LESSON **14**

Surface Gravity

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On the Moon, this astronaut weighs one-sixth of his weight on Earth. This is because the Moon's surface gravity is not as strong as Earth's.

INTRODUCTION

How much do you weigh? How massive are you? Suppose you could travel to other planets. What would happen to your weight and mass? In this lesson you will explore these questions. You will simulate what it is like to pick up objects on different planets. Then, using a spring scale, you will relate what you observe about the weights of objects to the force called gravity. The lesson ends as you continue the series of Mission readers to learn more about the Galileo mission to Jupiter.

OBJECTIVES FOR THIS LESSON

Use a model to compare the weight of a can of soda on different planets.

Analyze the relationship between an object's weight on each planet and the planet's mass and diameter.

Measure the weight of objects that have different masses.

Describe how mass and weight (force of gravity) are related.

Summarize and organize information about Jupiter and compare Jupiter to other planets.

Getting Started

1. What do you know about gravity as a characteristic of a planet's surface? Record your ideas in your science notebook.

2. Share what you have written with the class and discuss your ideas about the following questions:

   What is gravity?

   How are gravity and weight related?

   How can you measure gravity?

MATERIALS

For you

- 1 copy of Student Sheet 14.1: How Much Would a Can of Soda Weigh?
- 1 working copy of Student Sheet 10.1c: Planetary Chart

For your group to share

- 9 prepared cans
- 1 set of Planet Data Cards

For your group

- 1 spring scale
- 1 plastic cylinder
- 25 large steel washers

Inquiry 14.1
Analyzing Weight on Each Planet

PROCEDURE

1. Examine the prepared cans at your assigned station. Every can represents the same full can of soda but on different planets. Pick up each can and observe how heavy that can is on each planet (see Figure 14.1). On which planet does the can weigh the least? On which planet does the can weigh the most? Why do you think this is? Discuss your ideas with your group.

2. Rank the weight of each can on Student Sheet 14.1 by recording a "1" next to the name of the planet with the lightest can. Increase the numbers until you get to the heaviest can. If any cans seem to weigh the same, use the same number to rank them.

3. Turn over the following three Planet Data Cards: the planet you ranked "1" (the lightest can); the planet you ranked with the highest number (the heaviest can); and the planet with a number somewhere in between. Examine the data printed on the back of these three cards. What characteristics about each planet could explain why the weight of the can is different on each planet? Discuss your ideas with your group. Record your ideas below Table 1 on Student Sheet 14.1.

Figure 14.1 *Observe how heavy the can is on each planet. On which planet does the can weigh the most? On which planet does it weigh the least?*

REFLECTING ON WHAT YOU'VE DONE

1. Share your rankings from Student Sheet 14.1 with the class.

2. How do the characteristics of a planet affect its ability to pull on an object—giving the object its weight? Share your ideas with the class, using your explanation on Student Sheet 14.1 as your guide.

3. Record in your notebook what you know about the relationship between mass and weight. Then share your ideas with the class.

4. Read "Mass and Weight: What's the Difference?" Then record a working definition of these two terms in your notebook.

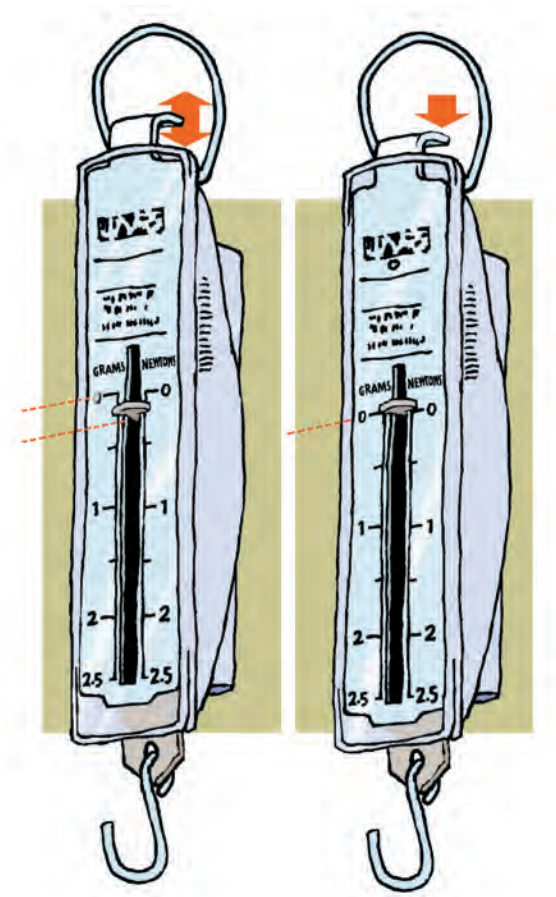


Figure 14.2 *Adjust the tab on the spring scale to zero before each trial.*

Inquiry 14.2
Investigating Mass and Weight

PROCEDURE

1. Why does mass affect weight? Discuss this question with your group or class. Record your group's ideas in your student notebook.

2. How do you think the spring scale works? Discuss your ideas with your group. Then watch as your teacher demonstrates how to use it. Discuss what a newton is. Try calibrating the spring scale by holding it vertically with nothing attached to the hook. Make sure the scale registers zero. If necessary, use the metal tab at the top of the spring scale to adjust the setting to zero (see Figure 14.2).

3. Lay the spring scale flat (horizontally) on the table. Place two to three washers on the spring scale's hook. What do you observe? Discuss your ideas with your group.

4. Hold the spring scale up vertically. Place two to three washers on the spring scale's hook. What do you observe? Are your results different from Step 3? Why or why not? Discuss your ideas with your group.

5. Pick up the clear plastic cylinder. Describe its weight to your group.

6. Increase the mass of the plastic cylinder by adding five washers to it and hold the cylinder in your hands. Did the mass of the cylinder change? Did the weight of the cylinder change? Discuss your ideas with your group.

