	17	~ 2 days
Moon	7×10^{22}	3475	384,400	1	~ 27 days

D. Compare Io and the Moon. Which planetary satellite travels faster (has a greater orbital speed)? Given your results from the inquiry, why do you think this is?

E. Orbital period is the time it takes a revolving object to orbit a central object. Which planetary satellite has a shorter orbital period? What is the relationship between orbital speed and orbital period?

F. In Lesson 14, you learned the approximate mass of each planet. How do you think scientists determine the mass of the planets?

- Clean up. Return all materials to their original condition.

REFLECTING ON WHAT YOU'VE DONE

- Share your answers to the inquiry questions with the class.
- Read "Heavy Thoughts." In your notebook, answer the questions at the end of the reading selection.
- With your class, return to the Question H folder for Lesson 1. Is there anything you would now change or add? Discuss your ideas with the class.
- Return to your list of ideas about gravity from Lesson 14. What new information about gravity do you want to add to your list?
- Read the "Mission" reading selections on Saturn, Uranus, and Neptune. Add any information about these planets to your working copy of Student Sheet 10.1c: Planetary Chart (and onto Student Sheet 10.1b: Planetary Brochure Outline if your Anchor Activity planet assigned during Lesson 10 was Saturn, Uranus, or Neptune).

HEAVY THOUGHTS

Do you ever wonder why when you jump up, you always come back down? Or do you ever wonder why the Moon keeps circling around Earth rather than drifting off into space? Throughout history, people have wondered about these things. Now we know that a property of the universe called “gravity” is responsible.

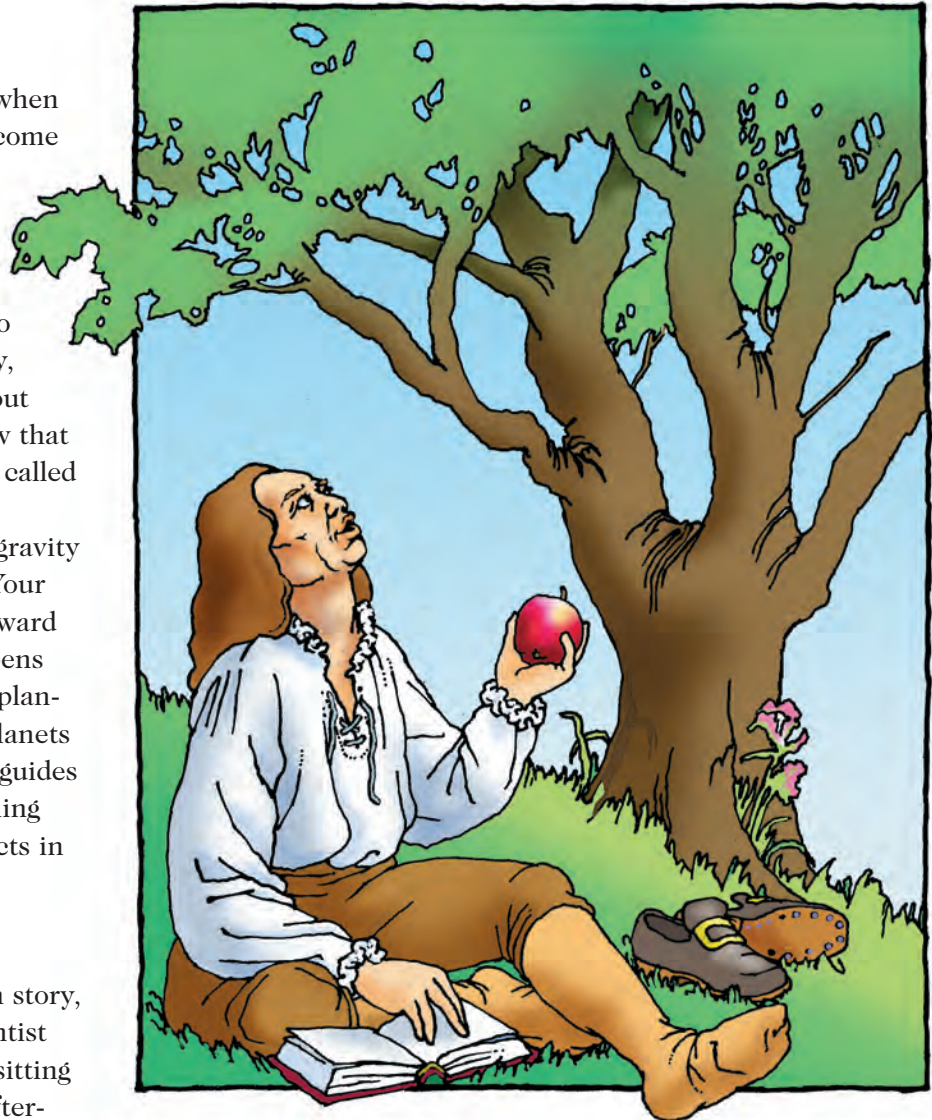
If you jump up, Earth’s gravity will pull you back down. Your gravity also pulls Earth toward you. The same thing happens between the Sun and the planets, and between all the planets and their moons. Gravity guides the movements of everything on Earth, and all the objects in the sky.

Newton’s Apple

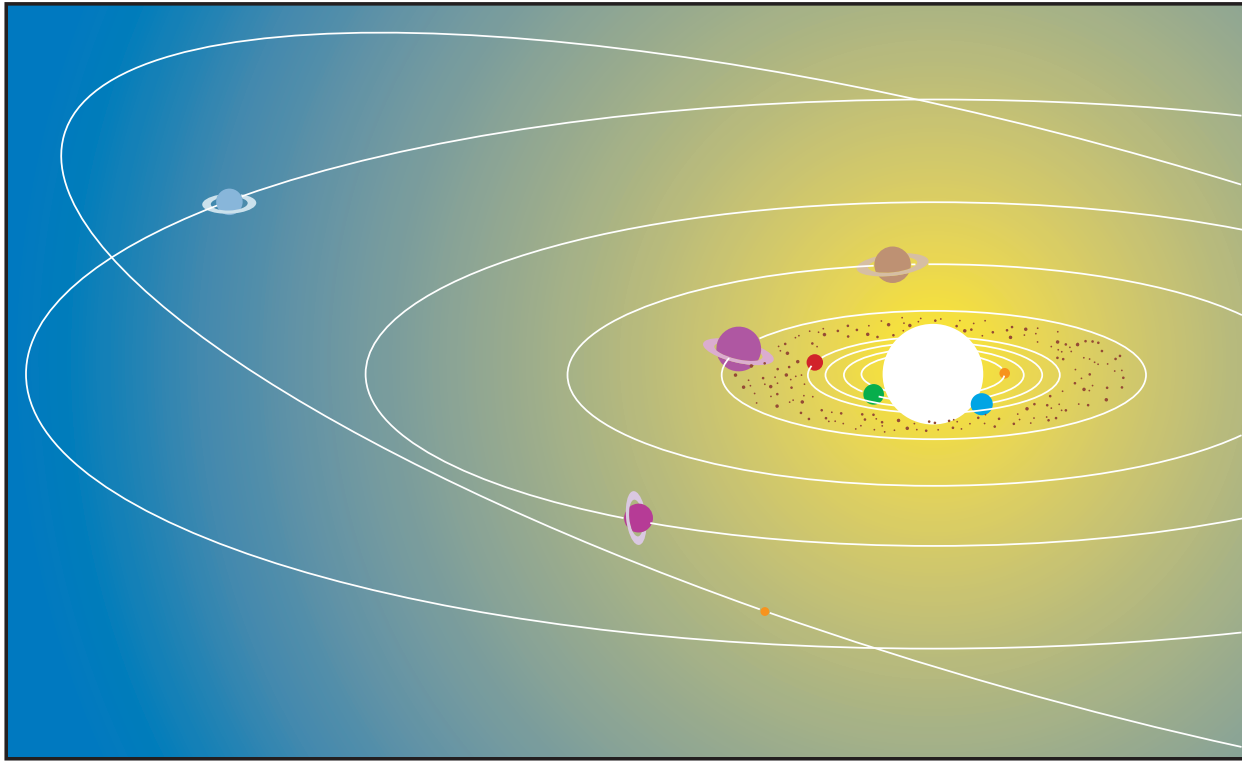
According to a well-known story, a 23-year-old English scientist named Isaac Newton was sitting under an apple tree one afternoon in 1666, when an apple hit him on the head. Newton began thinking about the force that pulled the apple from the tree.