7. Increase the mass of the cylinder to 25 washers and hold the cylinder in your hand. Did the mass of the cylinder change? Did the weight of the cylinder change? Discuss your ideas with your group.

8. Hang the cylinder with 25 washers from the spring scale hook, as shown in Figure 14.3. What is the weight of the cylinder with 25 washers? Record this number in your notebook. Discuss your observations with your group.

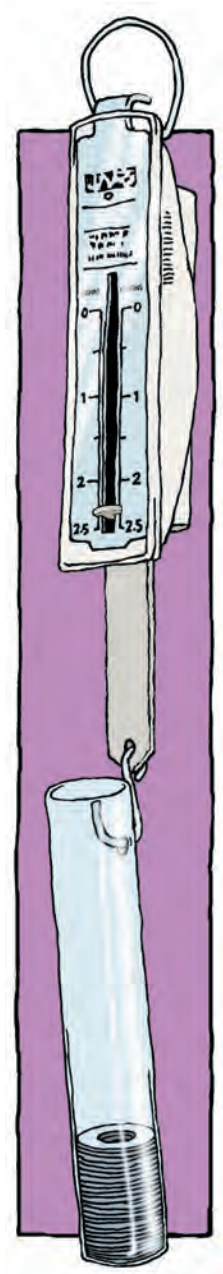


Figure 14.3 *Use the spring scale to measure the weight of the cylinder and 25 washers.*

9. Design an investigation with your group to prove that mass and weight are related. Record your design plan in your science notebook. Consider what you will change (independent variable), what you will measure (dependent variable), and what you will keep the same (controlled variable).

10. Create a data table in your notebook. For each trial, record the mass of the cylinder (number of washers) and the weight of the cylinder in newtons (a measure of the force of gravity). If you conduct more than one trial, average your results.

11. Before you begin each trial, remember to calibrate the spring scale by adjusting the setting to zero each time. Then complete your investigation.

REFLECTING ON WHAT YOU'VE DONE

1. Share your results from Inquiry 14.2 with the class.

2. Answer the following questions in your science notebook, and then discuss them as a class:

A. What is the weight of five washers?

B. When you increased the mass of the cylinder, what happened to its weight?

C. How are mass and weight related?

D. From your reading, you know that a force is a push or pull on or by an object. What is the name of the force that makes the cylinder have weight?

E. In what direction does this force pull on the cylinder?

F. Think back to Inquiry 14.1. If weight is the measure of the force of gravity pulling on an object, which planet has a greater force of gravity pulling on objects at its surface—Pluto or Jupiter? Explain your answer.

G. What force holds us to Earth's surface?

H. What two factors affect the gravity at a planet's surface?

I. If Mars has more mass than Mercury, why is the force of gravity on the surface of Mars nearly the same as the force of gravity on the surface of Mercury?

3. With your class, return to the Question G folder for Lesson 1 and its photo card. As a class, review the self-stick notes about where gravity exists and remove any that seem incorrect. Add your new ideas to the folder.

4. Read the "Mission: Jupiter" reading selection. Add any information about Jupiter 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 Jupiter).

Mass & Weight:

What's the Difference?

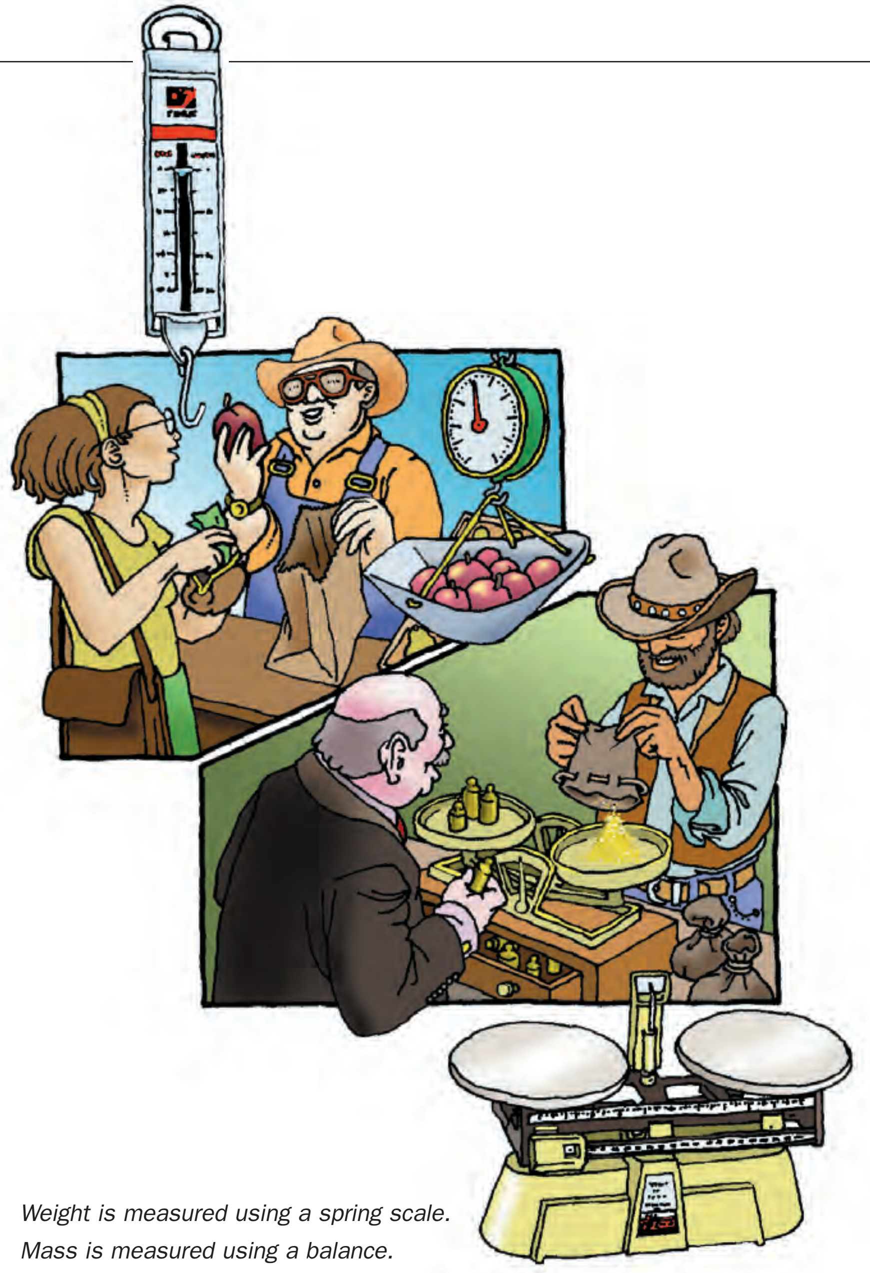
Many people think that there is no difference between the terms "weight" and "mass." But there is! Mass is related to the amount of matter (or "stuff") in an object, regardless of how much space the object takes up. As long as you do not add or take away any matter from an object, its mass stays the same, even at different locations. If you take an object to the Moon or Mars, it will have the same mass that it had on Earth.