Newton concluded that the force we know as gravity must be an invisible force, like the one you can feel when you place a magnet near a metal object (although gravity is

not as strong as electromagnetic forces). He also determined that gravity affects apples falling from trees and holds planets and moons in their orbits.



A famous story says that Isaac Newton began thinking about gravity on our planet and in our universe after an apple fell from a tree and hit him on the head.



Gravity keeps the nine planets and their moons, and thousands of asteroids and comets, in orbit around the Sun.

Newton's Law of Inertia

Newton wrote two famous laws about gravity: the Law of Inertia and the Law of Universal Gravitation. The Law of Inertia says that a body in motion tends to travel in a straight line unless it is disturbed by an unbalanced force. The Law of Inertia explains why you don't keep rising when you jump up in the air. The unbalanced force of gravity disturbs your motion and pulls you back down.

The Law of Inertia governs the motion of the planets and moons. If they weren't affected by gravity, they would travel in straight lines and leave the solar system. The Sun's gravity holds all the planets in orbit around it, and each planet's gravity captures and holds its moon(s) in orbit.

What is an unbalanced force?

If two individual forces are of equal magnitude (size) and opposite direction, then the forces are balanced. Think of the marble you held in your hand during Inquiry 15.1. One force—the Earth's gravitational pull—exerts a downward force on the marble. The other force—your hand—pulls upward on the marble. The forces acting on the marble are balanced; as a result, the marble's motion does not slow down or speed up. But if the two forces are not balanced, the marble will change its speed or direction. If you let go of the marble, the unbalanced force of gravity disturbs the marble's motion and the marble falls into the box. Unbalanced forces cause objects to accelerate (change their speed or direction).

Newton's Law of Universal Gravitation

From his experimental results, Newton formulated the Law of Universal Gravitation, which states that any two objects in the universe have gravity and will attract each other. Just how much those objects attract each other depends on two things—the mass of each object, and the distance between the objects.

The more mass a star—like our Sun—has, and the closer a planet is to that star, the greater the star's ability to hold the planet in its orbit (Mercury is a perfect example). Planets with a lot of mass can probably hold more moons in their orbit (Jupiter is a good example).

Mutual Attraction

An object with a large amount of mass can exert a huge gravitational pull even on objects that are quite distant and massive. The Sun's gravitational pull is so enormous that it easily hangs onto Jupiter, which weighs two-and-a-half times as much as all the other planets combined. The Sun also exerts a gravitational hold over Pluto. But more amazingly, tiny Pluto exerts a gravitational pull on the Sun, even though they are more than 4.5 billion kilometers apart!

Like the end of a lasso that circles around the head of a cowboy, an orbiting planet is “tied” to the Sun by gravity. However, the farther a planet is from the Sun, the more slowly it travels in its orbit. The closer a planet is to the Sun, the faster it travels in its orbit. Mercury, the planet closest to the Sun, travels at about 48 km/s (kilometers per second). But Pluto is quite a different story. Look at Table 15.2: Orbital Velocity of Planets and compare the orbital velocity of the planets. Do you notice patterns in the data? If so, what are they?

The attraction between two objects decreases as the distance between them increases. The Sun's pull on distant Pluto is much less than its pull on nearby Mercury. As a result, Pluto orbits the Sun at a much slower speed.

Table 15.2 Orbital Velocity of Planets

Planet	Orbital Velocity (km/s)	Approximate Distance from Sun (km)
Mercury	48	57,900,000
Venus	35	108,200,000
Earth	29	149,600,000
Mars	24	228,000,000
Jupiter	13	778,400,000
Saturn	9	1,426,700,000
Uranus	6	2,866,900,000
Neptune	5	4,486,100,000
Pluto	4	5,890,000,000

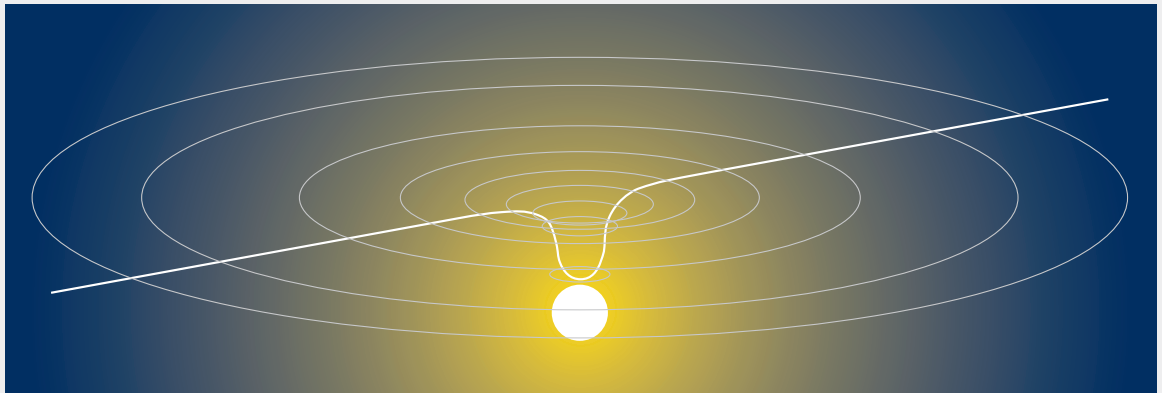
Newton and other scientists made important discoveries that describe how gravity works. These discoveries demonstrate that objects on Earth operate under the same principles as objects in space. Newton's work will influence planetary science for centuries. □

QUESTIONS

1. What force keeps the planets in their orbits around the Sun?
2. What would happen to the planets if there were no gravitational influences from the Sun?
3. Based on your classroom observations and the data in Table 15.2, how does an orbiting object's velocity depend on its distance from the Sun?
4. Given what you have learned in your investigations and in your reading, which planet should be able to hold the greatest number of moons in its planetary orbit?