But what about its weight? Would an object weigh the same on the Moon or Mars as it does on Earth? As you found out in your investigation, the answer is "no." The weight of an object changes from planet to planet. Weight even changes from one place on a planet (such as a mountaintop, where you might weigh less) to another (such as the bottom of a deep valley, where you might weigh more).

Measuring Mass and Weight

Weight is a measure of the force of gravity on an object. (A force is a push or pull on or by an object.) We use a spring scale to measure the strength of the gravitational pull on the mass of an object. Objects with the same mass have the same weight. An object with more mass has a stronger gravitational force pulling on it than an object with less mass. The spring scale is pulled down farther, showing that the object weighs more. In the metric system, weight is measured in newtons.

Mass is measured in kilograms and grams in the metric system. To find the mass of an object, we use a balance. When equal amounts of matter are placed on opposite sides of a beam balance, for example, the pull of gravity is the same on both sides, and the beam balances. If the mass of an object were measured with a balance on



Weight is measured using a spring scale. Mass is measured using a balance.

Earth, and then with the same balance on the Moon, the results would be identical. The amount of "stuff" in the object hasn't changed.

Mass and Weight on the Nine Planets

An object with mass attracts any other object with mass. The strength of that attraction depends on the mass of each object and their distance from each other. This gravitational pull is very small between objects of ordinary size and therefore is hard to measure. The pull between an object with a large amount of mass, such as Earth, and another object, such as a person on the planet's surface, can easily be measured.

Weight on a planet's surface is a measure of the pull of gravity between an object and the planet on which it is located. This force of gravity on an object on a planet's surface depends on the object's mass and the mass of the planet. If the

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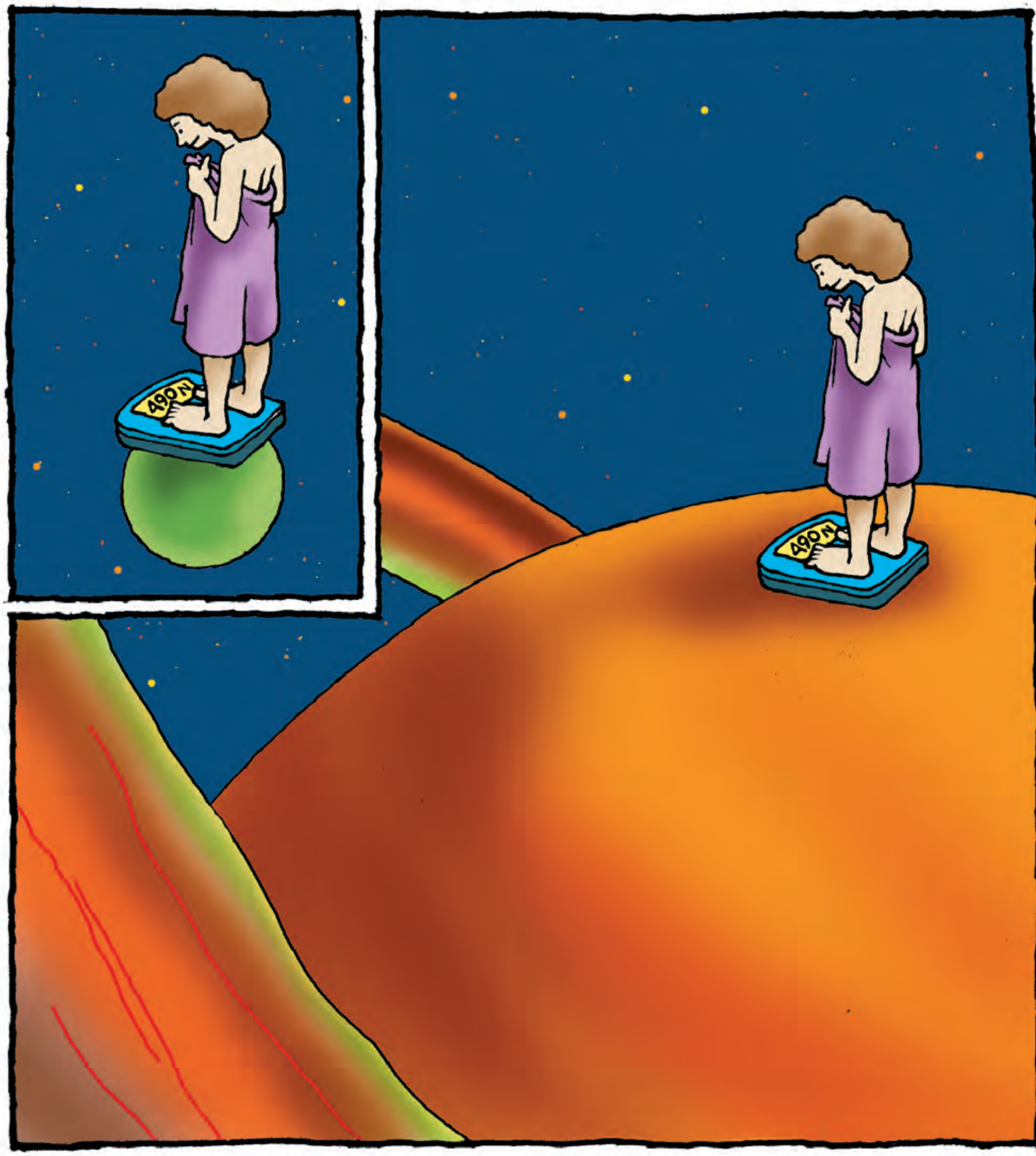


The farther the object is from the center of the planet, the weaker the pull between the planet and the object. This means that your weight on Saturn would be about the same as your weight on Venus, even though Saturn is more massive than Venus.

What Would You Weigh on Jupiter?

Jupiter has 318 times more mass than Earth, so you might assume that you would weigh 318 times more on Jupiter than you weigh on Earth. This would be true if Jupiter were the same size as Earth, but the diameter of Jupiter is more than 10 times the diameter of Earth. This means that if you stood on Jupiter, you would actually be farther from the planet's center than you would be if you stood on Earth. This reduces Jupiter's gravitational pull on you to only about 2.36 times (and not 318 times) your weight on Earth.

The number 2.36 is referred to as Jupiter's "gravity factor." The gravity factor is the ratio of each planet's gravity to that on Earth. Earth's gravity factor is 1 and Jupiter's gravity factor is 2.36. By multiplying your Earth weight by a planet's gravity factor, you can determine your weight on that planet. Use the table to find out how much you would weigh on each of the nine planets.

Table 1 Mass, Radius, and Surface Gravity of Each Planet

Planet	Mass (10^{22} kg)	Radius (km)	Surface Gravity Factor (Earth = 1)
Mercury	33	2439	0.38
Venus	487	6051	0.91
Earth	597	6378	1.00
Mars	64	3396	0.38
Jupiter	189,900	71,492	2.36
Saturn	56,850	60,268	0.92
Uranus	8683	25,559	0.89
Neptune	10,240	24,764	1.12
Pluto	1	1170	0.06

mass of that object is doubled, gravity pulls on it twice as hard. If the mass of the planet is doubled, gravity pulls on the object twice as hard.

The force of gravity also depends on the distance of an object from the center of the planet to its surface. This distance is called the radius of the planet. The farther an object is from the planet's center, the weaker the pull between the planet and the object. This force gets weaker quite rapidly, but there is a pattern to it. If you double the radius of the planet, the weight of the object will be one-fourth as much. If you triple the radius of the planet, the weight will be only one-ninth as much. The force of gravity drops off with the square of the distance between the center of the planet and the object.

Each planet in our solar system has a different mass and a different size. This means that the weight of the same object on the surface of each planet will be different. For example, you would weigh less on the Moon than you do on Earth because although the Moon is smaller than Earth, it also has less mass than Earth—and Earth's mass wins out. This means that the Moon exerts less gravitational force at its surface than Earth. Any given object will have the same *mass* on Earth and on the Moon, but that object's *weight* on the Moon will be only about 16 percent (one-sixth) of the weight as measured on Earth. ☐

Mission: Jupiter

In the early 1600s, astronomer Galileo Galilei looked at cloud-covered Jupiter through one of the world's first telescopes. What he saw amazed everyone—four moons!

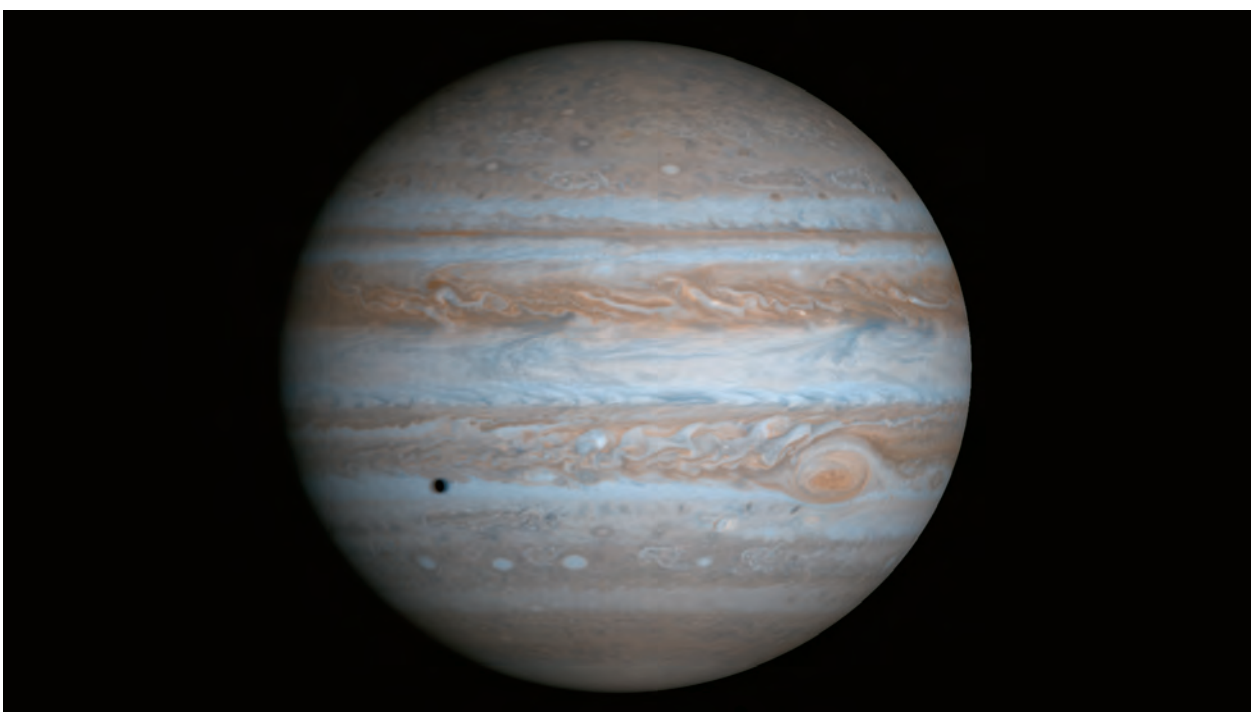
Telescopes improved over the years and other moons of Jupiter were found. More than 300 years after Galileo's discovery, spacecraft flew close enough to Jupiter to take detailed pictures. *Pioneer 10* flew by Jupiter first, in 1973. *Pioneer 11* followed a year later. *Voyager 1* and *2,* en route to the outer planets, sped past Jupiter in 1979.