The great mass of Jupiter helps it hold its many moons in orbit around the giant planet.



Space curves around matter, just like the surface of a rubber sheet curves when a heavy balloon rests on it.

How Matter Affects Space

Is gravity a force, or is it something else? About 250 years after Newton, another genius started thinking about gravity. His name was Albert Einstein. Einstein's theories changed the way we think about the universe.

Einstein came to believe that gravity isn't really a force, but simply the way that matter affects space. According to Einstein, wherever there's a chunk of matter—an apple, a person, a planet, or a star—space must curve around it. The bigger the matter, the more that space must curve. And when space curves, anything traveling through that space must follow those curves.

According to Einstein, the planets are caught in the curved space around the Sun. Our Moon is caught in the curved space around Earth. If you were far enough away from the gravitational force of Earth or the

Sun, small objects would become caught in the curved space around you!

Modeling Curved Space

Einstein believed that the more massive the object, the more space curved around it. Think back to your lab in which you placed a water-filled balloon in the center of a rubber sheet. The rubber sheet curved around the balloon. A marble placed on the sheet rolled toward the balloon, but not in a straight line. Instead, the marble followed the curves of the sheet and “orbited” the water-filled balloon in the center. The closer the marble got to the balloon in the center, the faster the marble rolled. Something similar happens with stars such as our Sun. Space curves around the star's mass and keeps other objects, such as planets, “rolling” around them.

Mission: Saturn, Uranus, and Neptune

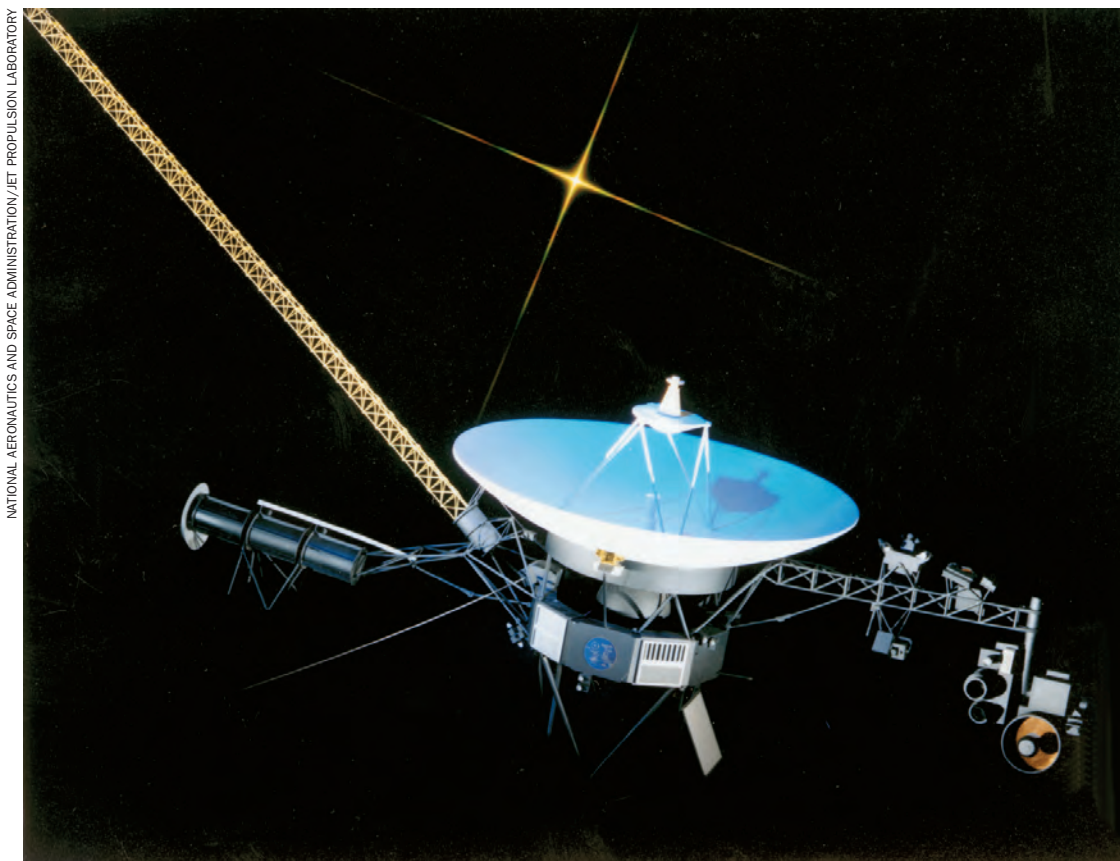
What a mission! The twin spacecraft, *Voyagers 1* and *2*, left Earth in the summer of 1977. Three years later, after its visit to Jupiter, *Voyager 1* flew past Saturn and sped north toward the outer edge of the solar system, as planned. *Voyager 2* was supposed to take the same course. But the spacecraft was performing so well, scientists and engineers on Earth found it not only possible, but irresistible, to send it on to Uranus and Neptune for a closer look. An alignment of the outer planets like this would not occur again until the year 2157.

Voyager 2 would be the first spacecraft to

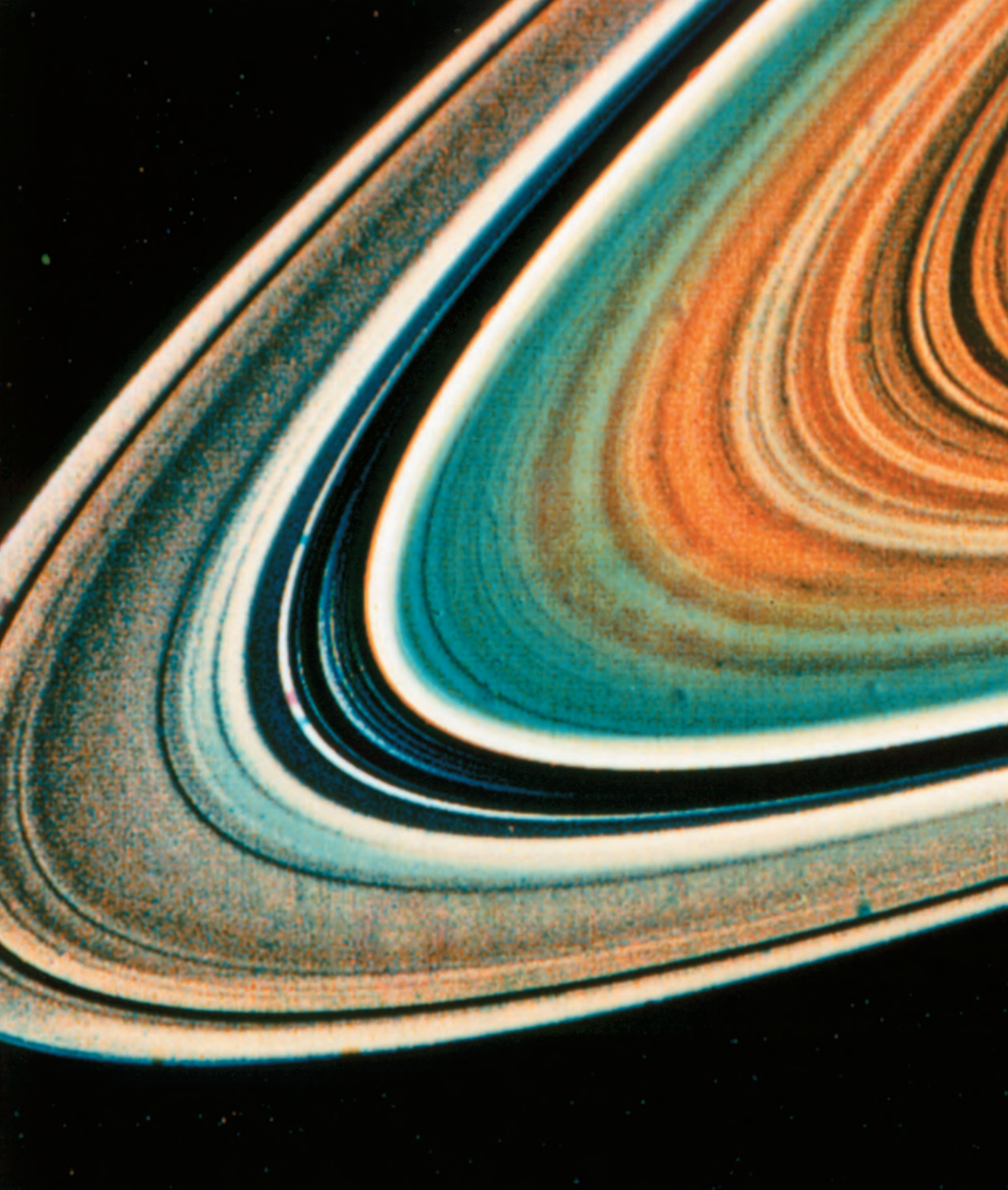
offer close-up views of the outer solar system. Saturn's huge gravitational field would hurl *Voyager 2* toward Uranus. A similar boost from Uranus would send *Voyager 2* to Neptune. This maneuver, called gravity assist, took decades off *Voyager's* flying time. (Unfortunately, the grand tour of the solar system conducted by *Voyager* couldn't include Pluto because Pluto's orbit took it far from the spacecraft's path.)

The remarkable journey of *Voyager 2* yielded many riches.

(continued)



Voyager spacecraft



Saturn

Voyager 2 gave us new insights into Saturn's rings. The rings are like a necklace with 10,000 strands, and they proved to be more beautiful and strange than once thought.

Evidence indicates that Saturn's rings formed from large moons that were shattered by impacts from comets and meteoroids. The resulting ice and rock fragments—some as small as a speck of sand and others as large as houses—gathered in a broad plane around the planet. The rings themselves are very thin, but together they are 171,000 kilometers in width!

(continued)

Mosaic of Saturn's rings created from pictures taken on August 28, 1981, by Voyager 2.

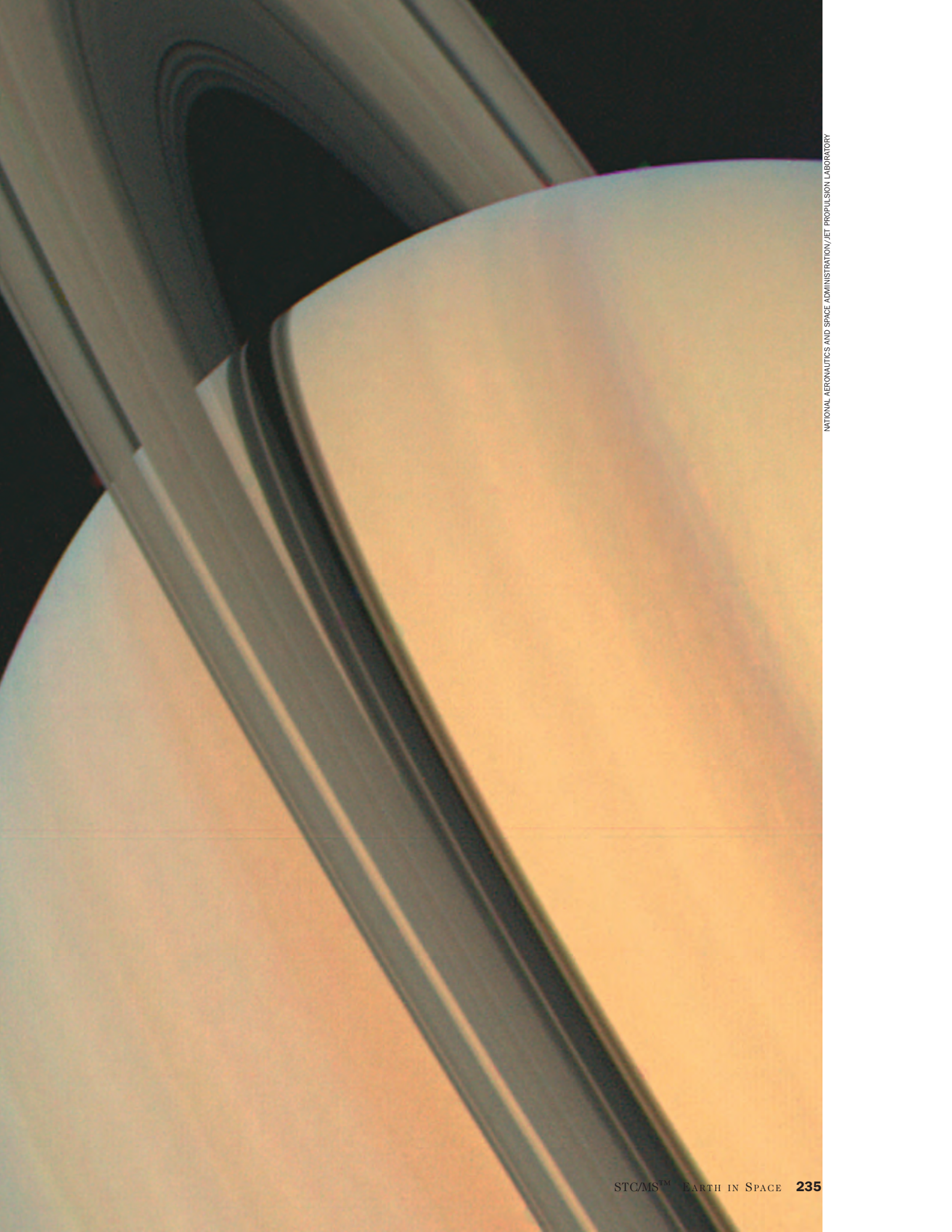
The irregular shapes of Saturn's eight smallest moons indicate that they, too, are fragments of larger bodies. Two of these small moons—Prometheus and Pandora—are located in one of Saturn's many rings.

Voyager 2 showed a kind of war going on at Saturn—a gravitational tug of war between the planet, its many moons and moonlets, and the ring fragments. This struggle has caused variations in the thickness of the rings. Some particles are even rising above the ring band as if they are trying to escape.