These flyby missions added to our knowledge, but they also left us with many questions. What are Jupiter's rings made of? How fast do the winds on Jupiter blow? And what *is* beneath those clouds?

Many scientists believed that only an orbiter could answer such questions, because an orbiter can observe a planet for a long time. The *Viking* orbiter had revealed much about Mars. And the *Pioneer* orbiter answered many questions about Venus. But how could an orbiter "see" beneath Jupiter's clouds? A probe would have to do that!

Plans got underway to send a spacecraft with an orbiter *and* a probe to Jupiter. The mission would be named after the Italian scientist who first spotted Jupiter's four large moons—Galileo.

The *Galileo* spacecraft was launched in 1989. Six years later, as it approached Jupiter, the probe and orbiter separated. In December 1995, the probe finally plunged into Jupiter's clouds.



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Jupiter

The orbiter, meanwhile, was starting on its path around the largest planet in the solar system.

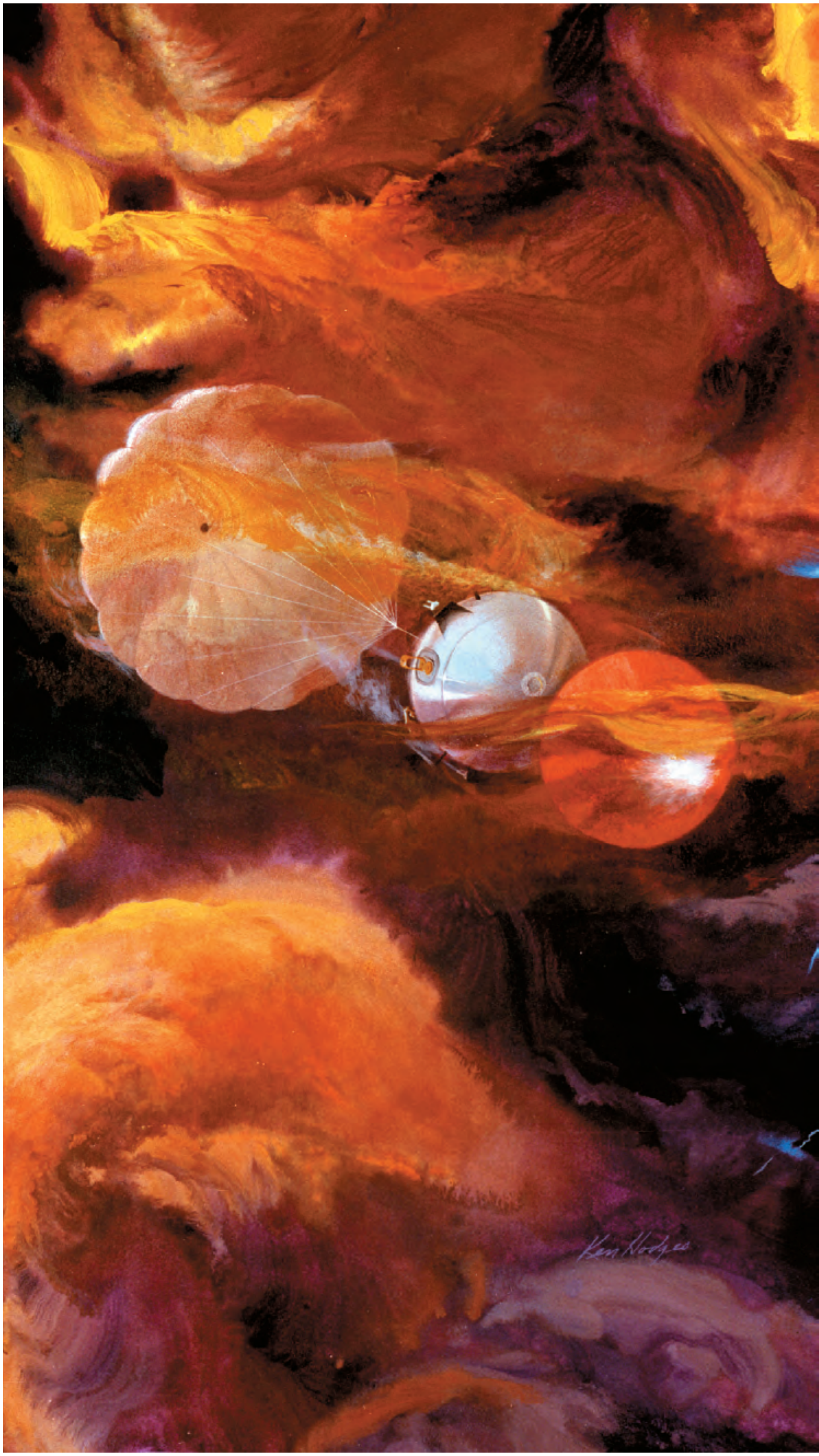
Galileo Probe Findings

Descending through Jupiter's atmosphere, frictional forces on the surface of the probe's heat shield raised the heat shield's surface temperatures to levels twice as hot as those of the Sun's surface! Still, it sent data for nearly 58 minutes before the heat and pressure destroyed it.