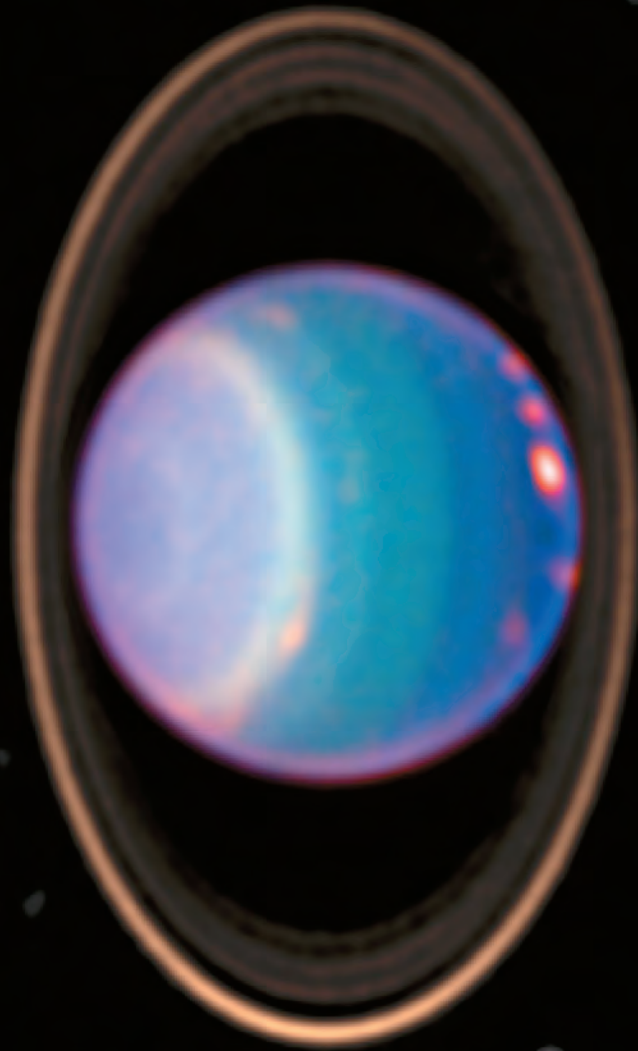
(continued)

NASA's Voyager 1 took this photograph of Saturn on November 3, 1980, when the spacecraft was 13 million kilometers from the planet. Two bright cloud patterns are visible in the mid-northern hemisphere and several dark spoke-like features can be seen in the rings left of the planet. The moons Tethys and Dione appear as dots to the south and southeast of Saturn.





NATIONAL AERONAUTICS AND SPACE ADMINISTRATION/JET PROPULSION LABORATORY



The rings of Uranus. Notice that Uranus is tilted 98 degrees on its axis.

SPACE TELESCOPE SCIENCE INSTITUTE, KENNETH SEIDELMANN, U.S. NAVAL OBSERVATORY, AND NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



This view of Uranus was acquired by Voyager 2 in January 1986. The greenish color of its atmosphere is due to methane and smog. Methane absorbs red light and reflects blue/green light.

Uranus

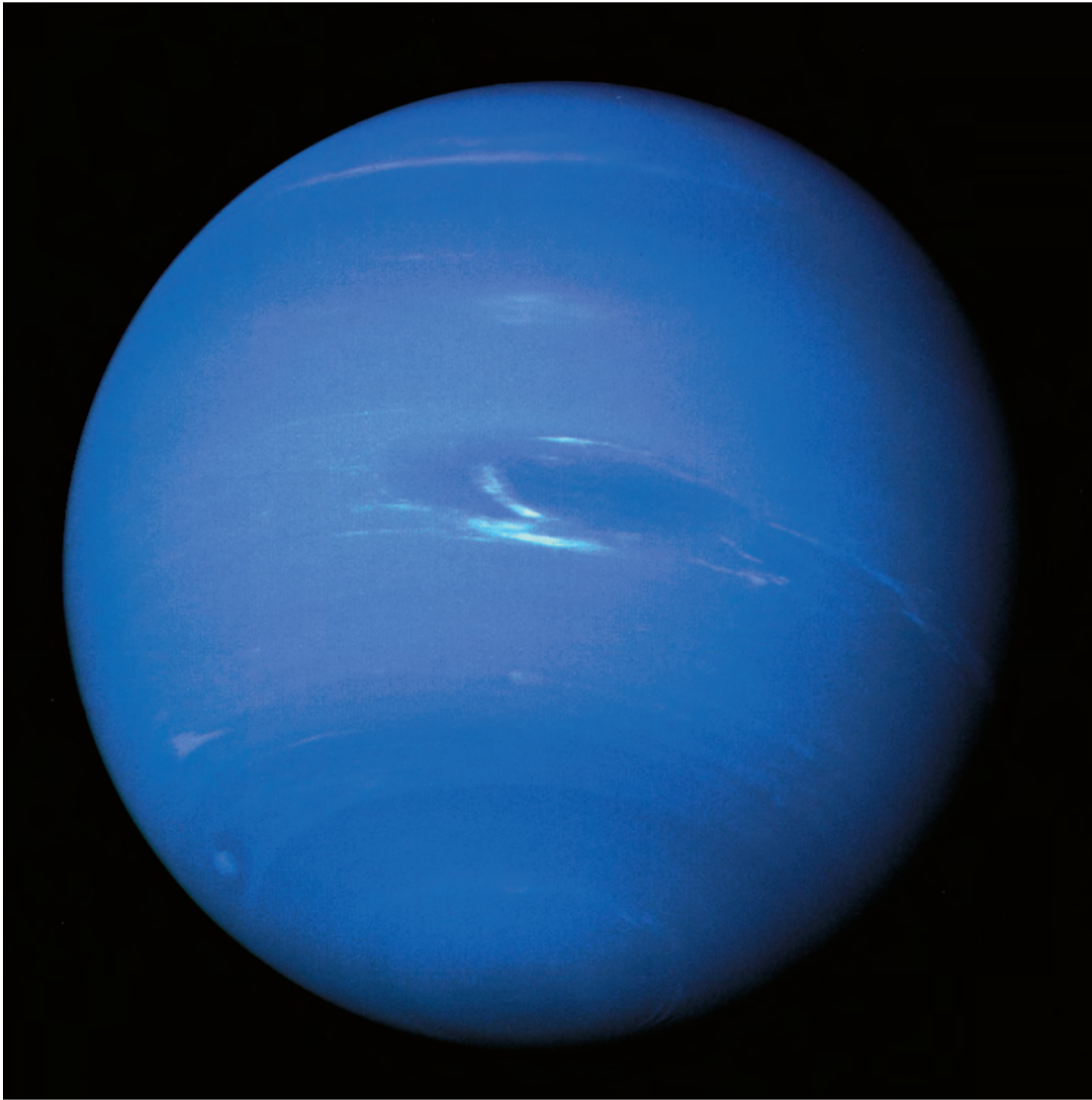
After its tug from Saturn's gravitational field, *Voyager 2* arrived at Uranus in 1986 where it discovered 10 new moons. With the moons already discovered by astronomers on Earth, the total number of moons was brought to 20. Scientists believed that there may be several more tiny satellites within the rings, and they were right!

The *Voyager* cameras detected a few additional rings around Uranus. They also showed that belts of fine dust surround the planet's nine major rings.

According to data, Uranian rings probably formed after Uranus. Particles that make up the rings may be remnants of a moon that was broken apart by a collision.

Voyager 2 made another major discovery at Uranus. It turns out that the planet has a magnetic field as strong as Earth's. The cause of this field isn't clear, but it's shaped like a long corkscrew. And, according to *Voyager's* measurements, it reaches 10 million kilometers behind the planet!

(continued)



Neptune is true blue.

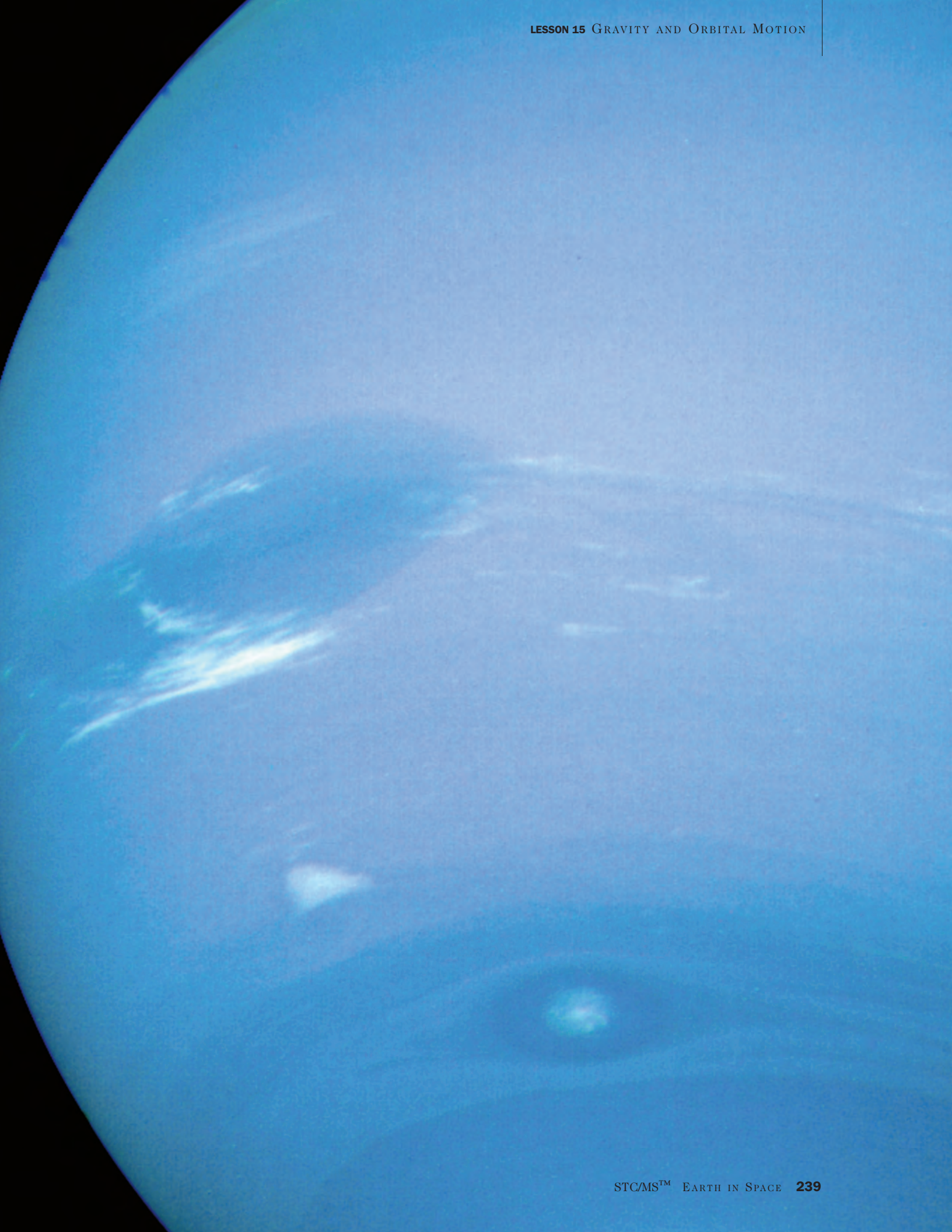
Neptune

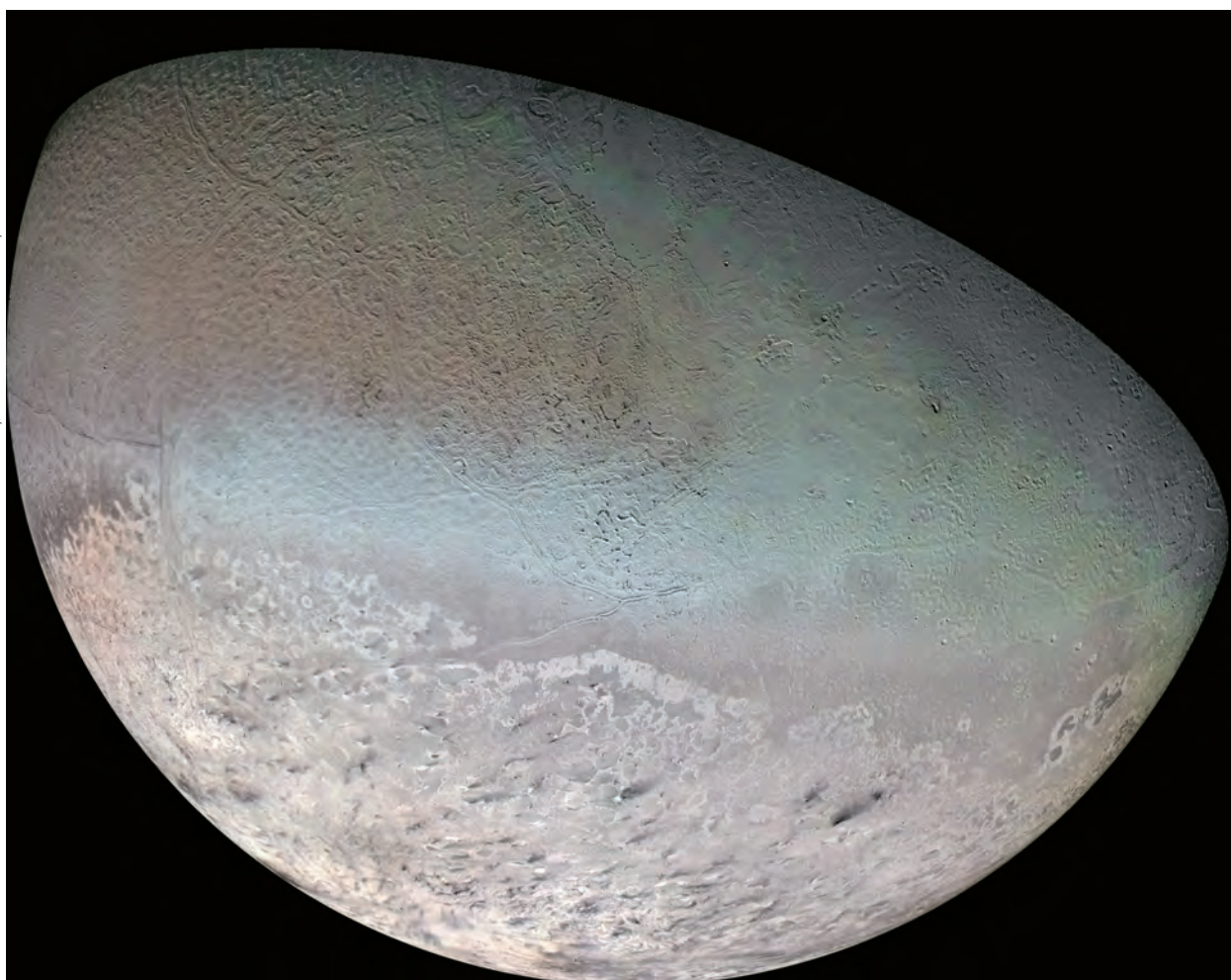
Until the *Voyager* encounter with Neptune in August 1989, scientists believed that the planet had arcs, or partial rings. But *Voyager* showed that Neptune has complete rings with bright clumps. *Voyager* also discovered six new moons, bringing Neptune's total to eight.