What can a space probe discover in less than an hour? As it turns out—lots! To the surprise of scientists, the probe showed there were no clouds in the lower part of Jupiter's atmosphere. The air below the clouds also was much drier than scientists expected. Scientists think the probe may have descended into a part of Jupiter's atmosphere that was unusually dry. Yet the wind speed—540 kilometers an hour—was the same both in the clouds and below them.

These winds puzzled scientists. On Earth, the Sun's heat helps make winds. But Jupiter receives only about 1⁄25 as much sunlight as Earth. So what's the source of Jupiter's winds? Some scientists believe they are powered by heat escaping from deep inside the planet.

The probe journeyed 600 kilometers into Jupiter's atmosphere. As expected, it hit no solid object or surface along the way. Jupiter is, after all, a *gaseous* giant. Its solid surface lies below tens of thousands of kilometers of atmosphere.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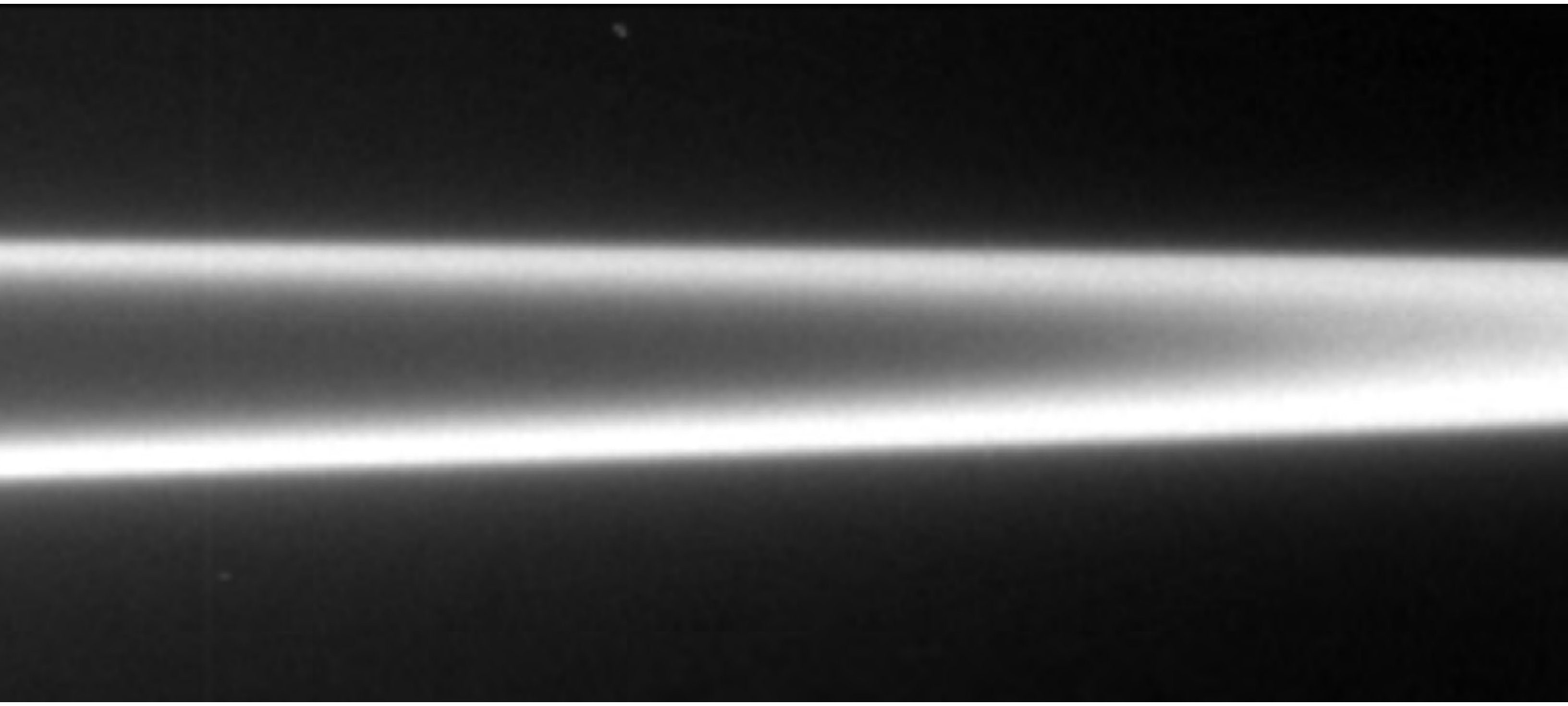
The Galileo *probe's descent through Jupiter's atmosphere*



The ring system of Jupiter was imaged by the Galileo *spacecraft on November 9, 1996.*

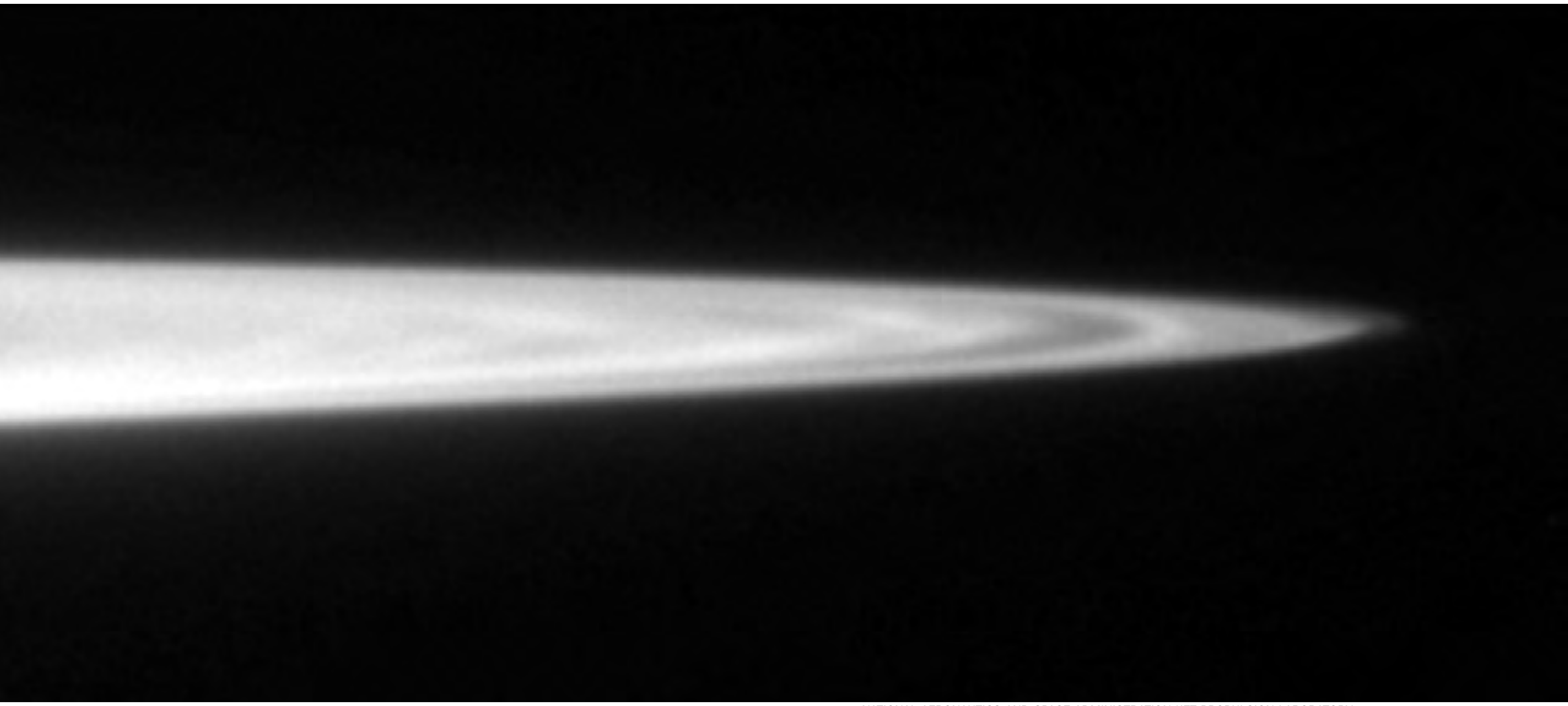
Galileo Orbiter Findings

In the late 1970s, the *Voyager* spacecraft discovered two, possibly three, rings around Jupiter. In 1995, the *Galileo* orbiter confirmed the presence of a third thin ring but also found a fourth ring inside it! According to the data transmitted by *Galileo,* all the rings consist of small grains of dust. It seems that meteoroid impacts blasted the grains off the surface of the four innermost moons.

Galileo also revealed that Jupiter is home to many more huge storms than once thought. The largest is the Great Red Spot. This raging storm is three times the size of Earth!

While Jupiter has more storms than expected, it has less lightning than scientists predicted. Lightning occurs on Jupiter only about one-tenth as often as on Earth. On our planet, there is an average of about 100 lightning flashes every second.

While orbiting Jupiter, *Galileo* flew near several of Jupiter's moons. Scientists knew that Io, the innermost of Jupiter's four major moons, has active volcanoes. The *Voyager* spacecraft discovered several of them in 1979. But the *Galileo* orbiter showed that hundreds of volcanoes cover Io. Many spew lava from deep below the moon's surface.



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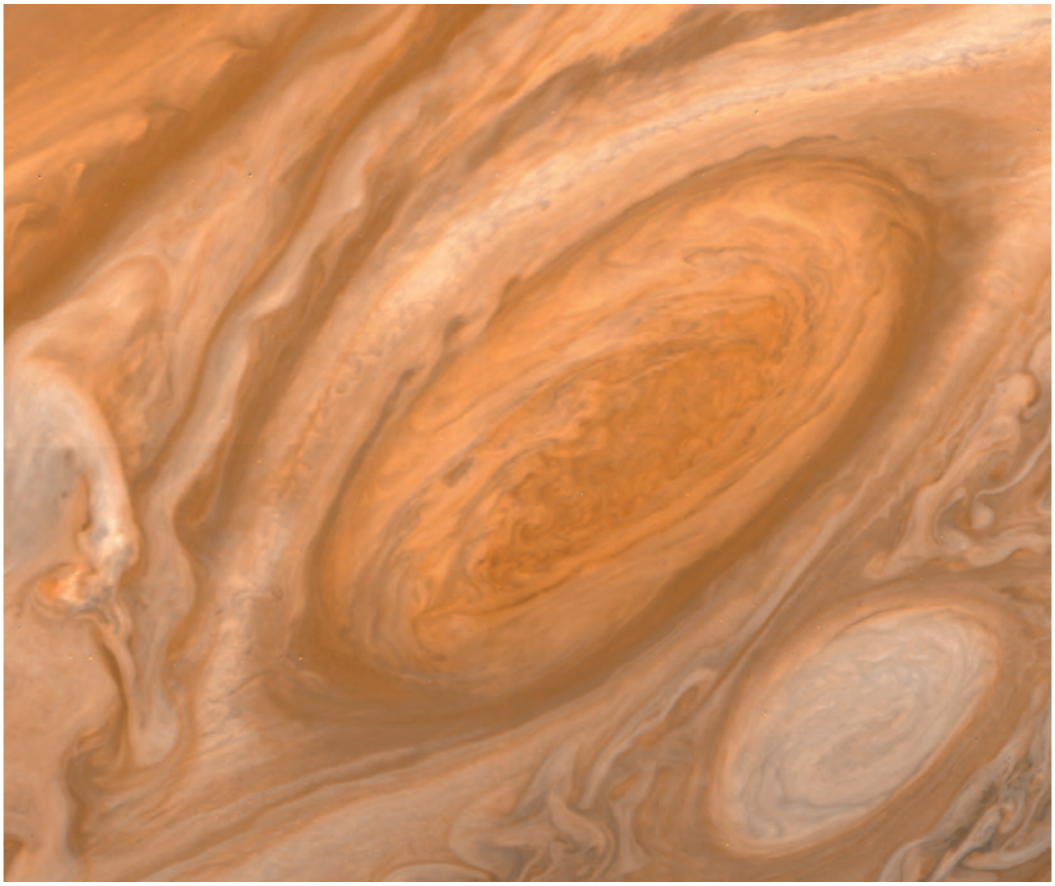

The Great Red Spot on Jupiter

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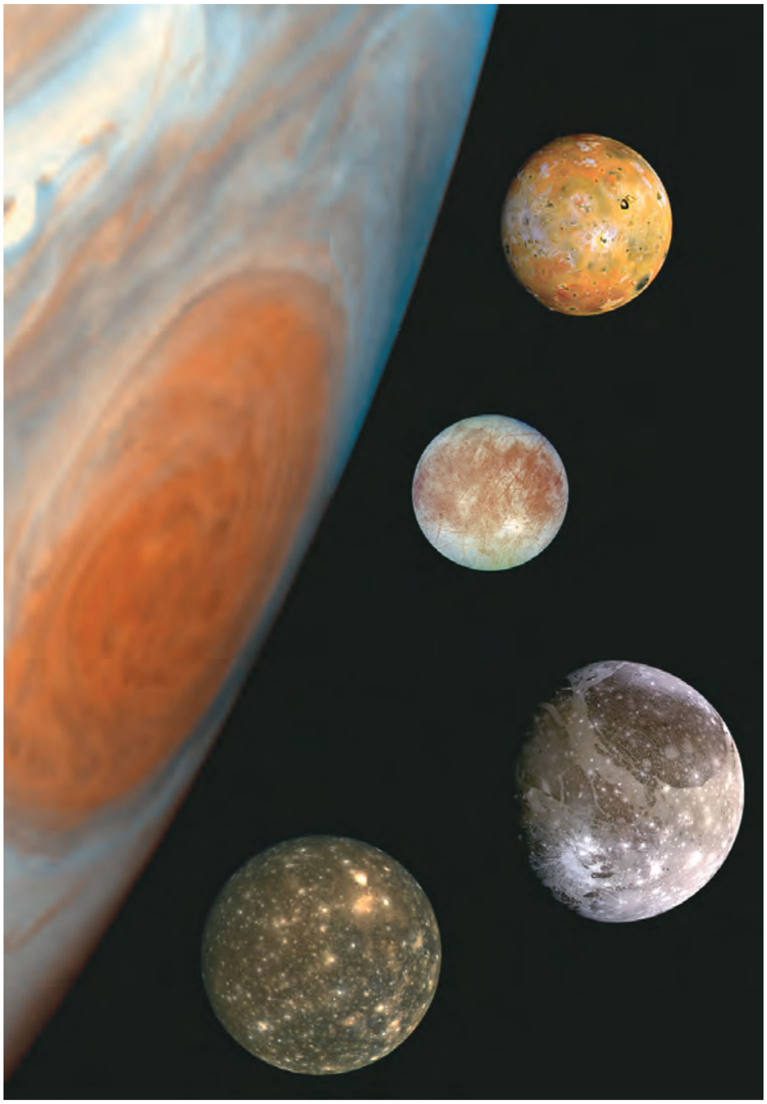

Jupiter's four largest moons: Io, Europa, Ganymede, and Callisto (top to bottom). Jupiter's Great Red Spot is shown in the background.

Jupiter's moon Europa seems to have an ocean beneath its cracked icy surface. In this ocean, gigantic blocks of ice the size of cities appear to have broken off and drifted apart. Callisto, the outermost of Jupiter's four major moons, also may have an ocean below its cratered surface.

Ganymede is the largest moon in the entire solar system. The data transmitted by the *Galileo* orbiter show that it is the only moon known to have a magnetic field.

The orbiter is scheduled to end its mission with a dive into Jupiter's deadly atmosphere—a dramatic ending for one mind-expanding trip! □

Planetary Facts: Jupiter

Jupiter

Jupiter: Quick Facts

Diameter	142,980 km
Average distance from the	778,400,000 km
Mass	189,900 × 10^{22} kg
Surface gravity (Earth = 1)	2.36
Average temperature	–108 °C
Length of sidereal day	9.92 hours
Length of year	11.86 Earth years
Number of observed moons	39*

*As of 2002