Voyager flew within 5000 kilometers of Neptune's long, bright clouds, which resemble

(continued)

Voyager 2 observed bright cirrus-like cloud cover in the region around the Great Dark Spot. The rapid changes in the clouds over 18 hours prove that Neptune's weather is perhaps as dynamic as Earth's. Neptune's dark spot is no longer visible. Could this "storm" finally have ended?





A partial view of Triton, Neptune's largest moon.

cirrus clouds on Earth. Instruments aboard *Voyager* measured winds up to 2000 kilometers an hour—the strongest winds on any planet.

Triton, Neptune's largest moon, is one of the most fascinating satellites in the solar system. Images from *Voyager 2* revealed volcanoes spewing invisible nitrogen gas and dust particles

several kilometers into the atmosphere!

In 1989, *Voyager 2* left Neptune and headed south onto a course that will take it, like *Voyager 1*, to the edge of our solar system and beyond. The tireless spacecraft—fueled by the radioactive decay of plutonium—is expected to continue operating for another 25 years. □

Saturn

PLANETARY FACTS:

Saturn

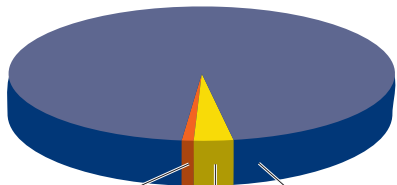
Saturn: Quick Facts

Average distance from the Sun	1.4 billion km
Mass	$56,850 \times 10^{22}$ kg
Surface gravity (Earth = 1)	0.92
Average temperature	-185 °C

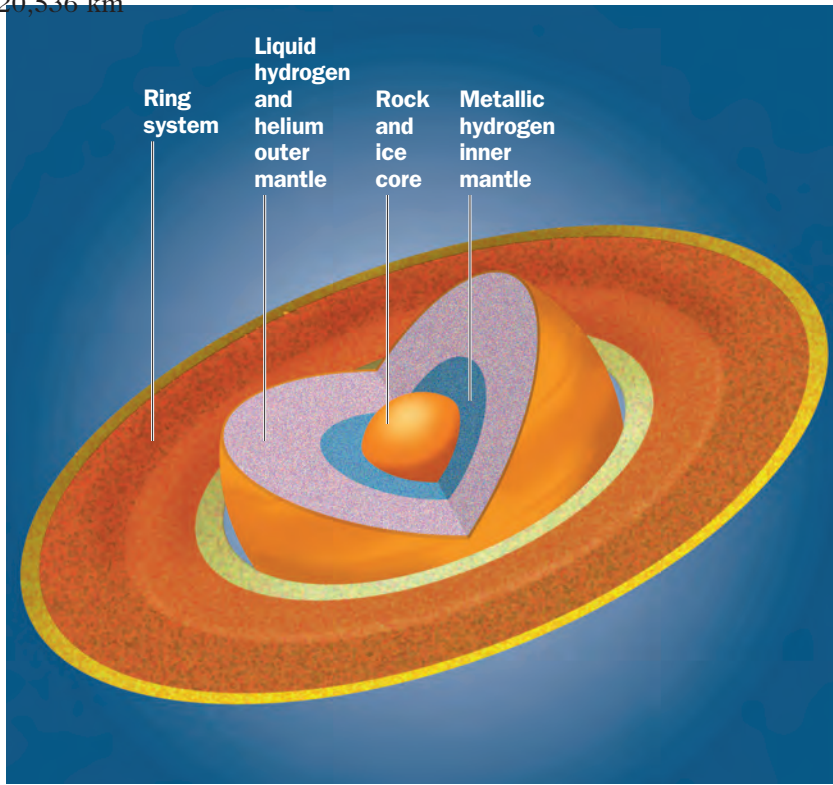
Diameter 120,536 km
of sidereal day



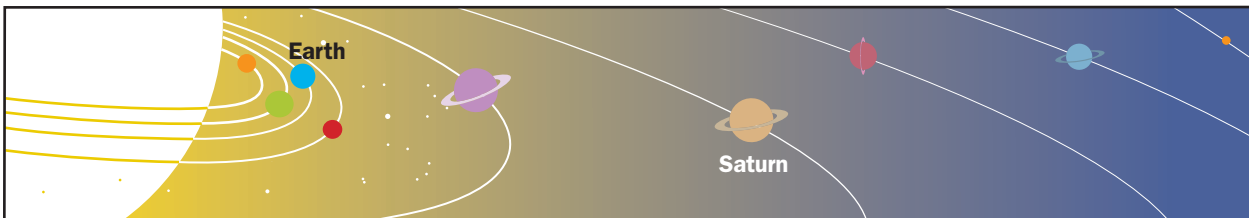
10.66 hours



Water ice, methane, ammonia, and other compounds (traces)
Hydrogen (96.3%)
Helium (3.3%)



Length of year 29.46 Earth years
Number of observed moons 30*
*As of 2002
Relative size Saturn atmosphere

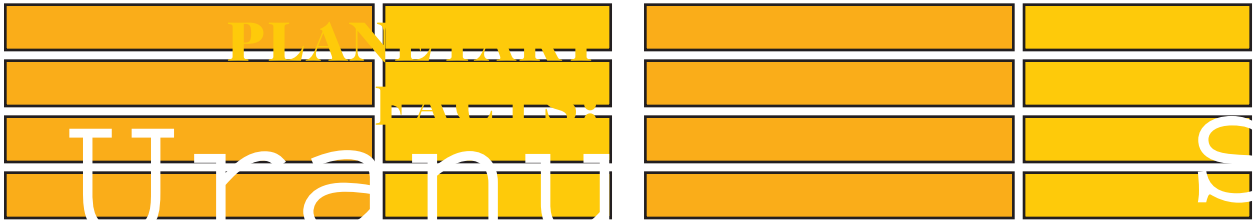


Length

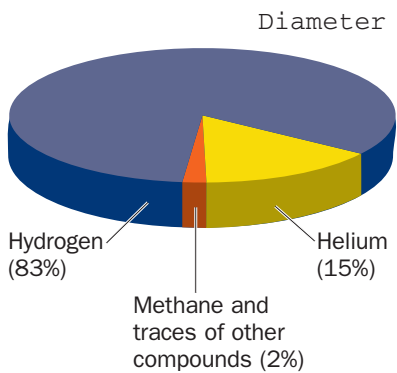
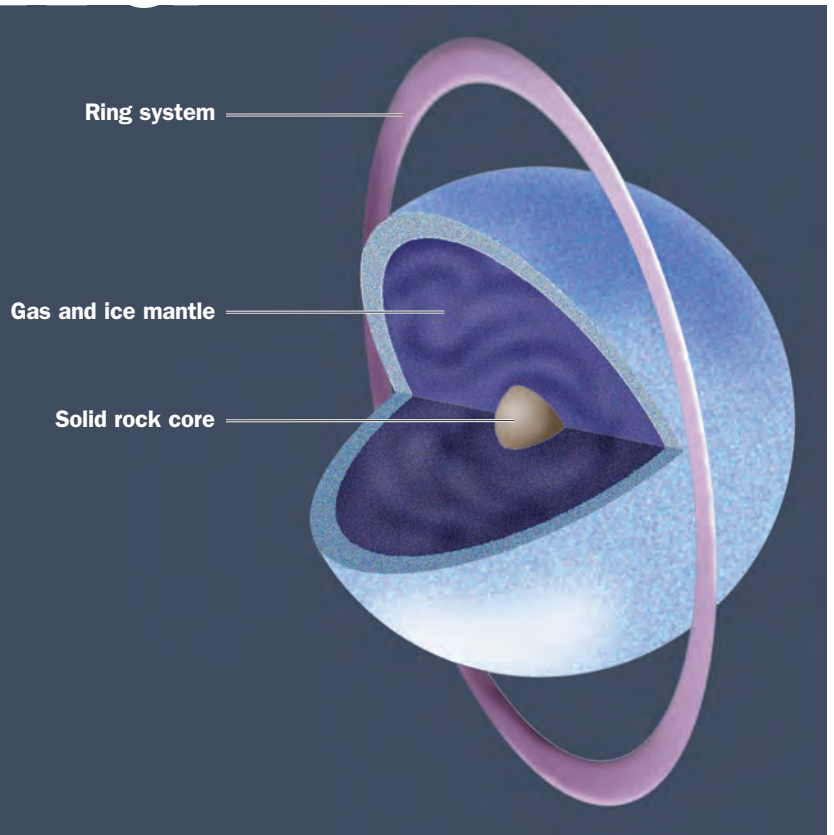
Uranus

- If there were an ocean big enough to plop Saturn into, the planet would float—just like an iceberg does on a planet Earth! That's because of Saturn's low density. Saturn is the only planet that is lighter than the same volume of water.

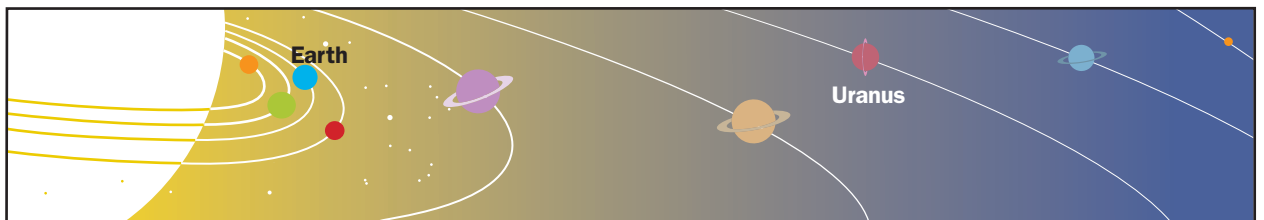
• Saturn's winds reach 1800 km/hour. (The strongest tornadoes on Earth have wind speeds of only 350 km /hour.)



Quick Facts



51,118 km
Average distance from the Sun 2.9 billion km
Mass 8683×10^{22} kg



Surface gravity (Earth = 0.89)

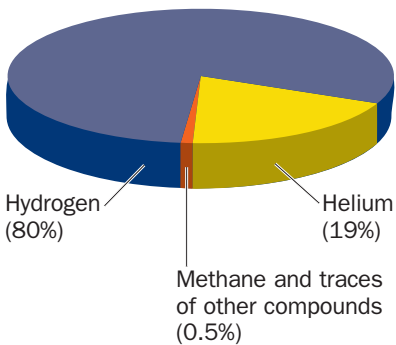
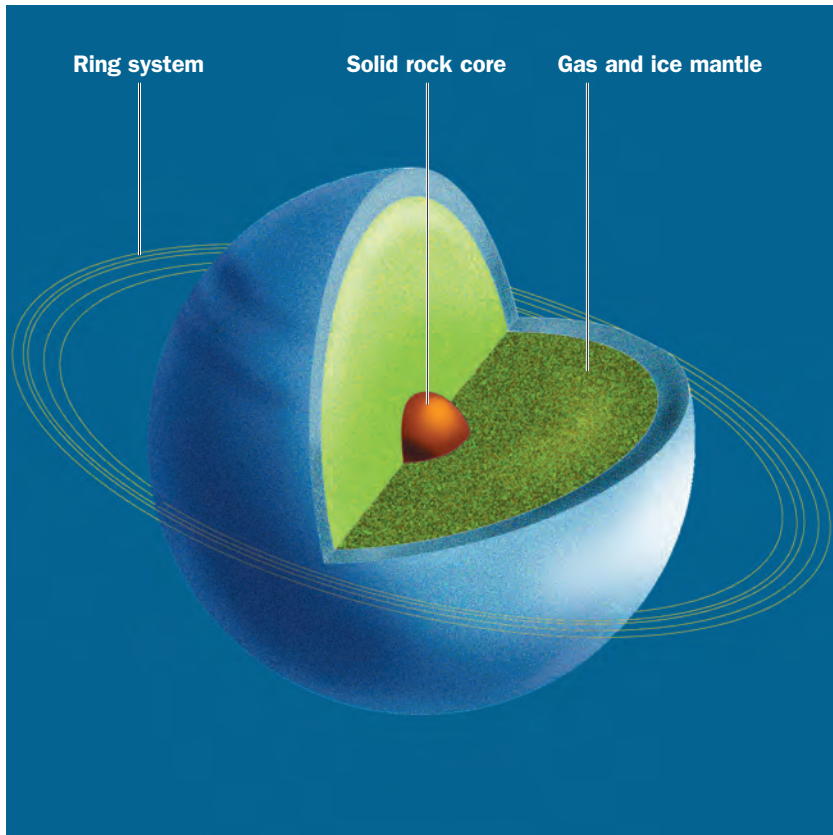
Average temperature -200 °C

Length of sidereal day 17.24 hours

Length of year 84.01 Earth years

Neptun

Number of observed moons	20*	<ul style="list-style-type: none"> The <i>poles</i> of Uranus are in the same position as the <i>equators</i> on other planets. That's because Uranus rotates on its side. It takes nearly 2½ hours for light from the Sun to reach Uranus. (It only takes about eight minutes for the Sun's light to reach Earth!)
*As of 2002		
Relative size		
Uranus atmosphere		
Did You Know?		



PLANETARY FACTS:

