

# Questions & Answers

## Saturn

### 1. When did we discover Saturn?

We don't know exactly when ancient observers first recognized what we now call the planet Saturn. Many ancient civilizations were aware of five wandering points of light in the night sky, which were later named for gods of Roman mythology — Mercury, Venus, Mars, Jupiter, and Saturn. These planets were easily observed with the unaided eye. It was not until the time of Galileo, who first looked at the sky through a telescope, that we observed these wandering “stars” to be other worlds.

The planets outside Saturn's orbit — Uranus, Neptune, and Pluto — were discovered using more modern telescopes, beginning with the discovery of Uranus by William Herschel in 1781. The discovery of each of these outermost planets generated great public interest at the time and made the discoverers famous.

### 2. How did Saturn get its name?

Nearly all ancient human cultures created names for, and stories about the Sun, the Moon, the planets and the stars. Like so many things in history, the naming of the planets happened by accident. For example, the ancient Babylonians recognized five specks of light moving across the night skies and believed that these specks were the images of their most important gods. Not surprisingly, they named the moving lights after these gods. When the Greeks (probably the Pythagoreans, in the 5th century B.C.) came into contact with the Babylonian sky-lore, they assigned to the five lights the names of those Greek gods corresponding most closely to the appropriate Babylonian deities. The Greek names of the five planets were: Hermes, Aphrodite, Ares, Zeus, and Kronos. In due

course (perhaps in the 2nd century B.C.), the Romans became acquainted with Greek astronomy and the Greek planetary names. The Romans then rendered the Greek names to fit their own gods. This is the origin of the names Mercury, Venus, Mars, Jupiter, and Saturn, the names still in use 2,000 years later.



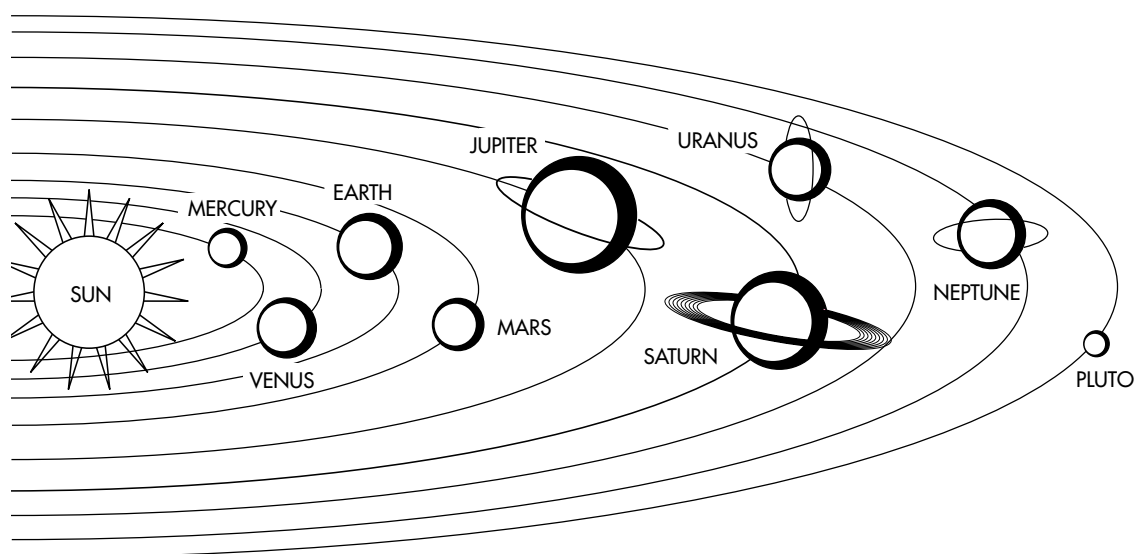
Saturn, the fearsome Roman god.

### 3. Where is Saturn located?

Saturn is the sixth planet out from the center of our Solar System. It orbits the Sun at a distance of about 1.4 billion km (870 million mi). Saturn is about 9.6 times as far from the Sun as is Earth. Saturn is almost twice as far from the Sun as is Jupiter, the fifth planet in the Solar System.

The Sun around which Saturn and the other planets orbit is one of hundreds of billions of stars in the Milky Way galaxy. The nearest star to the Sun, called Alpha Centauri, is more than





The Solar System (not to scale).

40 trillion km (25 trillion mi) away. Our Solar System is located a little more than half way from the center of the galaxy. The whole Solar System (Sun and planets) orbits the center of the galaxy once about every 225 million years. The Milky Way galaxy is only one of an estimated 100 billion galaxies in the known Universe. Each of these galaxies may have billions of stars with planets around them — perhaps even some like Saturn.

#### 4. How old is Saturn?

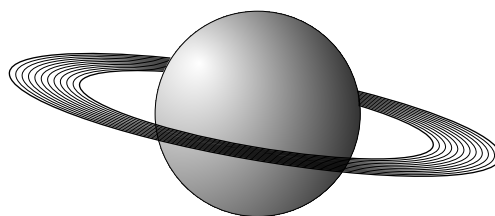
Astronomers believe that the Sun and the planets of our solar system first formed from a swirling cloud of gas and dust about 4.6 billion years ago. The Milky Way galaxy is older still, and the Universe itself is believed to be between 10 and 20 billion years old. Astronomers predict that the Sun will burn steadily for about another 5 billion years or so. Thus, in astronomical terms, the Sun and the planets orbiting around it could be called “middle-aged.”

#### 5. How big is Saturn?

*Radius and Volume:* Saturn is the second-largest planet in our solar system; Jupiter is the largest. Saturn measures about 60,000 km (37,200 mi) from its center to its equator, but is only

54,000 km (33,480 mi) from its center to its north or south pole. Its volume is almost 760 times that of Earth.

*Mass:* Saturn’s mass is about 95 times Earth’s mass. We know this by observing the orbital motions of Saturn’s many moons. Using Newton’s Law of Gravity and Kepler’s Laws, we can calculate a mass figure for Saturn that would create the gravitational force for the moons to move as they do.



COMPARATIVE SIZE OF EARTH

#### 6. If Saturn is so much more massive than Earth, why is it said that Saturn could float in water?

Even though Saturn is much more massive than Earth, this mass is spread throughout a much

larger volume than Earth and so Saturn is less dense than Earth. Saturn is the least dense of all the planets in the Solar System!

Saturn's average density is only  $0.69 \text{ g/cm}^3$ , which is less than that of water ( $1.0 \text{ g/cm}^3$ ). This means that a volume of water equal to the volume of Saturn would weigh more than Saturn does. So if we imagine a titanic tub of water big enough to hold Saturn, Saturn's weight would be supported by the water and Saturn would float! Of course, when the plug was pulled and the water drained away, Saturn might leave... a RING!



### 7. What is Saturn made of?

Like the other Jovian planets (Jupiter, Uranus, and Neptune), Saturn is primarily a ball of gas with no solid surface. According to studies based on Voyager's spectrometer, Saturn is made up of about 94% hydrogen, 6% helium, and small amounts of methane ( $\text{CH}_4$ ) and ammonia ( $\text{NH}_3$ ). The primary components, hydrogen and helium, are the same gases out of which the Sun and most stars are made.

Detailed analysis of Saturn's gravitational field leads astronomers to believe that the deepest interior of Saturn must consist of a molten rock core about the same size as Earth, but much more massive than Earth. This core is only a small percentage of Saturn's total mass.

### 8. Could we breathe Saturn's atmosphere?

No. Saturn's atmosphere is composed mainly of hydrogen and helium, the same gases out of which the Sun and most stars are made. Such an atmosphere is not poisonous to humans, but neither does it provide the oxygen needed to sustain human life.

### 9. Pictures of Saturn show that it sort of flattens out near the poles and is wider at the equator. Why is that?

Indeed, Saturn is about 60,000 km (37,200 mi) from center to equator, but only 54,000 km (33,480 mi) from center to pole. The difference is 6000 km (3,720 mi), which is about the radius of Earth! Saturn is thus said to be quite oblate: the greater the difference between the polar and equatorial distances, the more oblate is the shape of the planet.

Saturn spins around its polar axis much faster than Earth does. Though it is much larger than Earth, Saturn rotates once in 10 hours 39 minutes, over twice as fast as Earth rotates. This rapid rotation, combined with the planet's gaseous composition, forces material outward near the equator, just like a spinning merry-go-round can push its riders toward the outside. The oblateness of Saturn is actually less than would be expected if it were composed only of hydrogen and helium. This has led astronomers to believe that Saturn may have a massive rocky core.

### 10. Why is Saturn so much larger and more massive than Earth?

If we assume that the process of creation of the Solar System involved a spinning disk of gas and dust that slowly condensed to form the Sun and the planets, the question becomes, "Why was there so much more planet-building stuff in the orbit of Saturn compared to the orbit of Earth?" One idea is that at Saturn's distant orbit, the cloud of gas and dust from which the planets formed was cold enough for ice to solidify out of the gas (instead of only rock).



This extra ice makes a tremendous “seed” to gather in more rock and ice, and to gravitationally attract enormously more of the light gases like hydrogen and helium to form planets and moons.

**11. Since Saturn does not have a solid surface, would I sink to the middle of the planet if I tried to walk there?**

Saturn has an outer layer of clouds that we consider the “edge” of the planet. At the top of these clouds, the atmospheric pressure is the same as that of air on Earth. Thus to walk there would be like trying to walk on air. You would indeed sink — or fall — through the layers of Saturn’s interior. As you went deeper through the planet’s atmosphere, the pressure would increase and eventually you would be crushed.

**12. What’s gravity like on Saturn? Would I weigh the same on Saturn as on Earth?**

The gravitational acceleration at the cloud tops of Saturn is similar to that near the surface of Earth —  $10.4 \text{ m/sec}^2$  for Saturn, compared to  $9.8 \text{ m/sec}^2$  on the surface of Earth. Thus, it turns out you would feel about the same weight in an airplane flying through the cloudtops of Saturn as you would feel on the surface of Earth. If you flew deeper into Saturn’s atmosphere, gravity’s pull would increase and you would feel heavier.

Your weight depends on your mass and on the local acceleration of gravity. Your mass is the same no matter where you are, but the acceleration of gravity can be different. Therefore, your weight depends on where you are in the Solar System. For example, your *weight* would be about  $1/6$  as much on the Moon as on Earth because the acceleration of gravity is six times less on the Moon. Your *mass*, however, is exactly the same on the Moon or on Earth.

**13. What is the temperature on Saturn?**

Astronomers have measured the temperature near the cloudtops of Saturn to be about

$-143^\circ\text{C}$  ( $-225^\circ\text{F}$ ). This temperature increases with depth because the gases are compressed to dramatically greater pressures at depth. Computer models predict that Saturn’s core is as hot as  $10,000^\circ\text{C}$  ( $18,000^\circ\text{F}$ ).

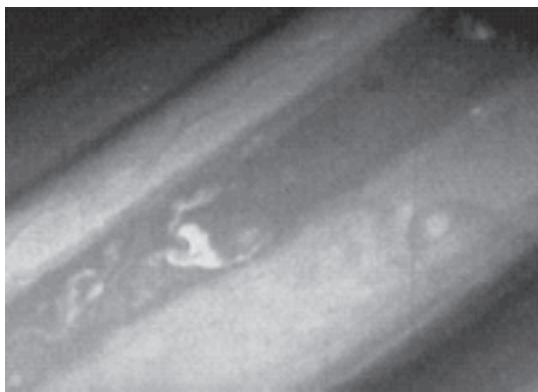
Saturn is about 10 times as far from the Sun as Earth is, so Saturn receives only about  $1/100$ th (1%) as much sunlight per square meter as does Earth. Nevertheless, Saturn is warmer than would be expected if there were a balance between the solar energy absorbed and the energy emitted. Mysteriously, Saturn emits 80% more energy than it absorbs from sunlight. Unlike the rocky Earth and the more massive Jupiter, Saturn should not have any heat left over from its original formation. Thus, there must be a source of heat inside Saturn producing the excess energy. One theory is that the energy comes from the friction of liquid helium raining down in the interior of the planet. Cassini scientists will be exploring Saturn’s energy balance for answers to this puzzle.

**14. Does Saturn have winds and storms?**

Yes, but the winds and storms on Saturn are very different from those on Earth. The Voyager spacecraft measured a giant jetstream near Saturn’s equator with a fantastic eastward speed of about  $1,800 \text{ km/hr}$  ( $1,100 \text{ mi/hr}$ ). By contrast, Earth’s jetstream flows eastward at about  $400 \text{ km/hr}$  ( $250 \text{ mi/hr}$ ).

Saturn also has “spots” which are like hurricanes on Earth, except they are longer lived and much larger. Saturn’s “spots” may last longer than Earth’s hurricanes, which lose their source of energy when they move over a solid surface. You may notice from weather reports that hurricanes generally lose their power as they move over continents. Jupiter’s Great Red Spot is the most notable example of a long-lived hurricane on another planet.





Voyager image of storms on Saturn.

**15. Since Saturn and Jupiter are both made up of mostly hydrogen and helium, why isn't Saturn the same color as Jupiter?**

Saturn is a world of white and pastel yellow cloud layers, perhaps somewhat reminiscent of the colors in a lemon meringue pie. Jupiter, by contrast, displays bright yellows, oranges, and reds in exotic swirls and storms.

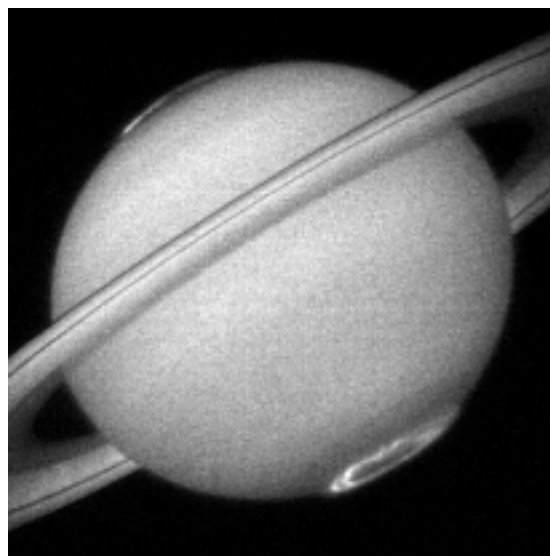
The colors of Saturn's cloud layers are due to the same basic cloud chemistry as on Jupiter. Near the top of the atmosphere, ammonia becomes cold enough to crystallize into ice particle clouds, like very high cirrus clouds in Earth's skies. But Saturn is colder than Jupiter, so the colorful ammonia cloud layers on Saturn are deeper in the atmosphere. The hazy atmosphere above the cloudtops is much thicker on Saturn, so we do not see the more colorful chemical layers below as we do on Jupiter. Although bands and storms (like Jupiter's Great Red Spot) do exist on Saturn, they are harder to see because the colors do not contrast as much.

**16. Is there life on Saturn?**

Probably not. Extreme temperatures, and lack of adequate water and oxygen make it highly unlikely that life as we know it exists anywhere in Saturn's atmosphere.

**17. Does Saturn have a magnetic field like Earth's?**

Yes. Deep inside Saturn, probably in the deepest layers of liquid hydrogen and helium, something is causing Saturn to act like a giant magnet. The same sort of thing happens in the hot liquid iron core of Earth. On Earth, this magnetism causes compass needles to align with Earth's magnetic poles. The north-seeking end of a compass needle used on Earth would actually point toward the south pole at Saturn! The Pioneer 11 and Voyager spacecraft discovered and explored Saturn's substantial magnetic field. Some of Cassini's instruments will make a more extensive exploration of Saturn's magnetic field. The Hubble Space Telescope has observed auroras on Saturn. Auroras are caused when particles streaming from the Sun interact with Saturn's magnetic field.



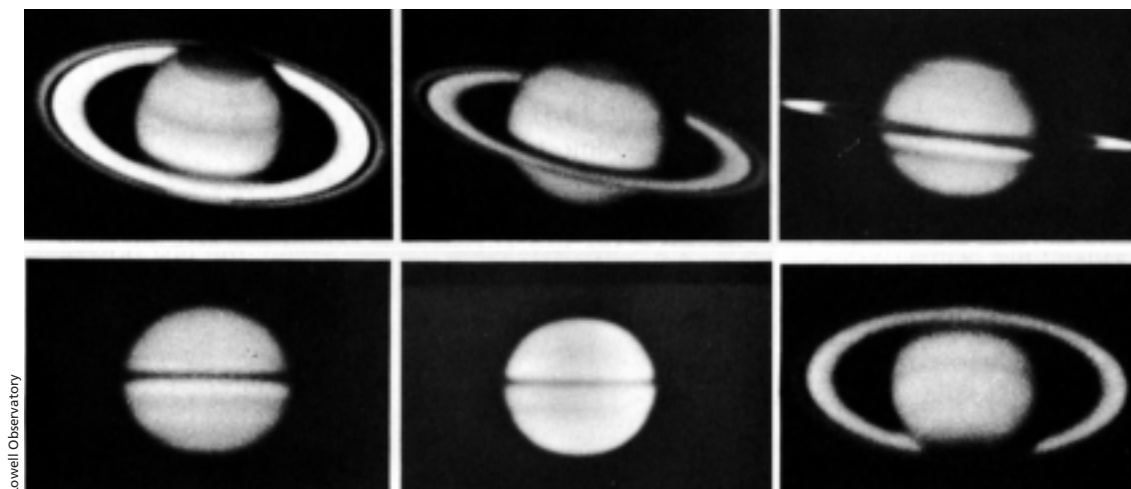
The Hubble Space Telescope took this ultraviolet image of Saturn's aurora.

**18. How long is a day on Saturn?**

A day on Earth is 24 hours long — the time it takes Earth to make one complete rotation relative to the Sun. Saturn's day is 10 hours 39 minutes — the time it takes Saturn to make one complete rotation on its axis. Even though Saturn is much larger than Earth, a Saturn day is less than half as long as an Earth day.







Lowell Observatory

The photographs show the changes in Saturn's appearance from Earth as Saturn moves around the Sun.

### 19. How long is a month on Saturn?

A calendar month on Earth is a bit longer than the time it takes for the Moon to completely orbit Earth and go through a full set of moon phases — about 29.5 days. Saturn has many moons whose times to orbit Saturn vary from half an Earth day to more than an Earth year; therefore, no Saturn month has been formally established. If a Saturn month were to be based on its largest moon, Titan, which takes about 16 Earth days to orbit Saturn, then a Saturn month would be 36 Saturn days long.

### 20. How long is a year on Saturn?

A year is the time it takes for Earth to make one complete trip around the Sun, or about 365 Earth days. It takes Saturn 29.5 Earth years to travel once around the Sun, so one Saturn year is about 30 Earth years. If you were 15 Earth years old, you would only be half a Saturn year old because Saturn would only have made half an orbit around the Sun since you were born! ( $15/30 = 1/2 = 0.5$  of a Saturn year old)

### 21. Does Saturn have seasons like Earth's?

Yes, sort of. Earth has seasons because of the tilt of its axis. Imagine a line drawn through Earth from the North Pole to the South Pole. This line always points toward the distant star Polaris, no matter where Earth is in its orbit of the Sun.

This means that during Earth's trip around the Sun each year, sometimes the northern hemisphere is tilted toward the Sun, making daytime longer so that the northern hemisphere receives brilliant, direct light that causes warmer temperatures (summer). Six months later, when Earth is on the other side of the Sun, the northern hemisphere is tilted away from the Sun, thus receiving less direct sunlight, causing longer nights and colder temperatures (winter). In both cases, the line between Earth's poles points toward the star Polaris.

Saturn has seasons in the sense that there are times of its year when the northern hemisphere is tilted toward the Sun, and times of its year when the northern hemisphere is tilted away from the Sun (with great ring viewing from Earth). The series of photos above shows how Saturn's appearance changes as viewed from Earth. But Saturn does not have dramatic seasonal differences in temperature in the northern and southern hemispheres as on Earth, nor do the temperatures cool down during the night on Saturn. Saturn's internal heat source and the way Saturn's thick atmosphere retains heat make the temperatures of Saturn's atmosphere less dependent on where the Sun is presently shining on it.



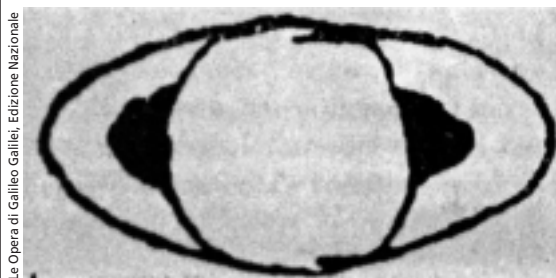
On Earth, a season only lasts about 3 months. But since Saturn takes almost 30 Earth years to go around the Sun, a Saturn season lasts more than 7 years — about the same amount of time it will take the Cassini–Huygens spacecraft to get to Saturn!

Some people have the misconception that seasons are caused by a planet changing its distance in relation to the Sun. Although both Saturn and Earth change distances to the Sun slightly during their orbits, this has a very small effect on their temperatures. Changing the distance to the Sun does not explain why it's winter in North America while it's summer in Australia: Earth is slightly closer to the Sun in January than it is in July.

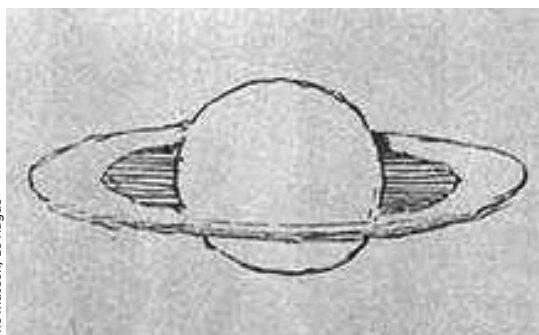
## Rings

### 22. How did we first find out about Saturn's rings?

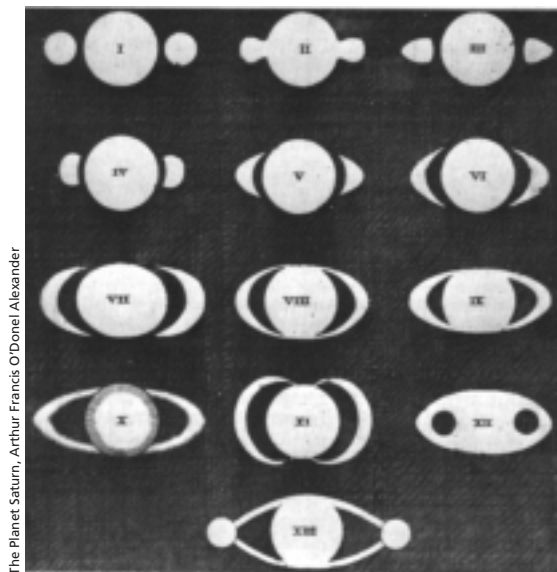
In 1610, Galileo Galilei observed Saturn through a small telescope that magnified objects about 30 times. He saw stationary “bulges” on either side of the planet that looked like



A 1616 drawing by Galileo.



Huygens' drawing of Saturn, 1683.



Early drawings of Saturn, originally from *Systema Saturnium* by Huygens, 1659.

“handles” or “ears.” Galileo speculated that the bulges were features of the planet or perhaps moons (he called them “lesser stars”). By 1616, he could draw more clearly the shapes he saw around Saturn, but did not know what they were. Galileo died not realizing that he had been the first human to observe Saturn's rings.

In 1655, Christiaan Huygens, a Dutch astronomer, observed Saturn using a better telescope than Galileo's. Using his observations, and by studying the observations of others, he proposed that Saturn has a flat ring around its equator. Unlike Galileo, he could see that the ring did not touch the planet. In the same year, Huygens discovered Saturn's largest moon (named Titan 200 years after its discovery).

In 1676, Jean-Dominique Cassini, an Italian-French astronomer, used an even more powerful telescope to discover that the ring that Huygens saw had a gap in the middle. The inner ring would later come to be called the B ring, and the outer one the A ring. The gap between these brightest rings of Saturn was

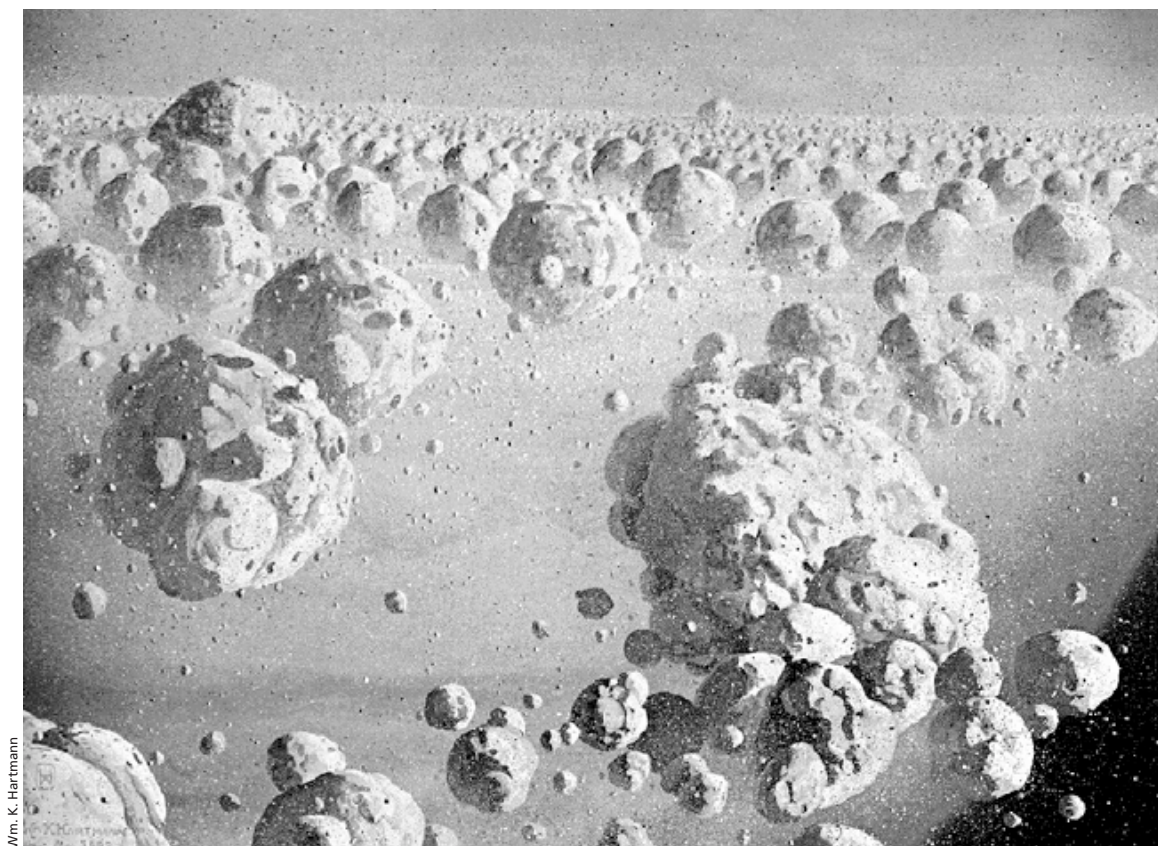
named the Cassini Division. Cassini discovered four moons of Saturn in addition to the one that Huygens found: Iapetus (in 1671), Rhea (in 1672), and Tethys and Dione (in 1684). The moons were named later. No one yet knew what the rings were made of, how thick they were, or if they were permanent features around Saturn.

### **23. What are the rings of Saturn made of? Are they solid?**

Saturn's rings are made up of millions and millions of orbiting particles interacting with each

other and with Saturn's moons. These particles are composed mostly of water ice and some rocky material. The icy particles' sizes range from that of specks of dust to "ringbergs" the size of houses.

We first began to learn about the nature of the rings when in 1857 James Clerk Maxwell, a Scottish scientist who developed the theory of electromagnetism (which predicted the speed of light), proved mathematically that the rings encircling Saturn could not be a single, solid disk.



Wm. K. Hartmann



This artist's concept represents a thinly populated locale in Saturn's rings. The rendering shows rings viewed from just above the ring plane. The largest ring particles shown here are house-sized. The large bodies are irregularly shaped and lie roughly in a flat layer; smaller particles are scattered among them.



He proposed that the rings are instead made up of many small particles. Observations by American astronomer James Keeler in 1895 proved the truth of his prediction.

#### 24. How many rings are there?

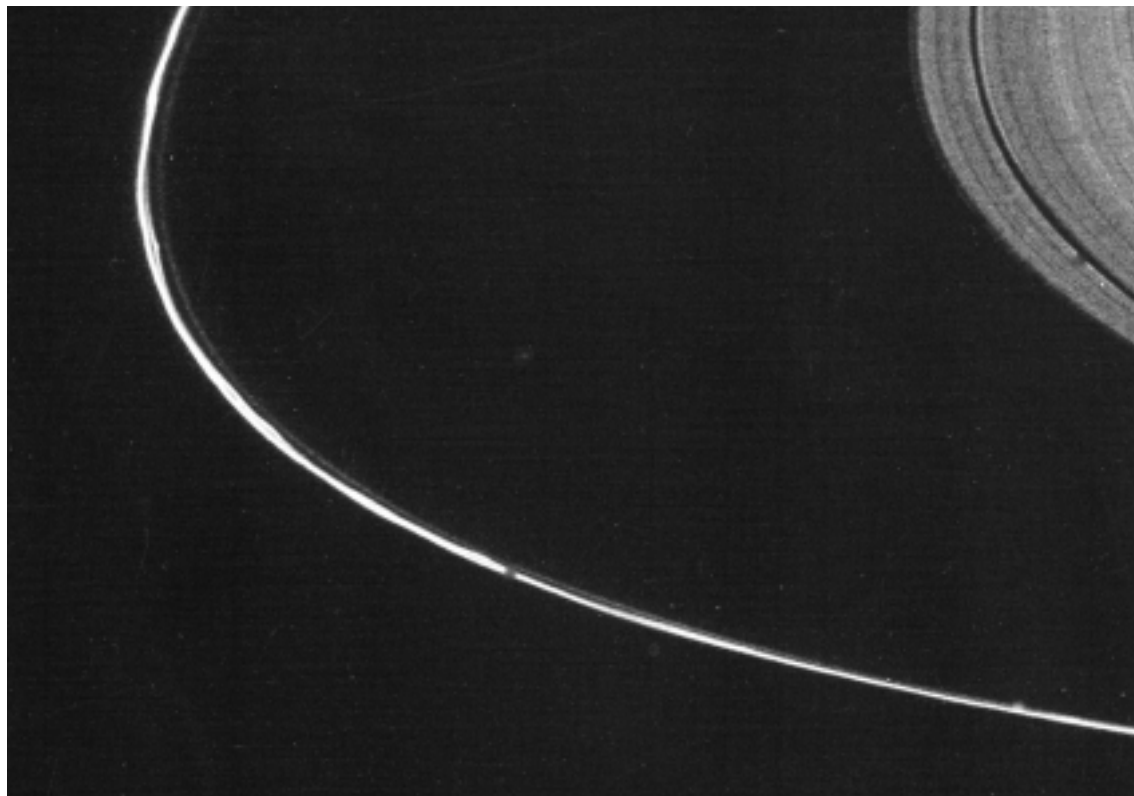
Saturn's ring system has been divided into seven main ring groupings. Astronomers have named these main ring groupings the A, B, C, D, E, F, and G rings. (See the illustration on page 234.) The rings are not located in alphabetical order because they were named in the order of their discovery. From inner to outer, the rings are named D, C, B, A, F, G, and E. One possible way of remembering this is: *Daring Cassini Begins A Far Greater Exploration.*

The two brightest rings easily seen through telescopes from Earth are the A and B rings, which are separated by the Cassini Division. The B ring is closer to the planet than the A ring. The faint C ring inside the B ring is barely visible from Earth. The D ring is closest to the planet

and has only been seen clearly by Voyager as the spacecraft was looking back as it left the Saturn system.

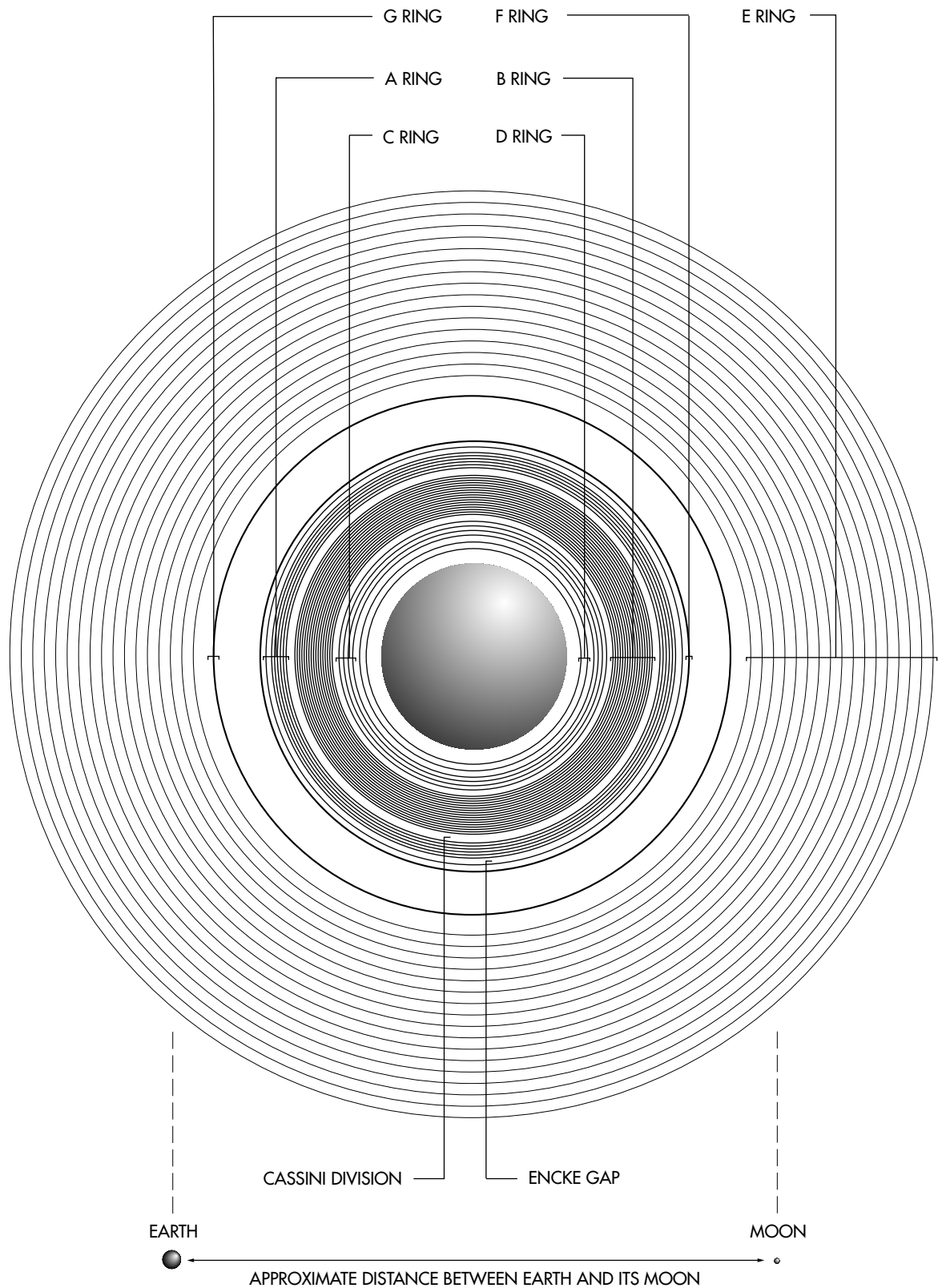
Saturn also has three other rings. Just outside the A ring is the narrow F ring, discovered by the Pioneer 11 spacecraft when it flew by Saturn in 1979. This mysterious ring sometimes contains clumps or "braids." The clumps move, and come and go with time. Next is the faint G ring. This ring isn't very bright and it is difficult to see, even from Saturn. In fact, the G ring is so thin that Voyager 2 actually flew through the edge of the ring without damaging the spacecraft! Finally, there is a broad, faint ring called the E ring. The moon called Enceladus may have ice volcanoes or geysers that supply the E ring with tiny ice particles. The Cassini mission hopes to find out if this is true!

Depending on how you define an individual ring, Saturn's rings number in the thousands. Voyager observed that the main rings (A, B, C)



A Voyager image showing the clumped and braided F ring.

Note: Saturn's rings consist of individual particles. The relative density of particles is represented by the spacing of the circles within each ring.



Saturn and its ring system shown to scale.

are composed of ringlets so numerous that the ring system looks much like a phonograph record, with thousands of thin grooves in it.

### 25. Do the rings move?

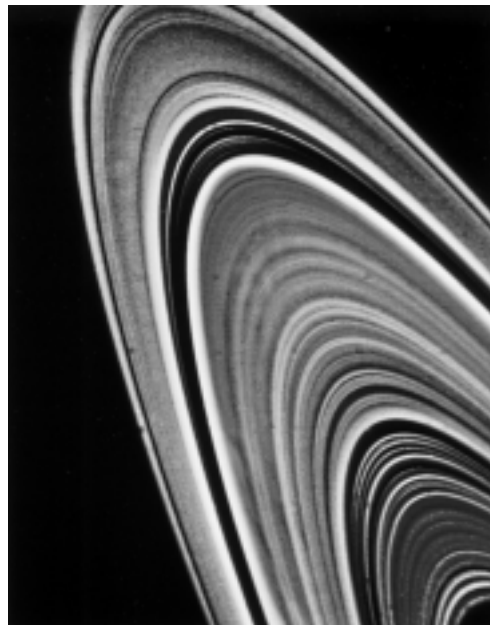
Yes, but not like a solid would move. The bits and boulders of Saturn's rings each orbit like tiny moons. They move around Saturn in the same direction as Saturn rotates and the same direction as all the known moons (except the outermost moon, Phoebe, which orbits in the opposite direction). The ring particles closest to Saturn whiz around the fastest, and those farther away travel around at a slower speed (in keeping with Kepler's Laws).

The orbital speed of a ring particle depends only on its distance from Saturn's center; it does not depend on the particle's mass or size. For example, if a house-sized ring particle and a sugar grain-sized ring particle are both orbiting at the inner edge of the B ring, they move at the same speed around Saturn. However, ring particles at the outer edge of the B ring orbit at a slower speed. The particles of the innermost rings are moving around Saturn faster than Saturn rotates.

Ring particles can also move randomly in other directions, such as perpendicular to the rings. These motions are usually damped out quickly by collisions or gravitational interaction between the particles. If you wait a much longer time (millions of years), some of the rings may spread out and eventually disappear.

### 26. In the opening sequence of the TV show *Star Trek: Voyager*, a ship passes through the rings of Saturn. Do the rings contain more empty space or more solid particles?

Most of the volume of the rings is empty space. Each of the main rings (A, B, and C) contain different densities of particles. The B ring is the densest, followed by the A ring, and then the C ring. The A and B rings are separated by a gap



Voyager close-up image of Saturn's rings.

that is 4,600 km (2,900 mi) wide, called the Cassini Division, but close-up images by Voyager showed that the Cassini Division contains many more ring particles than expected. There is a region in the Cassini Division near the outer edge of the B ring that is relatively free of ring particles. Near the outer edge of the A ring there are two gaps almost empty of material: the 330 km (210 mi) Encke Gap, and the 35 km (22 mi) Keeler Gap. The best places to fly through the rings might be in gaps such as these.

The rings have more empty space than ring particles, even in the brightest B ring, which contains most of the mass of Saturn's rings ( $2.8 \times 10^{19}$  kg). But this doesn't mean you could fly through from top to bottom without hitting any of the particles. Even if you had a tiny spacecraft a few centimeters across, it would be unlikely that it could pass through the A or B rings without being hit by ring particles. The particle impacts would not be gentle nudges, but chunks hitting the spacecraft at relative speeds "faster than a speeding bullet"! At this speed, even a millimeter-sized particle might be enough to damage Cassini, but the

spacecraft will not be flying in regions of the rings where many particles like these exist. The probability of Cassini being hit by such a particle is less than 1%. When Voyager 2 flew through the edge of the G ring in 1981, instruments recorded hits by tiny dust particles less than 1 mm in size. Voyager made it through without any damage.

## 27. How big are the rings?

Saturn's ring system is both very broad and very thin. The inner edge of the rings begins approximately 6,700 km (4,200 mi) from the cloudtops of Saturn. The outer edge of the A ring is at approximately 76,500 km (47,600 mi) from the cloudtops of Saturn. The outer edge of the outermost ring (the E ring) has been measured out to about 420,000 km (260,000 mi) from Saturn's cloudtops. This distance is greater than that between Earth and the Moon — 384,000 km (242,000 mi). It is likely that the rings extend even farther from Saturn in an ever-diminishing zone of fine, icy dust.

In terms of thickness from top to bottom, the bright A and B rings may be as thin as a hundred meters — the length of a football field. At its outer edge, the E ring increases in thickness to several thousand kilometers.

## 28. How much stuff is in the rings?

If all the material in Saturn's rings were collected together, it would form a moon about the size of Saturn's moon Mimas, which is 392 km (244 mi) across. This is about 9 times smaller than the diameter of Earth's Moon. Scientists estimate the mass of Mimas to be  $4 \times 10^{19}$  kg, or about 1,800 times less massive than Earth's Moon.

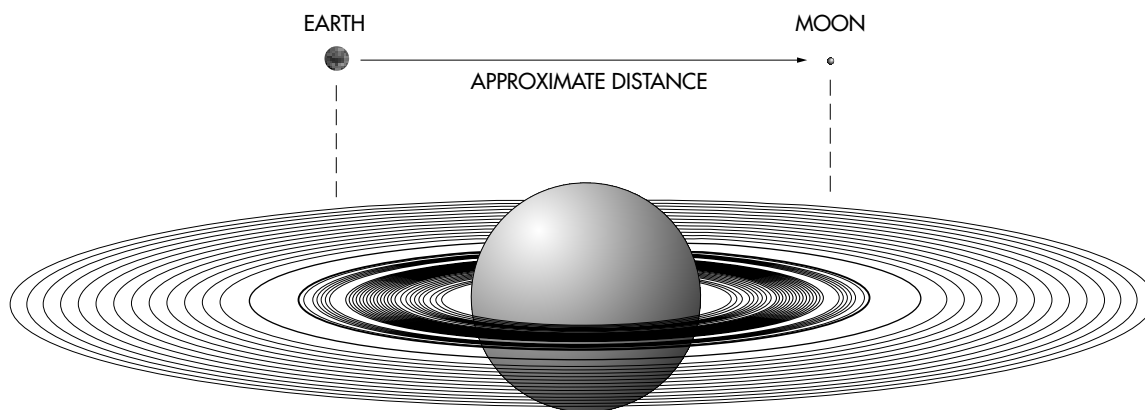
The majority of the mass of the rings is in particles from a few centimeters to a few meters in size — neither very large nor very small. This is because there are very few really big particles in the rings, and the mass of the dust is very small, so the biggest and smallest particles do not contribute very much to the overall mass.

There is far less mass in Saturn's rings than is found in the asteroid belt between the orbits of Mars and Jupiter. Furthermore, the asteroids are made of rock and iron, substances which are many times denser than the water ice out of which Saturn's rings are made.

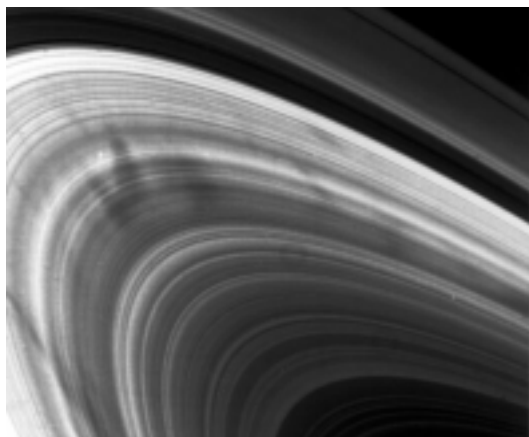
## 29. Do ring particles collide?

Yes, there are several types of forces that can alter a ring particle's normal orbital path, causing it to collide with neighboring particles. Saturn's rings represent an ever-changing, dynamic sys-

Note: Saturn's rings consist of individual particles. The relative density of particles is represented by the spacing of the circles within each ring.







A Voyager image of “spokes” in Saturn’s rings.

tem of particles which evolves with time. Understanding that change is one of Cassini’s goals as it studies the rings.

Saturn’s moons are important gravitational influences that can cause ring particles to move out of their normal circular orbits. The orbit of a ring particle becomes circular once again through collisions with other ring particles, and the ring particle may end up in a slightly different orbit from the one it was in before it got a “kick” from the moon. These “kicks” occur at specific locations in the rings and can actually cause large “waves” or “knots” to form in the rings.

Saturn’s magnetic field can also cause the smallest ring particles to alter their orbits, causing collisions with other ring particles. The smallest particles are easiest to electrically charge, and once charged, they can be lifted above the rings by Saturn’s magnetic field. This is one of the most popular theories for what causes the mysterious B ring “spokes” that were discovered by the Voyager spacecraft.

### **30. Why does Saturn have rings? How were the rings made?**

The rings probably formed primarily because one or more small moons broke up close to Saturn. This breakup could have been the result of

a collision with a comet or asteroid, or with another moon in close orbit around Saturn. Over millions of years, the moon bits and cometary ice chunks spread out into the complex ring system that exists today.

Ring formation can also start or be sped up if a large enough moon, asteroid, or comet comes close enough to Saturn that the gravitational pull of Saturn gently breaks it apart. This can happen when the difference between gravity’s pull on the side facing Saturn and its pull on the side facing away from Saturn is enough to tear the object apart. After it is pulled apart, the smaller particles will begin to collide with each other and with preexisting ring particles. This slowly grinds them down in size and spreads them out, gradually adding to Saturn’s rings.

### **31. How old are the rings? Has Saturn always had rings? Will it always have rings?**

Using data collected by NASA’s Pioneer and Voyager spacecraft, scientists have estimated that Saturn’s rings are “only” 100 million years old, a small fraction of the 4.6 billion years the Solar System has existed. It is possible that the rings come and go. They might be constantly renewed and reformed over time by internal collisions and by the addition of comets or asteroids that are captured as they pass close to Saturn. If we were to come back and visit Saturn in a billion years, the faint rings may be gone completely, and an entirely new ring system formed in their place.

The E ring may be younger than the A and B rings. Scientists have speculated about how material in the E ring might come from small dust or ice particles knocked loose from Saturn’s icy moons. It is also possible that Enceladus may have water volcanoes or geysers constantly feeding the E ring with new dust-sized ice particles. Enceladus’ bright young surface and apparent episodes of surface melting are evidence of heat sources that could also generate volcanism.



The Cassini spacecraft will learn more about the unusual ring system of Saturn. It is now apparent that Saturn's rings are complex, dynamic, and constantly evolving things.

### 32. Are there other planets with rings?

Yes! The Voyager spacecraft saw rings at Jupiter, Uranus, and Neptune. However, the rings of these planets are all much fainter than Saturn's and have only recently been discovered. In 1977, observers using a telescope aboard an airplane flying high over the South Atlantic Ocean discovered a series of narrow rings around Uranus. These rings appear to be made of very dark particles, unlike the bright, icy particles of Saturn's rings. In 1979, Voyager 1 discovered a faint, dusty ring around Jupiter. Neptune's ring system was first detected in 1984, when astronomers on the ground noticed that the light from a distant star dimmed slightly as the Neptune system moved in front of it. This suggested a ring system or unknown moons orbiting the planet. Voyager 2 later flew by Uranus and Neptune and returned stunning images of these planets' rings.

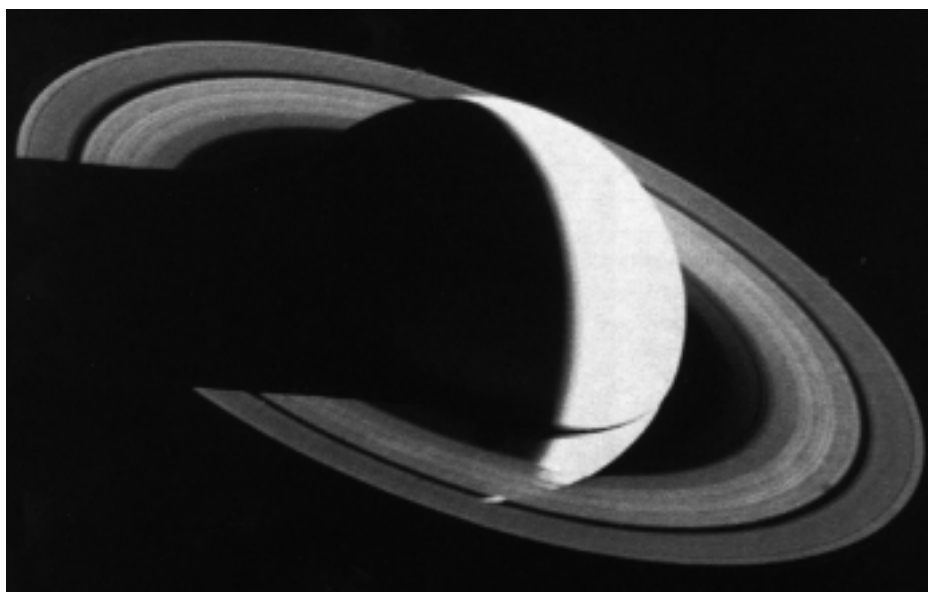
Although all the giant gaseous planets are now known to have rings, none has a ring system

that compares with the size and grandeur of Saturn's. Saturn really is "Lord of the Rings"! Some scientists believe that Mars may have a very faint ring system associated with its tiny, dusty moons Phobos and Deimos. A future spacecraft mission to Mars might be able to detect these rings, if they exist.

### 33. Why doesn't Earth have rings?

The small inner planets may have had rings in the past and may have rings again in the future. One prevalent theory says that ring systems are much younger than the age of the Solar System, and as such, may come and go with time. If Earth had rings in the past — for example, from the breakup of a comet or asteroid that came too close — then those rings may have spread out and disappeared long ago. Earth might have a ring in the future if a comet or asteroid passes Earth in just the right orientation to be broken apart by Earth's gravity rather than disintegrating in Earth's atmosphere.

Our Moon is too distant to provide material for a future Earth ring; however, the Moon may have formed from a huge, very short-lived ring of material encircling Earth. Such a ring would have been formed if a huge body — the size of



A Voyager image of Saturn casting its shadow across the rings.

Mars or larger — hit Earth, spewing huge amounts of debris into orbit around our planet. In a very short time, this debris would gather together to form the Moon.

### **34. If Earth had rings like Saturn's, what would they look like from the ground?**

If you were to scale down Saturn and its ring system so that Saturn was the size of Earth, the outer edge of the A ring would stretch about 6,400 km (4,000 mi) from Earth's surface. The rings would look quite different in the sky depending on the latitude at which you were standing, the time of year, and the time of day.

If you were standing on Earth's equator, you would have to look directly overhead to see the rings. The rings would only appear as a thin line running across the sky from east to west, because the rings would orbit nearly over Earth's equator. If you were standing at a higher latitude in the northern hemisphere, you would have to look to the south to see Earth's rings. The rings would form an arching band across much of the sky. If you were standing all the way at the North Pole, you would not be able to see any rings at all, because they would be below your southern horizon.

If you were standing about halfway between the equator and the North Pole, the rings would appear different depending on what time of year you looked. In the summer, Earth's tilt would orient the rings toward the Sun and you would see sunlight reflected directly off the top side of the rings. But during the winter, the Sun would be shining more directly on Earth's southern hemisphere, and thus the rings would be lit up from the bottom side! In that case, you would see some light pass through the rings, but they wouldn't appear as brilliantly lit as during summer.

You would also have to be sure to look at the rings at a time of day when the Sun was shining on them. Noontime would be best. Earlier or later in the day, the east or west edges of the rings might be blocked by Earth's shadow falling on them. If you looked at midnight, the rings would be mostly blacked out from being in Earth's shadow. Many Voyager pictures show Saturn's shadow on the rings.

So, if Earth had rings like Saturn's, they would appear exceptionally beautiful on the summer solstice from midlatitudes at noon.

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## **Moons**

### **35. How many moons does Saturn have?**

At least 18 moons orbit Saturn. Until recently, Saturn was the moon champion, recognized as having more than any other planet in the Solar System. However, astronomers have announced discoveries of additional moons around Uranus, bringing that planet's total to 20 if the observations are confirmed. There are probably many additional small moons amidst Saturn's rings, and the Cassini mission may find some of them.

Saturn's 18 moons are listed in the table on page 240, along with their distances from the center of Saturn, orbital periods (time to go once around Saturn), sizes, and notable features. The smallest moons (Pan, Atlas, Prometheus, Pandora, Epimetheus, Janus, Telesto, Calypso, Helene, Hyperion, Phoebe) have irregular shapes. For these moons, an average "radius" has been calculated by averaging measurements of their sizes in three dimensions. The larger moons (Titan, Rhea, Iapetus, Dione, Tethys, Enceladus, Mimas) are very close to being spheres.

Just like Earth's Moon, most of Saturn's moons rotate at the same rate as they revolve around Saturn, and thus keep the same face toward Saturn. This also means the moons always have one



**Saturn's Moons**

Name	Distance from Center of Parent (km × 1,000)	Period of Orbit Around Parent (hours)	Average Radius (km)	Special Features or Behavior
Pan	133.6	13.85	10	Orbits in Encke Gap, sweeping it clean.
Atlas	137.6	14.42	16	May keep outer edge of A ring well-defined.
Prometheus	139.4	14.71	53	Shepherd moon; helps keep the F ring narrow.
Pandora	141.7	15.07	43	Shepherd moon; helps keep the F ring narrow.
Epimetheus	151.4	16.68*	60	Irregular; may have been joined with Janus.
Janus	151.5	16.68*	90	Irregular; trades orbits with Epimetheus.
Mimas	185.5	22.61	199	Has giant crater, Herschel; looks like "Death Star" battle station from movie.
Enceladus	238.0	32.88	249	Icy, shiny; may have ice geysers that feed the E ring.
Tethys	294.7	45.31	530	Has large trench, Ithaca Chasma; also a large crater, Odysseus.
Telesto	294.7	45.31	12	Co-orbital with Tethys, 60° behind.
Calypso	294.7	45.31	10	Co-orbital with Tethys, 60° ahead.
Dione	377.4	65.69	560	Cratered leading face; wispy features on trailing hemisphere.
Helene	377.4	65.69	18	Co-orbital with Dione, 60° ahead.
Rhea	527.0	108.42	764	Largest icy satellite; densely cratered.
Titan	1,221.9	382.69	2,575	Largest moon of Saturn; second-largest moon in Solar System; only moon with a dense atmosphere.
Hyperion	1,481.1	510.64	144	Irregular, dark surface; chaotic tumbling orbit.
Iapetus	3,561.3	1,903.92	718	Much darker leading hemisphere; lighter trailing hemisphere.
Phoebe	12,952	13,211	110	Retrograde orbit; may be captured asteroid.

**Earth's Moon**

The Moon	384.5	665.73	1,738	Rocky, cratered, mountainous; prominent flat, dark areas called <i>maria</i> on Earth-facing side (probably lava flows following huge, ancient cratering events).
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\* The orbital periods for Epimetheus and Janus are slightly different but round off to the same value





side that faces toward the direction of their motion around Saturn, and one side that faces away from their direction of motion. These are called the leading and trailing hemispheres.

### 36. Who discovered all these moons?

In 1655, Christiaan Huygens, a Dutch astronomer, observed Saturn through a telescope and discovered Saturn's largest moon, Titan, although it wouldn't be named this for another 200 years. Titan's diameter is about 5,150 km (3,200 mi), or 1.5 times as large as the diameter of Earth's Moon — 3,500 km (2,200 mi). Titan is the second-largest moon in the Solar System — Jupiter's Ganymede is the largest. Both Titan and Ganymede are larger than the planets Mercury and Pluto. Titan and Ganymede are defined as moons because they orbit planets, while Mercury and Pluto are defined as planets because they orbit the Sun.

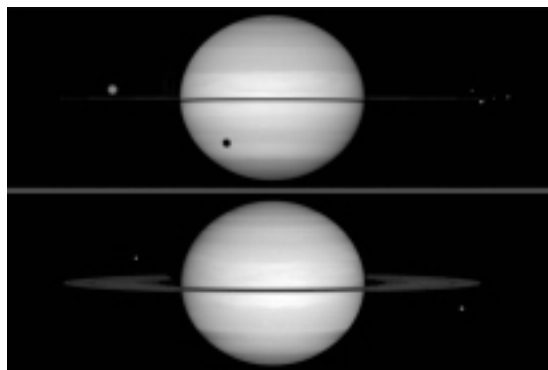
Later in the 1600s, the Italian–French astronomer Jean-Dominique Cassini discovered four more moons of Saturn: Iapetus (1671), Rhea (1672), and Tethys and Dione (1684). Not surprisingly, these moons were Saturn's next largest, with diameters ranging from 1,400 km (870 mi) for Tethys to 1,500 km (960 mi) for Rhea. Cassini noted that when Iapetus was on one side of Saturn, it could be easily seen; however, when it was on the other side of its orbit, it was invisible. He correctly deduced that Iapetus was keeping the same side always toward Saturn, and that one side of the moon (its leading hemisphere) was much darker than the other side (its trailing hemisphere).

In 1789, William Herschel in England discovered moons of Saturn that would later be named Mimas and Enceladus. These moons have even smaller diameters: about 500 km (310 mi) for Enceladus and 400 km (250 mi) for Mimas.

In 1848, astronomers William Bond and George Bond (father and son) of Harvard College discovered Hyperion, with a diameter of 290 km (180 mi). The very same night, William Lassell of England also discovered it with his telescope. In 1898, William Pickering, also of Harvard, discovered Phoebe, with a diameter of 220 km (140 mi). Phoebe was the first moon discovered using photography, rather than by looking directly through a telescope's eyepiece.

The innermost four moons (Pan, Atlas, Prometheus, and Pandora), which are intertwined with Saturn's A and F rings, were not discovered until Voyager 1 flew past Saturn in 1980. Pan, in fact, eluded discovery until even after Voyager. It was not until 1991 that astronomer Mark Showalter searched through Voyager images of the narrow, clear Encke Gap in Saturn's A ring and found Pan.

The rest of Saturn's currently known moons were discovered by observers on Earth during the 1966 and 1980 ring-plane crossings, when Saturn's thin rings were seen edge-on from Earth. With the rings temporarily not visible from Earth, faint objects near the planet are easier to see. During the 1966 ring-plane crossing, Audoin Dollfus discovered Janus, and John Fountain and Steve Larson discovered its companion, Epimetheus. Telesto, Calypso, and Helene were discovered by three different

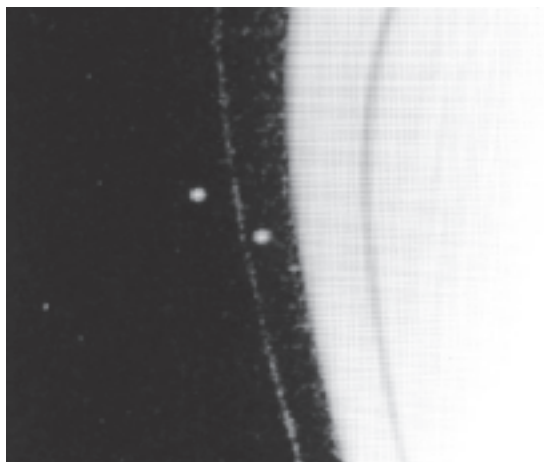


Hubble Space Telescope images of the 1995 ring-plane crossing.



groups of astronomers during the 1980 ring-plane crossing.

Ring-plane crossings occur about every 15 years. Like Earth's North Pole, Saturn's north pole is tilted with respect to the plane of its orbit, and this causes our view of the rings to change as Saturn travels in its 30-year orbit around the Sun. Ring-plane crossings occur near Saturn's equinoxes when the planet's tilt is neither toward nor away from the Sun.



The gravity of Prometheus and Pandora keeps the F ring particles confined to a very narrow ring.

In 1995, astronomers using the Hubble Space Telescope announced that they had discovered two — perhaps even four — previously unknown moons. Amanda Bosh and Andrew Rivkin spotted what appeared to be new moons of Saturn in photographs they made during the ring-plane crossing. Two of the “newly discovered moons” in the photos turned out to be the previously known moons Atlas and Prometheus, but they were at different positions than predicted by previous estimates of their orbits.

Careful analysis of the remaining two moons showed that they were at the distance of the F ring, and appeared to change shape as they orbited Saturn. These objects are now believed not to be moons, but rather “clumps” of ring material within the F ring. Bosh was not disap-

pointed that the “moons” turned out not to be moons after all. Astronomers were still excited, because this was the first time the F ring clumps had been seen from Earth.

### 37. How did the moons get their names?

In the mid-1800s, English astronomer John Herschel (son of William Herschel, who had discovered two moons of Saturn) wrote that it would not be right to name the moons of Saturn after Saturn's children. In Roman mythology, Saturn ate all his children. Instead, said Herschel, Saturn's moons should be named after Saturn's brothers, the Titans, and Saturn's sisters, the Titanesses. These were mythological giants who were believed to rule in the heavens before Jupiter conquered them. Astronomers accepted Herschel's suggestion for naming the moons. Because the moon discovered by Huygens was so much larger than the rest, they chose to name it Titan rather than naming it after one of the giants. For more information, see *Discussion 4 — Mythology of Saturn*, page 219.

### 38. Are Saturn's moons like Earth's Moon?

Yes and no. Many of them are covered with impact craters like our Moon, but the moons of Saturn are made up of much more water ice than Earth's moon. Earth's Moon may have very tiny patches of ice, but almost all its mass is rock. Because of this, most of Saturn's moons are about one-third the density of our Moon. Titan's density is a little higher, but still only about half as dense as Earth's Moon. Saturn's outermost moon, Phoebe, may be a captured asteroid, in which case it would likely have a much higher density.

Titan is the only one of Saturn's moons that is larger and more massive than our Moon. All the rest are significantly smaller and less massive, and many of them are irregularly shaped rather than spherical. (See the table on page 240 for comparisons.) Also, unlike our Moon, and un-



like all of the other 60 or so moons in the Solar System, Titan has a thick atmosphere.

### **39. Why does Saturn have so many moons, but Earth has only one?**

Here again, astronomers can make some educated guesses. There is more planet-building “stuff” at Saturn’s orbital distance than at Earth’s orbital distance. This is because Saturn’s orbit is so far from the Sun that ice becomes a substantial source of planet-building material. The more planet-building material, the more material for forming moons around the planet. Many of Saturn’s moons and rings are composed largely of ice. Saturn may also have moons that are captured asteroids. This is the most likely origin for Saturn’s outermost moon, Phoebe, and the Cassini spacecraft will make an investigation of this on its way into the Saturn system.

Earth’s Moon is unusually large relative to the size of its parent planet. The diameter of Earth is less than 4 times larger than the Moon’s diameter. By contrast, Saturn’s diameter is nearly 25 times greater than Titan’s diameter. Thus, Earth’s Moon is far too large, compared with the size of Earth, to have been formed as an original moon from the spinning disk of gas and dust that formed the planet. The present Moon was most likely formed as a result of a tremendous collision between Earth and a huge asteroid the size of Mars or larger, which broke apart Earth and created the Moon. This impact may have actually created multiple moons around Earth, which later collided with each other or Earth, and now we are left with one large moon.

### **40. Are Saturn’s moons in the rings? Do the moons collide with the ring particles?**

One small moon has been found orbiting within the main rings (A, B, C). This moon, named Pan, orbits in the Encke Gap, near the outer edge of the A ring. Pan sweeps the gap clear of the smaller ring particles, thereby maintaining the gap. If Pan disappeared, so would the Encke

Gap. Scientists suspect that other moons are lurking in the Saturn system, creating some of the other gaps in the main rings. Cassini may find these moons during its mission.

Collisions between ring particles occur frequently in the main rings, and ring particles can easily be knocked into a new orbit by these collisions. If a moon collided with a large enough ring particle, the moon could be fractured or lost within existing ring material. In either case, it might no longer be identifiable as a separate moon.

Saturn’s E, F, and G rings orbit outside the main rings. The outermost ring — the E ring — is the most extended. Enceladus moves through the E ring, and it may have ice volcanoes that are responsible for producing the ring’s tiny particles of ice. The G ring is so thin that it would probably disappear quickly if it did not have several small moons orbiting within it and producing particles. No one has yet seen these probable G ring moons — perhaps the Cassini spacecraft will!

### **41. What’s the difference between a moon and a ring particle?**

The rings are nothing more than a dense swarm of tiny, interacting moons. In principle, you could find an orbit for every ring particle around Saturn if the particles did not interact with one another and change orbits slightly. Different kinds of forces act on ring particles of all sizes and modify their orbits. If you cannot track an object and predict its orbital path, you might call it a ring particle rather than a moon.

The orbits of the largest particles in the rings probably change the least. However, we do not have much data on this question since the largest “ring particle” Voyager imaged was Pan, and we don’t know how Pan’s orbit may be changing with time. Cassini will provide a wealth of new data on Pan and will probably discover



new moons embedded in the rings. You might ask: At what size something is no longer a moon but is just a “ring particle”? There’s no clear distinction. Suppose the ring particles sometimes stick together in larger collections of many particles, and sometimes break apart via collisions. In this case, do some “moons” come and go?

There really is no sharp cutoff between a moon and a ring particle (or “ringberg”). The smaller the moon, the harder it is for it to maintain an empty gap around Saturn. We think that smaller “moons” might clear small areas that are then filled in with ring particles after the “moon” has passed by. However, maintaining a gap depends in part on the density of ring particles in the region in which the moon orbits. Denser regions like the A or B rings would require a larger moon to maintain a gap than a much more diffuse region such as the C ring. Hence, defining a moon as an object that maintains a gap in the rings would produce differing cutoffs in moon sizes for each ring region.

It will be interesting to see just what definitions evolve once Cassini begins making its closer examination of Saturn’s rings!

#### **42. What’s gravity like on Saturn’s moons? Could we walk there?**

Titan’s gravity is a bit less than that of Earth’s Moon, which has 1/6 the surface gravity of Earth. Someone who weighs 110 pounds on Earth would weigh only 20 pounds on the Moon, and 15 pounds on Titan. Just think how easy it would be to jump over a 6-foot high fence! The person’s mass, 50 kg, would be the same on both Earth, the Moon, and Titan.

To compute the surface gravity for a moon, you need to know the moon’s size and mass. For several moons, we only have guesses for these numbers. Many moons are oddly shaped, so depending on where you stood, you would weigh a different amount.

#### **43. Are there volcanoes on any of Saturn’s moons?**

Although the evidence is circumstantial, it is possible that Saturn’s moon Enceladus has water volcanoes or geysers, active today or in the recent past. Cassini plans close flybys of Enceladus to search for direct evidence of such volcanoes. Some scientists believe that volcanoes on Enceladus are the source of particles in Saturn’s E ring. Because Titan is so large, it is possible it may have a warm, active core that also causes volcanoes on its surface. The Huygens probe will help us see if any volcanoes exist on Titan.



Artist's rendition of ice geysers on Enceladus.

#### **44. How cold are Saturn’s moons?**

Saturn’s moons and rings are even colder than Saturn, with surface temperatures ranging from  $-145^{\circ}\text{C}$  to  $-220^{\circ}\text{C}$  ( $-230^{\circ}\text{F}$  to  $-365^{\circ}\text{F}$ ). The brightest moons are the coldest, because they reflect almost all the Sun’s light, rather than absorbing it.

#### **45. Do any of Saturn’s moons have an atmosphere? Could we breathe it?**

Among Saturn’s moons, only Titan has a thick atmosphere. Titan’s atmosphere is mainly nitrogen, like Earth’s, but it does not have enough oxygen for humans to breathe. Gerard Kuiper [KOY-per], a Dutch-born American astronomer, first discovered Titan’s atmosphere in 1944 using a spectrometer that detected infrared light (heat). This instrument was attached to a telescope with an 82-inch mirror. Many gases are hard to detect using visible light, but much easier to detect using infrared. Kuiper detected





the presence of methane gas. Before Voyager 1's flyby of Titan in 1980, only methane and a few other simple chemicals called hydrocarbons had been detected on Titan.

Observations from the Voyager spacecraft using radio waves and infrared light indicated that Titan's deep atmosphere was composed mostly of nitrogen — at least 90%, compared to the Earth's 79%. Most of the remainder of Titan's atmosphere is methane. On Earth, methane is found bubbling out of marshes or swamps. Voyager 1 also determined that Titan's atmosphere is nearly 10 times as deep as Earth's. However, because Titan's gravity is weaker, the atmospheric pressure on Titan is only about 50% higher than on Earth.

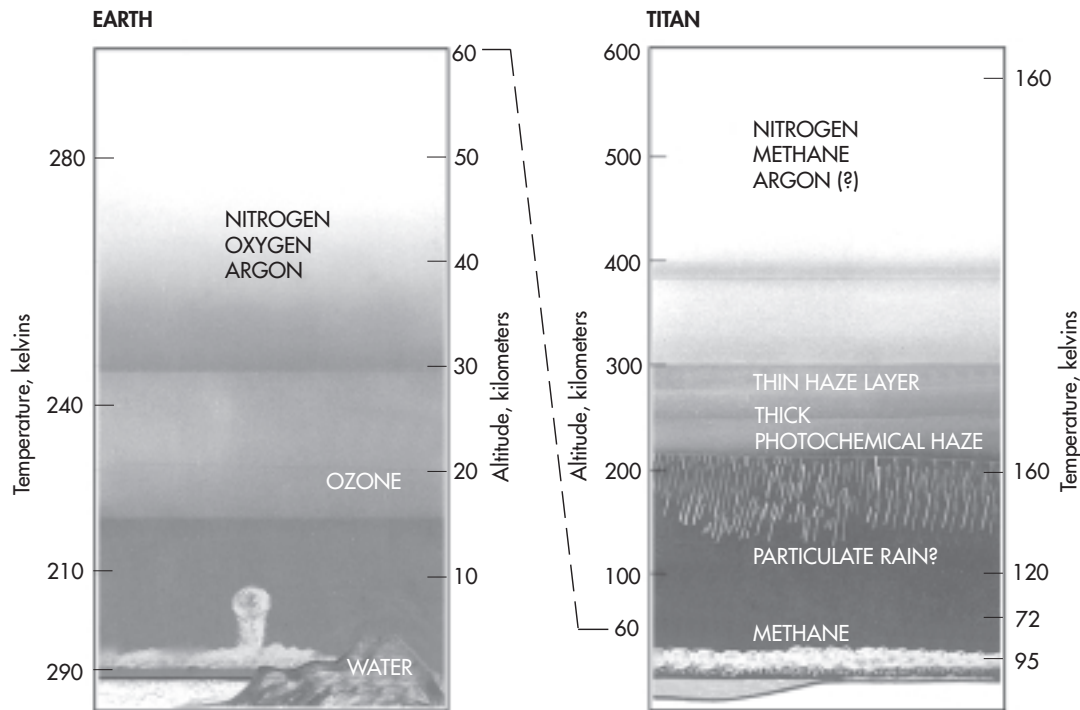
Some of Saturn's other moons may have extremely thin atmospheres, but these have not yet been detected.

#### 46. Is there water on Titan?

If there is water on Titan, it is probably frozen solid at the bottom of lakes or oceans of liquid hydrocarbons like ethane and methane. However, like most of Saturn's other moons, much of Titan's interior is probably water ice.

#### 47. Is there life on Titan?

With detectable organic compounds like methane in the atmosphere, it is very natural to wonder whether life exists there now, existed there in the past, or might yet exist there in the future. Few people believe that life as we know it currently exists on Titan, because of the extreme cold and the lack of oxygen and liquid water. However, the environment is in some ways similar to that of the early Earth, and it is possible that Titan could teach us something about how life began on Earth.



Comparison of atmospheric cross-sections of Earth and Titan. Note the difference in vertical scale — while both Earth and Titan have atmospheres composed primarily of nitrogen and the surface pressures are similar, the atmosphere of Titan is much more extended because of its low gravity.



**48. What is the weather like on Titan?**

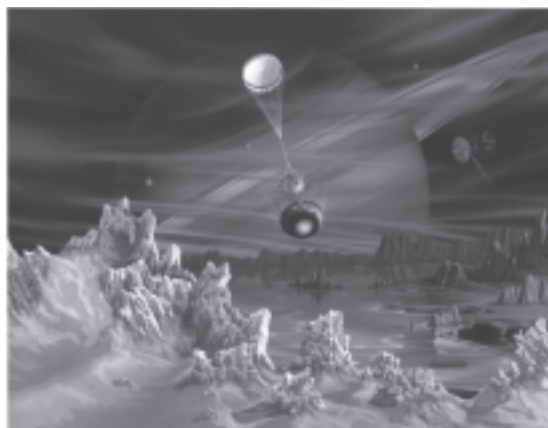
We know it is very cold on Titan, and that the atmospheric pressure at the surface is 1.5 times that of Earth, but we are not at all certain about the motions (winds and storms) in Titan's atmosphere. Titan turns very slowly, so a day on Titan is almost 16 Earth days long. There are 192 hours of dim sunlight followed by 192 hours of darkness. Temperatures probably do not change much from day to night. Titan is nearly 10 times as far from the Sun as Earth is, and temperatures there hover around  $-180^{\circ}\text{C}$  ( $-292^{\circ}\text{F}$ )!

Several of the experiments on the Huygens probe, which will descend through Titan's atmosphere during the Cassini mission, are designed to detect various aspects of Titan's weather, such as temperature, pressure, and wind speed.

**49. Cassini carries a probe that is going to Titan and not Saturn or any of the other moons. Why Titan?**

Saturn's atmosphere is mostly hydrogen and helium. While this is interesting in its own right, Titan, with its nitrogen atmosphere and mysterious surface features, is extraordinarily intriguing for several reasons. Titan and the Earth are the only two bodies in the Solar System with thick nitrogen atmospheres. Titan is the only body where cold, exotic lakes of ethane and methane are believed to exist. Liquid ethane exists between the temperatures of  $-183^{\circ}\text{C}$  ( $-297^{\circ}\text{F}$ ), where it freezes, and  $-89^{\circ}\text{C}$  ( $-128^{\circ}\text{F}$ ), where it boils. Some scientists believe Titan's environment is similar to that of Earth before life began on our planet.

Titan is a unique place, and a great way to explore it is to visit it! In previous flyby missions, Pioneer 11 visited the Saturn system in 1979, Voyager 1 visited in 1980, and Voyager 2 visited in 1981, but none of these spacecraft could see through the haze in Titan's atmo-



Artist's concept of the Huygens probe landing on Titan.

sphere to determine what the surface looked like. We now anticipate what the Cassini mission might be able to do with the cameras and instruments aboard the Huygens probe. We wonder what Titan's landscape will be like. Will it have mountains of ice? Mysterious lakes? Organic goo covering its surface?

**50. Will there be a mission that takes humans to Titan in the near future?**

None are currently planned. Because of Saturn's great distance from Earth, we would be more likely to send humans to nearer destinations, such as the Moon, Mars, or an asteroid, before sending humans to Titan.

**Observing Saturn in the Sky****51. Can I see Saturn in the sky at night?**

Yes! Saturn normally appears as an unflickering yellowish point of light about as bright or brighter than stars in the Big Dipper. From Earth's northern hemisphere, Saturn appears to the south, slowly moving along the same arc in the sky as do the Moon, the Sun, and the rest of the planets. There are always times of the year when Saturn is not visible in the night sky. This is because Earth is on the other side of the Sun from Saturn, and so Saturn is in the sky during the daytime. During the cruise phase of the Cassini mission (1997–2004), Saturn will be



best visible in the sky during the winter. You can use astronomy magazines and many World Wide Web sites to find information about locating Saturn in the night sky. See the Appendices for information on resources.

In *Appendix 3*, there is a table of information about where Saturn appears in the night sky over the course of the Cassini mission (1997–2008). At Cassini's launch date of 15 October 1997, Saturn, Venus, and Jupiter were easily visible in the night sky, but when Cassini arrives at Saturn on 1 July 2004, Saturn will not be visible in the night sky. On its way to Saturn, Cassini does two flybys of Venus, one of Earth, and one of Jupiter. (These flybys provide gravity assists to help the spacecraft reach Saturn by July 2004.) Venus was easy to see in the night sky during the Cassini flybys, and Jupiter will also be visible in the sky when Cassini passes by in December 2000. After the Sun and Moon, these two planets are the next-brightest objects in the sky.

## **52. Can I see Saturn's rings from Earth?**

You cannot see the rings with the unaided eye, but the rings are easily visible if you peer through a telescope with a magnification of 30 times or more. Such a telescope typically uses a mirror or lens several inches across to focus the light from Saturn. You can purchase a quality telescope for several hundred dollars, or build your own from kits available through catalogs. (Beware of cheap telescopes.) A larger telescope and a more powerful eyepiece would enable you to view more detail, such as some of the larger moons (which appear as small points of light near Saturn), the Cassini Division between the A and B rings, and bands in the atmosphere of Saturn.

There are times when Saturn is observable, but the orientation of Saturn's tilt is such that its rings seem to disappear. When Saturn is at a place in its orbit around the Sun where this tilt

has the north pole tipped toward the Sun, the rings are illuminated on the north (top) side. When Saturn is at a place in its orbit where this tilt has the south pole tipped toward the Sun, the rings are illuminated on the south (bottom) side. At the beginning of Saturn's summer and winter (i.e., at the solstices), when the poles are most tipped toward the Sun, the rings are most open as seen from Earth. The rings close with respect to the Sun at the beginning of Saturn's spring and autumn (i.e., the equinoxes). At these times, the poles are tipped neither toward nor away from the Sun, and the rings appear exactly edge-on, becoming nearly invisible to Earth observers for a short time. This event is called a ring-plane crossing, and it is a good time to look for Saturn's moons and to measure the thickness of the rings.

The last ring-plane crossing occurred in 1995–96. The Earth-orbiting Hubble Space Telescope, as well as telescopes all over the world, took advantage of these few days to observe Saturn from this rare perspective. Saturn ring-plane crossings occur about every 15 years, but the next two ring-plane crossings will be difficult to observe from Earth, because Saturn will be in the sky mostly during the day. Earth observers will not have another good edge-on view of Saturn until 2038–39.

## **53. What do I do if I want to see Saturn's rings, but I don't have a powerful enough telescope?**

Try to find someone who does have one. In many communities there are clubs of amateur astronomers, most of whom own their own telescopes. These clubs often hold star parties in which anyone is invited to come out and observe through the telescopes. Some universities or communities have larger observatories that hold periodic open houses for the public. Moreover, amateur and professional astronomers in your area may be willing to conduct star parties in conjunction with school open houses.



Science museums and planetariums can be a place to start for information about tracking down an opportunity to view Saturn through a telescope. National Astronomy Day, held every year in April or May, is a good time to be on the lookout for opportunities. Also, you can look in the calendar sections of magazines such as *Astronomy* or *Sky & Telescope* for regional star parties near you. The same two magazines may be useful for finding good quality, secondhand telescopes at bargain prices. See the Appendices for resource information.

**54. If I were on Saturn or Titan, could I see Earth and its Moon? Would I need a telescope?**

The astronomer Christiaan Huygens saw Saturn's moon Titan from Earth with a 17th-century telescope, using lenses a few inches across. Earth's Moon is about the size of Titan, and Earth is about twice as large as Titan, so at first glance it seems you could certainly detect Earth and its Moon from Saturn with a telescope of modest power. However, if you were to try to look at Earth from Saturn, you'd be looking almost directly at the Sun. Even though Earth and the Moon would be large enough to see in a dark nighttime sky, they would be very difficult to detect in the Sun's glare.

**55. If I were standing on Titan, how would Saturn look?**

To see Saturn, you would need to be standing on the side of Titan that always faces Saturn. But even if you were doing that, Titan's thick, hazy atmosphere would prevent you from seeing Saturn. If somehow you could see through the clouds, the rings of Saturn would stretch across about 15° of the sky. If you reach out your arm fully and spread your fingers toward the sky, the angle between your pinkie and your thumb is also about 15°. Saturn and its rings would appear almost 30 times wider in the sky than the Moon does from Earth!

## The Cassini-Huygens Mission

**56. Why are we sending a spacecraft and not people to Saturn?**

Spacecraft are robots that represent humans in space. Neither humans nor robots can survive unprotected in the dangerous environment of outer space, but humans require a greater degree of protection and safety. Robotic spacecraft like Voyager and Cassini have shields to protect them from extremes of heat and cold, from intense radiation, from the vacuum of space, and from collisions with small particles. Astronauts in the Space Shuttle also have these protections, but even so they cannot stay in space very long. The additional needs of people for long journeys — for instance, oxygen, water, food, and artificial gravity — make human space travel cost a great deal more than robotic space travel. Also, safety measures taken for human spaceflight are generally more costly than those needed for robotic space travel.

Even if humans were more easily accommodated as travelers in space, the Space Shuttle is not designed to travel out of Earth orbit. The Space Shuttle flies only about 600 km (370 mi) above Earth's surface. This is barely the distance between Los Angeles and San Francisco. By contrast, it is over 1 billion miles to Saturn from Earth. We no longer have the ready capability to send humans to Earth's Moon, let alone to a more distant planet. Time is also a consideration. Even if the Cassini spacecraft were large enough to carry humans, it would need to carry enough food, water, and oxygen for the 7-year trip to Saturn, plus several years exploring, and finally the return to Earth.

If we cannot visit the planets in person, with our own bodies, to see them with our own eyes, how can we ever hope to learn anything about





them? Robotic spacecraft offer an alternative to human spaceflight and can more easily be built to endure in the harsh environment of space.

### **57. What will the Cassini robot do?**

The Cassini spacecraft will make a 4-year scientific tour of the Saturn system. The Cassini orbiter will conduct long-term, detailed, close-up studies of Saturn, its rings, its moons, and its space environment. Cassini is the best-equipped spacecraft we have ever sent to another world.

The Cassini orbiter carries six instruments to “see” in four kinds of light (visible, infrared, ultraviolet, and radio). There are also instruments for detecting dust particles, magnetic fields, and charged particles such as protons and electrons.

The Cassini orbiter will release the Huygens probe, which will parachute through Titan’s hazy atmosphere to the surface. The Huygens probe will carry a suite of instruments to measure various properties of Titan’s atmosphere and surface. One of the probe’s instruments will make more than 1,000 images of Titan’s surface and clouds — sights never before seen by human beings!

### **58. What spacecraft have been to Saturn? How have we gathered information about Saturn up until now?**

Saturn was first visited by Pioneer 11 in 1979 and later by Voyager 1 in 1980 and Voyager 2 in 1981. These spacecraft passed through the Saturn system and made many extraordinary observations and discoveries. Scientists have also used the Hubble Space Telescope (HST), which NASA placed in orbit around Earth in 1990, to study Saturn. HST has observed storms in Saturn’s atmosphere and detailed structure in its rings. Using infrared cameras, HST has also detected large bright and dark regions deep beneath Titan’s veil of haze. Scientists don’t know yet what these features are — perhaps continents and ethane oceans?

There are many aspects of Saturn that cannot be studied or detected by remote sensing techniques such as using a telescope. For example, only a spacecraft flying within the Saturn system can directly sense Saturn’s magnetic field. Also, only from a spacecraft beyond Saturn can we look back at the night side of Saturn (or its moons) to collect data on such things as nighttime temperatures or how much sunlight is blocked by the dust in Saturn’s rings.

### **59. What will Cassini learn that we do not already know from Voyager and Hubble Space Telescope data?**

The Pioneer 11 and Voyager flybys were an initial reconnaissance of Saturn. The Hubble Space Telescope (HST) has been used to detect possible continents or other large features on Titan’s surface. Cassini is a follow-on to these missions, but instruments on the Cassini orbiter are capable of much more detailed observations of the planet, moons, and rings than either Voyager or HST. The Cassini spacecraft will also have 4 years to study the Saturn system instead of a few days as with a flyby mission like Voyager or a few hours every few months as with HST.

In addition, the Huygens probe will parachute into Titan’s atmosphere to the surface, and instruments on the probe will observe detailed properties of an atmosphere and surface that Voyager and Hubble could never have seen. Cassini’s scientific objectives cannot be completed by HST because of HST’s huge distance from Saturn and the very different instruments that HST and Cassini carry.

### **60. Why care about the Cassini mission?**

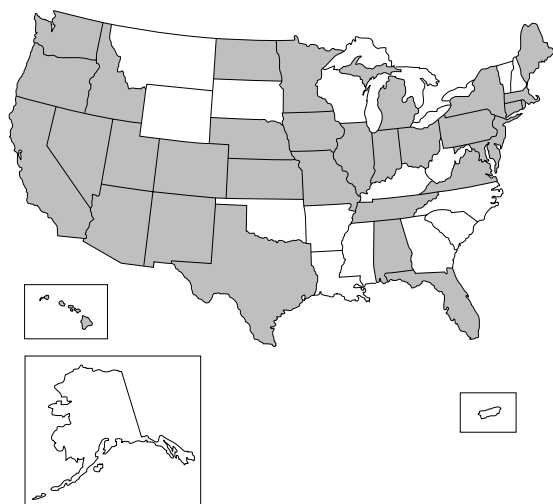
The Cassini spacecraft is a robotic ambassador for all of humanity. It is an extension of our senses to a distant, magnificent world full of mysteries. Solving some of these mysteries has the power to teach us about ourselves and our place in the Universe. The Cassini mission is an expression of our deep desire to learn — to



cross the boundary between the known and unknown. Thanks to the world's myriad possibilities for communicating what Cassini is doing, through the Internet, newspapers, television, radio, and classrooms, it is possible for all of us to share in this extraordinary adventure! How exciting it will be at last to unveil some of the mysteries of Saturn and Titan — and certainly create just as many new mysteries as well.

### 61. Why is NASA's mission to Saturn called Cassini?

The Cassini spacecraft is named after the Italian–French astronomer Jean-Dominique Cassini (or Giovanni [Gian] Domenico Cassini), who figured prominently in the earliest discoveries about the Saturn system. The astronomer Cassini made his observations of Saturn from the Paris Observatory in the late 17th century. He used a series of increasingly larger telescopes to discover four of Saturn's major moons: Iapetus, Rhea, Tethys, and Dione. In 1675, Cassini discovered that Saturn's ring was split into two parts by a division about 4,600 km (2,900 mi) wide. The gap between the two parts of the ring would become known as the Cassini Division, and the rings were given separate names.



### 62. How much does the Cassini mission cost? Who pays for it?

The total cost for the Cassini mission is about \$3.2 billion. This includes the Cassini orbiter, the Huygens probe, the Titan IV launch vehicle, and the United States' portion of mission operations and data analysis.

NASA projects are funded by the U.S. government, and thus much of Cassini is paid for by the taxpayers of the United States. The Cassini mission involves extensive international collaboration. The Huygens probe, the high-gain antenna on the Cassini orbiter, and portions of three science instruments were built in Europe, and were paid for by the people of Europe. We all have a vested interest in the success of the Cassini mission!

### 63. How long does it take to plan and carry out a mission like Cassini?

About 5 to 8 years are required from approval to launch for a sophisticated mission like Cassini. For example, Voyager 2 was approved in May 1972 and launched in August 1977. Cassini was approved in October 1989 and launched in October 1997. Cassini is the last of NASA's series of giant missions to the outer



Areas shown in gray represent the states and countries participating in the Cassini-Huygens mission.



planets of our Solar System. Smaller spacecraft are being developed and launched in 2 to 3 years. In the case of Cassini, the mission is designed to last at least 11 years after the launch: 7 years traveling to Saturn, and 4 years investigating the Saturn system.

Planning and carrying out a mission like Cassini requires several phases, which are named as follows: Phase A, Concept Study; Phase B, Definition and Preliminary Design; Phase C, Detailed Design; Phase D, Development through Launch and Instrument Check-out; and Phase E, Mission Operations and Data Analysis.

NASA defines the end of a spacecraft mission according to a specific plan, but this doesn't mean the spacecraft won't outlive that plan. For example, although the grand scientific tours of Voyager 1 and 2 are complete, flight controllers are still in touch with the two Voyager spacecraft as they hurtle away from the Solar System toward interstellar space. Astronomers hope that the Voyagers will eventually return data about the heliopause, which is the boundary between the region of space influenced by our Sun and the region of space influenced by other stars.

## The Spacecraft

### 64. How big is the Cassini spacecraft?

*Height and Width:* Cassini is the largest interplanetary spacecraft ever built by the United States. It is about the size of a school bus. The spacecraft is about two stories tall (6.8 m, or 22 ft), and 4 m (13 ft) across. It would take about 7 large adults with arms outstretched to encircle Cassini.

*Mass and Weight:* The mass of the Cassini spacecraft is 5,650 kg, which includes the Huygens probe (370 kg), the Cassini orbiter's



Cassini-Huygens in High Bay 2 at the Jet Propulsion Laboratory.

science instruments (370 kg) and 3,130 kg of propellant. Before launch, more than half of Cassini's weight was rocket propellant! At the surface of Earth, the Cassini spacecraft would weigh about 12,400 pounds, or approximately 6 tons. That's about the weight of three or four medium-sized cars!

### 65. How much wire is used in the Cassini spacecraft?

Engineers estimate that Cassini uses approximately 12 km (7.5 mi) of wiring to interconnect its electrical components.

### 66. Is the Cassini spacecraft really all covered with gold?

Much of Cassini is covered with gold-colored material, but it's not really gold. It's a multilayer fabric attached to the spacecraft like clothing to protect it from extremes of hot and cold and from impacts by small space rocks and dust in space called micrometeoroids. The fabric looks gold because the top layer is a translucent amber



material called KAPTON®, which has a coating of shiny aluminum. Together, they look like shiny gold foil.

In addition, a large portion of Cassini's protective layers are graphite-filled blanketing. This black covering protects Cassini's science instruments without interfering with their operations. For example, gold blanketing near one of Cassini's cameras might cause unwanted reflections to appear in the images it makes.



Cassini-Huygens in the test chamber at the Jet Propulsion Laboratory.

**67. Will the spacecraft use solar panels to provide power to the instruments on Cassini?**

No. Cassini uses radioisotope thermoelectric generators, or RTGs. To identify the most appropriate power source to run Cassini's instruments, radios, and computers, NASA's Jet Propulsion Laboratory conducted an in-depth analysis of the available electrical power systems, including systems that use solar energy. Cassini's instruments, radios, and computers require 600 to 700 watts. For comparison, the power demand for an average American residential home is about 1,400 watts. The challenge for Cassini's designers was that this power must be produced

reliably for many years at a distance that is 9.6 times farther from the Sun than Earth is. This power must also be supplied while keeping the spacecraft small enough and light enough to be launched from Earth.

If the Cassini spacecraft were equipped with the highest efficiency solar cells available, such as those developed by the European Space Agency, it would make the spacecraft too heavy for launch to Saturn. The resulting solar arrays would cover an area larger than two tennis courts! RTGs are thus the only feasible power system for the Cassini-Huygens mission.

The RTGs start the mission providing about 820 watts of power, and end the mission providing about 650 watts. The power output declines because RTGs generate energy from a radioactive substance called plutonium that decays over time. It is important to know that Cassini's three RTGs have nothing to do with the launch or propulsion of the spacecraft.

**68. How does an RTG work? If it involves plutonium, is it dangerous?**

An RTG uses the heat energy from a radioactive source, plutonium (Pu-238). The radioactivity generates heat, which in turn is converted to electrical energy that powers Cassini's instruments, radios, and computers.

Although plutonium is indeed a very toxic substance if breathed into the lungs, Cassini's RTGs contain a heat-resistant, ceramic form of it called plutonium dioxide. These ceramic modules are designed and packaged to prevent the formation of fine dust particles of plutonium that would be harmful if breathed into the lungs. Years of extensive safety testing and analyses have demonstrated that RTGs are extremely rugged and resistant to a release of the plutonium dioxide fuel, even in severe accident environments. In October 1968, an Atlas rocket carrying an RTG was destroyed shortly after

launch from Vandenberg Air Force Base. The plutonium-containing portions of the RTG fell into the ocean intact, and all the plutonium was recovered and reused in a subsequent mission.

### **69. How well can Cassini aim its instruments?**

Some of Cassini's instruments must be aimed precisely to gather data. They do not swivel by themselves but require the entire spacecraft to point in the desired direction. The spacecraft can point the instruments with an accuracy of about  $0.06^\circ$  (1/17th of a degree). Once pointed, the Cassini spacecraft is extremely stable.

## **The Science Instruments**

### **70. What kinds of instruments does the Cassini orbiter have? What do they do?**

In some ways, the Cassini spacecraft has senses better than our own. For example, Cassini can "see" in wavelengths of light and energy that the human eye cannot. (See the *Appendices* for an illustration of the electromagnetic spectrum.) The instruments can "feel" things about magnetic fields and tiny dust particles that no human hand could detect. The Cassini spacecraft has been designed with 18 major science instrument packages: 12 on the Cassini orbiter, and six on the Huygens probe.

Even without knowing the details of all of the instruments and the nature of what they are measuring or detecting, it is still possible to discern several things about them from their descriptions. For example, you can classify the science instruments in a way that enables you to make a comparison with the way your own senses operate. Your eyes and ears are "remote sensing" devices because you can receive information from remote objects without being in direct contact with them. Your senses of touch and taste are "direct sensing" devices. Your nose can be construed as either a remote or direct

sensing device. You can certainly smell the apple pie across the room without having your nose in direct contact with it, but the molecules carrying the scent do have to make direct contact with your sinuses. The Cassini instruments are:

#### *1. Imaging Science Subsystem (ISS)*

Makes images in visible light, and some infrared and ultraviolet light. The ISS has a camera that can take a broad, wide-angle picture and a camera that can record small areas in fine detail. Engineers anticipate that ISS will return hundreds of thousands of images of Saturn and its rings and moons! [Remote sensing / sight]

#### *2. Radio Detection and Ranging (RADAR)*

Produces maps of Titan's surface and measures the height of surface objects (like mountains and canyons) by bouncing radio signals off of Titan's surface and timing their return. This is similar to listening for the echo of your voice across a canyon to tell how wide the canyon is. Radio waves can penetrate the thick veil of haze surrounding Titan. In addition to bouncing radio waves, the RADAR instrument will listen for radio waves that Saturn or its moons may be producing. [Remote active sensing / listening to echo; Remote passive sensing / sight]

#### *3. Radio Science Subsystem (RSS)*

Uses radio antennas on Earth to observe the way radio signals from the spacecraft change as they are sent through objects, such as Titan's atmosphere or Saturn's rings. RSS uses radio receivers and transmitters at three different wavelengths. This gives detailed information on the structure of the rings and atmosphere. [Remote sensing / sight or hearing]

#### *4. Ion and Neutral Mass Spectrometer (INMS)*

Analyzes charged particles (like protons and heavier ions) and neutral particles (like atoms) near Titan and Saturn to learn more about their atmospheres. [Direct and remote sensing / smell]





5. *Visible and Infrared Mapping Spectrometer (VIMS)*

Makes pictures using visible and infrared light to learn more about the composition of moon surfaces, the rings, and the atmospheres of Saturn and Titan. VIMS also observes the sunlight and starlight that passes through the rings to learn more about ring structure. [Remote sensing / sight]

6. *Composite Infrared Spectrometer (CIRS)*

Measures the infrared light coming from an object (such as an atmosphere or moon surface) to learn more about its temperature and what it's made of. [Remote sensing / sight]

7. *Cosmic Dust Analyzer (CDA)*

Senses the size, speed, and direction of tiny dust grains near Saturn. Some of these particles are orbiting Saturn, while others may come from

other solar systems. [Direct sensing / touch or taste]

8. *Radio and Plasma Wave Science (RPWS)*

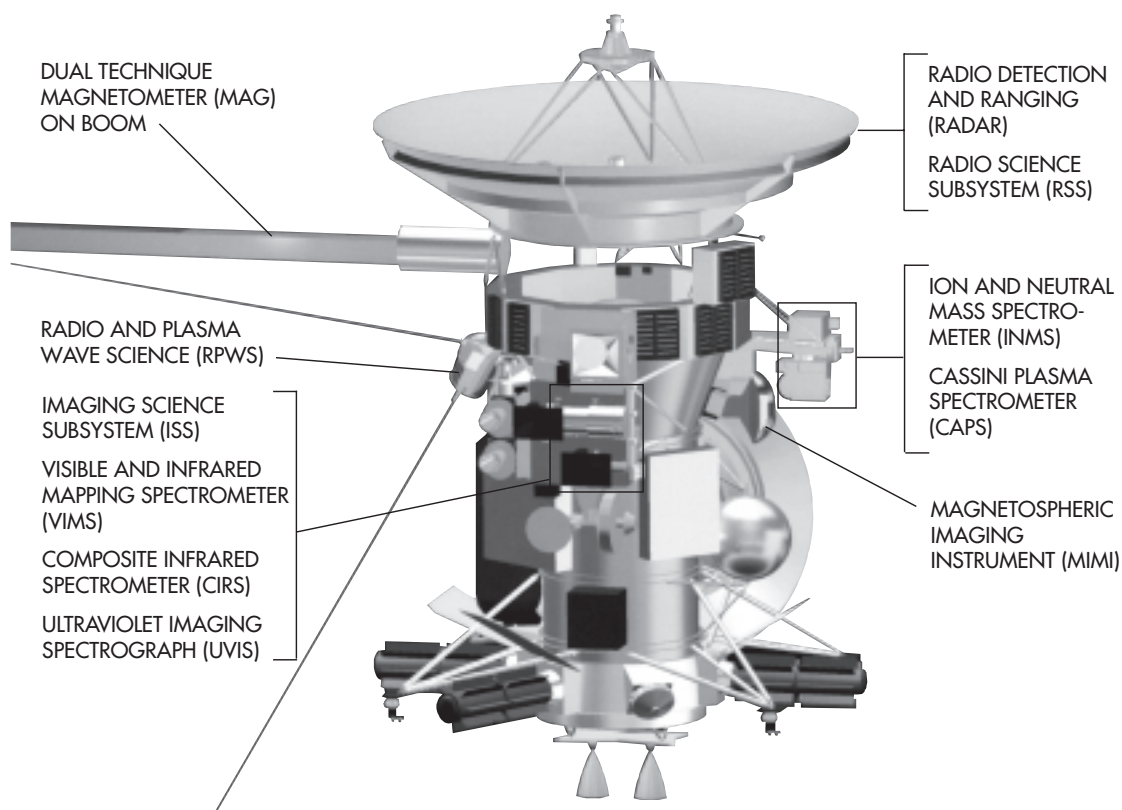
Receives and measures the radio signals coming from Saturn, including the radio waves given off by the interaction of the solar wind with Saturn and Titan. [Direct & remote sensing / many senses]

9. *Cassini Plasma Spectrometer (CAPS)*

Measures the energy and electrical charge of particles such as electrons and protons that the instrument encounters. [Direct sensing / touch, taste, smell]

10. *Ultraviolet Imaging Spectrograph (UVIS)*

Makes images of the ultraviolet light reflected off an object, such as the clouds of Saturn and/or its rings, to learn more about their structure and composition. [Remote sensing / sight]



The Cassini-Huygens spacecraft.



*11. Magnetospheric Imaging Instrument (MIMI)*

Produces images and other data about the particles trapped in Saturn's huge magnetic field, or magnetosphere. [Direct and remote sensing / sight and smell]

*12. Dual Technique Magnetometer (MAG)*

Measures the strength and direction of the magnetic field around Saturn. The magnetic fields are generated partly by the intensely hot molten core at Saturn's center. Measuring the magnetic field is one of the ways to probe the core, even though it is far too hot and deep to actually visit. [Direct and remote sensing / touch and smell]

**71. How well can the Cassini cameras see?**

Cassini's highest-resolution camera is able to see a penny, 1.5 cm (0.5 in) across, from a distance of nearly 4 km (2.5 mi).

**72. How do we know what color a planet or moon really is?**

In several of Cassini's cameras, color filters can be placed in and out of the cameras so that the detector sees only one color at a time. Each image is then transmitted to Earth. Image processing computers on Earth combine the data to recreate the image in its original colors. Our eyes work in a similar way: we can really see images just in three primary colors — red, green, and blue. Our brains combine these three colors to make other colors, such as purple, yellow, and orange.

**73. What does the Huygens probe do?**

Soon after arriving in the Saturn system, the Cassini orbiter will release the Huygens probe, which will descend into the atmosphere of Titan — Saturn's largest moon. The Huygens probe, built by the European Space Agency, carries six instruments to collect data on Titan's clouds, atmosphere, and surface.



Rendition of the Huygens probe being released above Titan.

The 320 kg probe is built a little bit like a clam: it's hard on the outside, to protect the delicate instruments on the inside. The shell must be built so it can survive the 20,000 km/hr (13,000 mi/hr) rush when it first hits the atmosphere, and the 12,000 °C (22,000 °F) temperatures as the friction from Titan's atmosphere violently slows it down.

As the 2.7 m (8.9 ft) diameter probe enters Titan's atmosphere, it will begin taking measurements in the haze layer above the cloud tops. During its 2.5-hour descent — first on a main parachute and later on a smaller “drogue” parachute — various instruments will measure the temperature, pressure, density, and composition of the atmosphere. As the Huygens probe finally breaks through the bottom layer of clouds, a camera with 11 simultaneous viewing directions will capture panoramic images of Titan's surface.

The probe's instruments will also measure properties of Titan's surface as it descends and possibly after landing — if the probe survives the impact with the surface. The probe lands relatively hard, at about 25 km/hr (15 mi/hr) and thus may not survive the landing.



#### 74. What kinds of instruments does the Huygens probe have?

The Huygens probe carries six instruments. As the probe falls through the atmosphere toward Titan's surface, some of the instruments will be busily monitoring the atmosphere by looking out windows in the probe or "sniffing" the atmosphere through holes. Other instruments will start working after the probe lands — or floats — on Titan. Radios on the probe will send back data to the Cassini orbiter. These are the instruments on the Huygens probe:

##### 1. Gas Chromatograph and Mass Spectrometer (GCMS)

Analyzes the amounts of various gases in Titan's atmosphere. It will look for organic molecules that may indicate interesting chemistry happening in Titan's atmosphere, as well as simpler molecules that will help scientists understand how Titan formed. [Direct sensing / smell]

##### 2. Aerosol Collector and Pyrolyser (ACP)

Detects the particles in Titan's thick, hazy clouds. The ACP might help detect the gases and clouds that would be spewed by any active volcanoes on Titan. [Direct sensing / smell]

##### 3. Descent Imager / Spectral Radiometer (DISR)

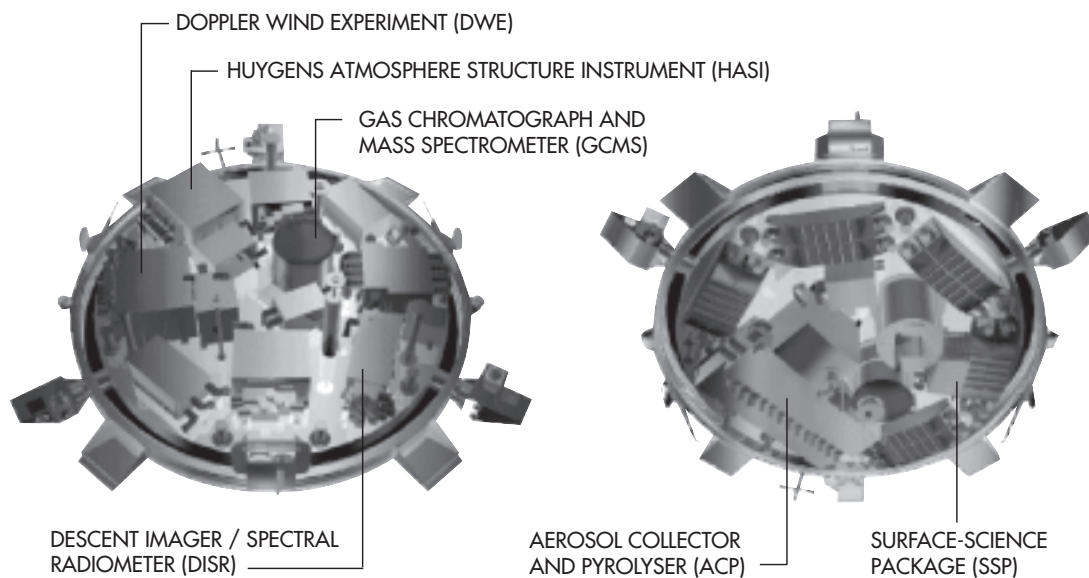
Takes pictures of Titan as the probe descends toward the surface. It also measures how Titan's clouds dim the Sun's light. This will help astronomers understand how Titan is heated by the Sun. [Remote sensing / sight]

##### 4. Huygens Atmosphere Structure Instrument (HASI)

Watches for lightning and listens for thunder in Titan's clouds. Using the probe's batteries for power, HASI will also create its own very tiny lightning bolts to explore how Titan's atmosphere interacts with electricity. [Remote sensing / sight, hearing; direct sensing / touch]

##### 5. Doppler Wind Experiment (DWE)

Measures the speeds of Titan's winds. Does Titan have huge hurricanes, or is it a relatively calm place? Maybe, like Earth, it's windy at some altitudes and more calm at others. This instrument is so sensitive that it might also measure the probe gently swinging below its parachute! [Direct sensing / touch, balance]



Instruments on the two sides of the Huygens probe.



### 6. *Surface-Science Package (SSP)*

This set of eight instruments examines the probe's landing site — whether rocks, snow, “goo,” or a lake. The SSP has detectors to measure how hard the probe hits, the temperature, the speed of sound in Titan's atmosphere, and the type of liquid in which the probe may be floating. [Direct sensing / touch, hearing, taste]

### 75. What happens to the Huygens probe after it lands on Titan?

The Huygens probe may survive landing on solid ground, ice, or even liquid. Engineers designed it to float! Many scientists theorize that Titan may be covered by lakes or oceans of methane or ethane, so the Huygens probe is designed to function whether it goes “splash” or “splat.” One instrument on board will tell us if Huygens is bobbing in liquid, and other instruments on board will tell us what that liquid is made of. If the battery-powered probe survives its landing, it will send measurements from Titan's surface until its batteries die or the Cassini orbiter flies out of radio contact — for up to 30 minutes.

After the probe runs out of battery power, it could sit wherever it lands for thousands of years. It could be caught in a landslide or an avalanche, if such phenomena occur on Titan! Huygens could wash up on some frigid Titanic beach. Or, it could land on a methane iceberg and float endlessly on an ethane sea. Wherever it lands, organic chemical compounds falling from Titan's sky will likely rain down on it. Like a car parked outdoors in Los Angeles for too long, Huygens eventually would be coated with the residue of this light brown, smog-like goo. Maybe in the far future, we will return to Titan to find out what became of the Huygens probe.

### 76. If the Huygens probe were to sink, would there be any way to send information back?

No. If the probe were to sink in cold liquid ethane, which may well be present on Titan, the

batteries and radio would not operate well, and the probe would not be able send information back to the Cassini orbiter.

## The People of the Cassini Team

### 77. How many people have worked on Cassini?

At its peak, Cassini's development involved about 4,500 people, including 3,000 in the U.S. and 1,500 in European countries. This includes engineers, scientists, and many other people at universities, research institutions, and in industry. These people worked in 32 U.S. states and 16 European countries.



A life-size model of Cassini-Huygens at JPL, with a few of the thousands of Cassini team members.

Another way of expressing the magnitude of the human effort involved is to consider the number of workyears needed to prepare Cassini for launch. One workyear is equivalent to 1 person working full-time for 1 year. Preparing the Cassini mission for launch took about 13,000 workyears of effort — almost half of what it must have taken to build the Great Pyramid of Cheops at Giza!



### 78. Who manages the Cassini Project?

The Jet Propulsion Laboratory (JPL), a division of the California Institute of Technology, manages the Cassini Project. JPL is under contract with NASA to design and fly robotic space missions. JPL is especially famous for its work in planetary science, including the Voyager missions to the outer planets and Pathfinder to Mars.

### 79. What sorts of people work on a space project like Cassini?

It is a monumental task to design, build, launch, and fly a sophisticated robot like Cassini. A great diversity of talented people are required to make it happen. Most of those who work on the Cassini project are scientists and engineers, but the project also involves people such as computer programmers, educators, machinists, electricians, secretaries, security guards, and travel agents.

### 80. How could I prepare for a career involving a space project?

In preparation for careers involving a space project, it is wise to take all the courses you can in school, especially math, science, and English courses. Go to college if possible, and pick a field of study that particularly interests you. Science and engineering are the most likely pathways to becoming involved in a space exploration project, but there are other ways as well. Seek out someone who is already in a space-related career and talk to them about what skills and attitudes they needed to be successful. It is helpful to become aware of, and begin to cultivate, some of the useful job skills that may not necessarily be taught in school. In addition to having basic mathematical skills and some sort of technical training, it is helpful to be enthusiastic, creative, able to learn new things, speak and write well, use a computer, work well in a team, and persevere through problems.





## Launch and Navigation

### 81. When was Cassini launched?

Cassini was scheduled to be launched on 6 October 1997. Several weeks before launch, engineers detected a minor problem with insulation inside the Huygens probe, and program managers rescheduled the launch for 13 October 1997. After the launch was postponed once more due to technical problems, Cassini was sent on its journey to Saturn at 4:43 in the morning on 15 October 1997, from Cape Canaveral, Florida.

### 82. Which launch vehicle did Cassini use?

A Titan IV rocket launched Cassini on its way to Saturn. Cassini has a mass of 5,650 kg, and thus it takes a mighty force to free the spacecraft from Earth's gravity. The Titan IV is the most powerful expendable launch vehicle in the US fleet. It was built by Martin Marietta — now Lockheed Martin — under contract to the U.S. Air Force.

The Titan IV did not send Cassini by itself. Rather, the Titan launched both Cassini and an upper stage rocket called a Centaur. The Centaur helped to place Cassini into a temporary orbit around Earth called a parking orbit. From there, the Centaur waited until Cassini was in the right position, and then fired its engines to propel Cassini away from Earth and toward Venus for Cassini's first gravity assist. After firing its engines, the Centaur disconnected from Cassini and the spacecraft began its long, unpowered coast through space. The Centaur was developed by General Dynamics and is the most powerful upper stage in the world.

The Titan IV launch vehicle, including the Centaur, has a mass of 4.4 million kilograms, of which about 90%, or 4 million kilograms, is fuel! The 370 kilograms of Cassini's scientific instruments seems amazingly tiny next to the mass of the launch vehicle.



The Titan IV vehicle launching Cassini.

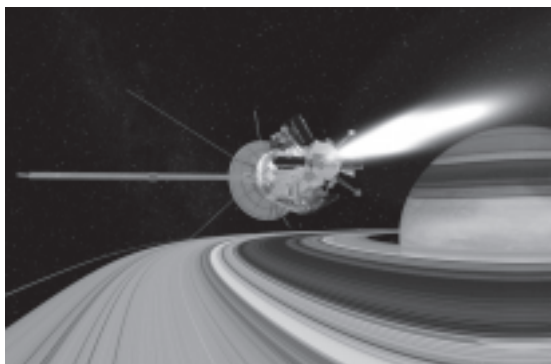
### 83. How much rocket fuel does Cassini carry in order to complete its mission at Saturn?

Cassini carries about 3,000 kilograms of fuel (or propellant). Some of the fuel will be used to direct the spacecraft's course on its way to Saturn, some will be used to slow down the spacecraft as it arrives at Saturn, and some will be used while touring the Saturn system. Well over 99% of Cassini's trip, however, will be an unpowered coast through space.

### 84. When does Cassini arrive at Saturn?

Cassini is due to arrive at Saturn on 1 July 2004. Just before Cassini's closest approach to Saturn, the spacecraft fires its engines for over an hour to slow itself down enough to be captured into orbit around Saturn. Cassini will be moving so fast — 32 km/sec (71,000 mi/hr) — that if it didn't fire its engines, it would cruise past Saturn and never return.





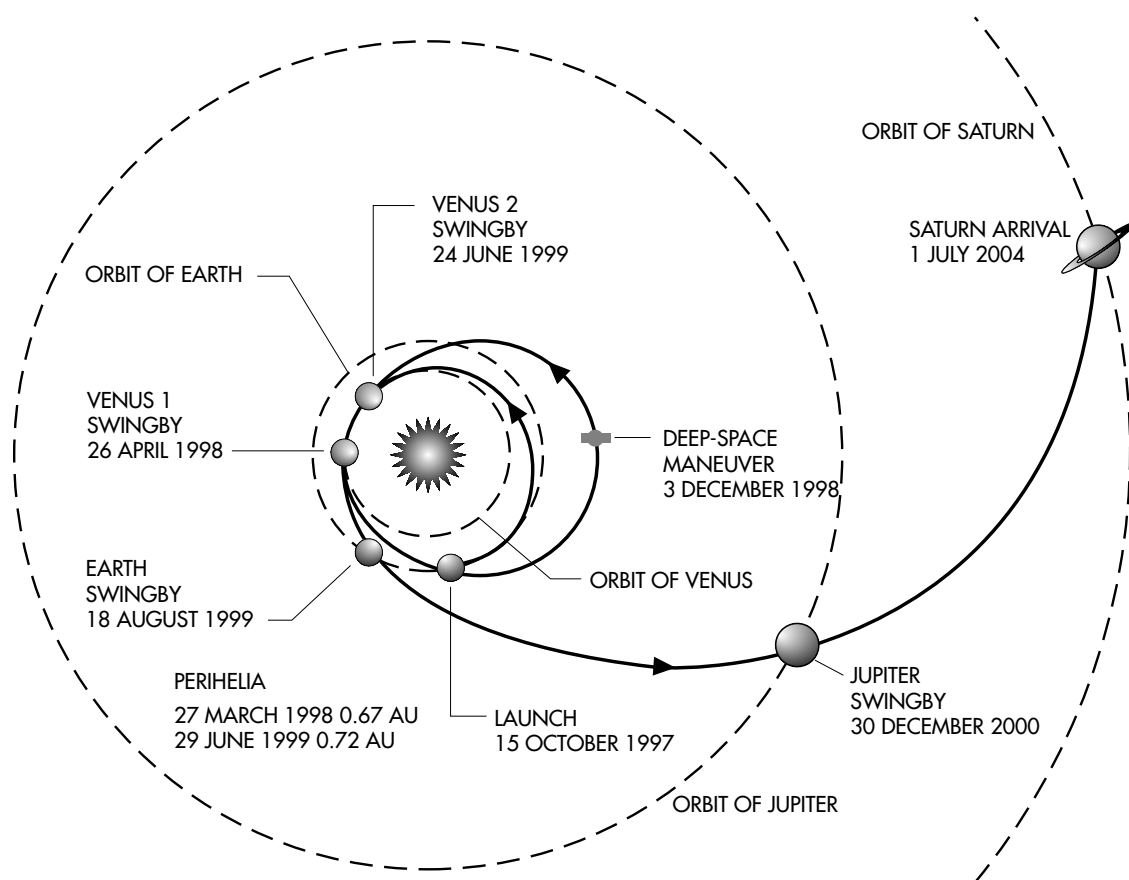
Artist's concept of Saturn orbit insertion.

### 85. How long does the Cassini mission last?

The Cassini mission is planned to last a total of 11 years: 7 years traveling from Earth to Saturn, and 4 years touring the Saturn system. However, the spacecraft could continue to send information back to Earth for many more years.

### 86. Why does it take so long to get to Saturn?

Cassini is an extremely heavy spacecraft — the heaviest interplanetary spacecraft ever launched by the United States. Because it is so heavy, it was not feasible to boost it to Saturn directly. Instead, the spacecraft was launched inward toward Venus, and has two Venus flybys, one Earth flyby, and one Jupiter flyby on the way to Saturn. Each of these flybys increases the speed of the spacecraft using a gravity assist. (This kind of flyby is sometimes called a swingby.) Cassini will eventually get to Saturn, but it takes time to speed up the spacecraft and get it going fast enough.



Cassini-Huygens' interplanetary trajectory.



**87. Couldn't we get to Saturn faster if we flew directly to Saturn instead of wrapping around other planets?**

Yes, but we would need a much more powerful launch vehicle or a much smaller spacecraft than Cassini. Given the launch technology and the mass of Cassini, using gravity assists from other planets is absolutely necessary to increase Cassini's speed. Without using gravity assists from other planets, or a larger launch vehicle, it just wouldn't be possible to get Cassini to Saturn at all, in any amount of time!

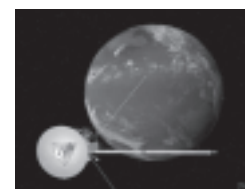
The increase in speed provided by the gravity assists from Venus, Earth, and Jupiter would otherwise require an additional 3.6 million kilograms of fuel. During Cassini's 4-year tour of Saturn, the 40 gravity assists from Titan will provide the equivalent of another 49 million kilograms of fuel. This is over 12 times as much fuel as the Titan IV launch vehicle carries!

**88. What is gravity assist?**

Gravity assist is a way of using the gravitational pull of a massive planet on a spacecraft in order to transfer momentum and energy from the planet to the spacecraft that is flying (or "swing-ing") by it. When the Voyager spacecraft flew by Jupiter, it gained 16 kilometers per second of speed relative to the Sun, at a cost of initially reducing Jupiter's orbital speed by about 30 cm (1 ft) per trillion years. Exploration of the outer planets would not be possible without gravity assist, unless we were to use smaller payloads and mightier rockets than currently exist. Cassini gained about 6 km/sec relative to the Sun at the first Venus swingby, 7 km/sec at the second Venus flyby, 6 km/sec at Earth, and will gain about 2 km/sec at Jupiter.

**89. How close does Cassini come to Earth during its flyby?**

Cassini flies about 1,170 km (720 miles) over Earth during its flyby on August 18, 1999 — higher than the Hubble Space Telescope's



Artist's concepts of the Venus flyby (left) and the Earth flyby (right).

altitude of 600 km (370 miles). Cassini swings by Jupiter at a much greater distance of almost 10 million km (6 million mi).

**90. Can we see the Cassini spacecraft from Earth during its flyby of Earth?**

Yes, but at Cassini's closest approach to Earth, it travels very fast and is just about to pass into Earth's shadow. It would be visible for about 30 seconds as a moving point of light about as bright as stars of the Big Dipper. If you were at a location on Earth near Cassini's path, Cassini would come from the west at dusk and traverse about half the sky before passing into Earth's shadow. Cassini would emerge from Earth's shadow and reappear about 24 minutes later. At this point, Cassini would be much more distant from Earth and so would appear much dimmer, although you could still see it with binoculars if you knew where to look.

**91. How far does Cassini travel from Earth to Saturn?**

The direct distance from Earth to Saturn varies from about 1.2 billion km (750 million mi) to 1.6 billion km (980 million mi), depending on where Saturn and the Earth are on their laps around the Sun. Due to its flybys of Venus, Earth, and Jupiter, Cassini actually travels more than 3 billion km (2 billion mi) to reach Saturn. Once there, Cassini travels another 1.7 billion km (1.1 billion mi) on its tour of the Saturn system.



**92. How fast does Cassini go?**

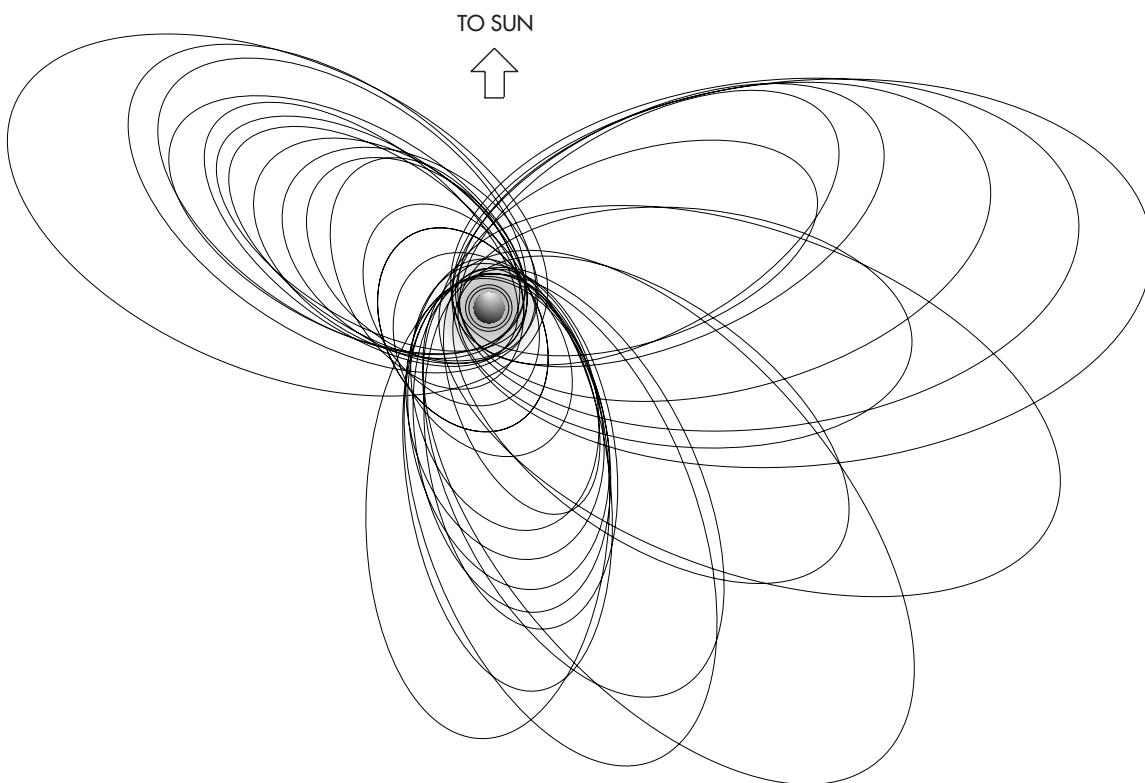
During the Cassini mission, the spacecraft reaches relative speeds of 13 km/sec (or about 29,000 mi/hr) flying by Venus (equivalent to flying from Los Angeles to Boston in under 5 minutes!), and 19 km/sec (43,000 mi/hr) flying by Earth. While cruising to Saturn, Cassini's speed is as high as 32 km/sec (71,000 mi/hr). At this speed, even the gravity of Saturn is not enough to capture it — Cassini must fire its engines to slow down at Saturn, or it would continue on past the planet and never return.

**93. How close does Cassini fly to Saturn's cloudtops?**

Upon reaching Saturn, Cassini swings close to the planet, to an altitude only one-sixth the diameter of Saturn itself — about 20,000 km (12,000 mi). This begins the first of more than 70 orbits during its 4-year mission, and it's the closest that Cassini ever gets to the planet.

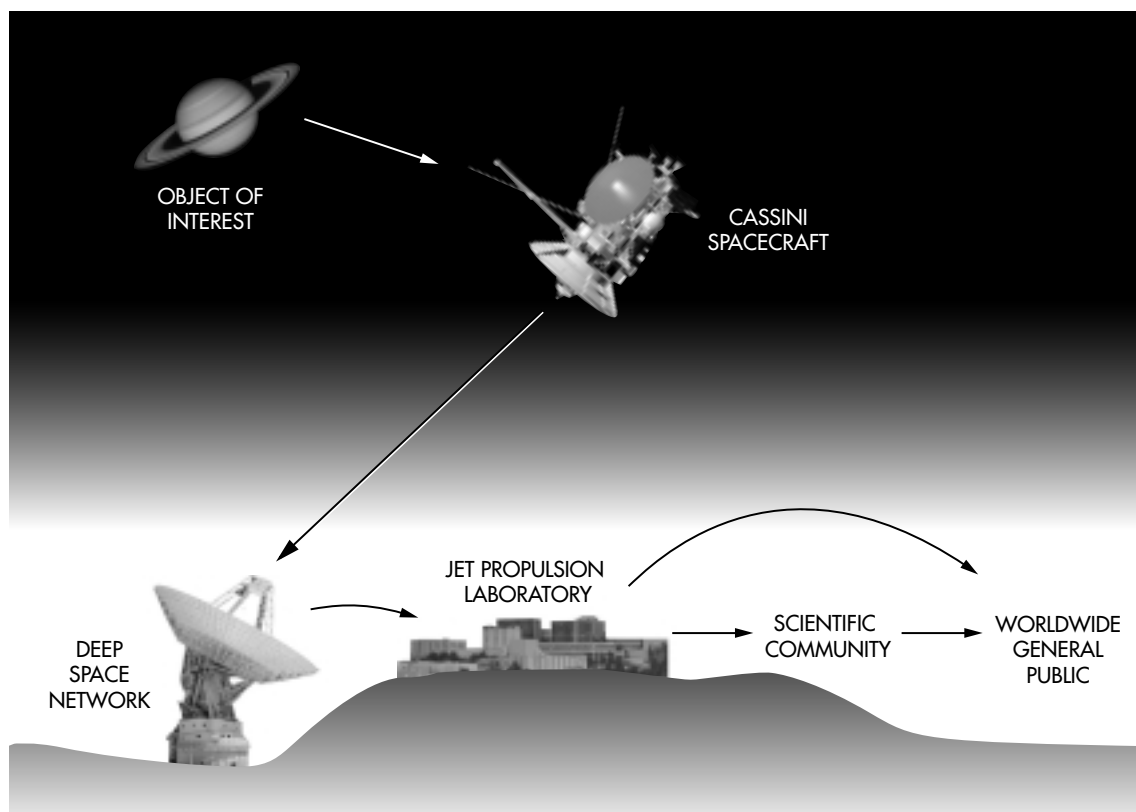
**94. What happens to Cassini after it completes the Saturn tour?**

After completing its tour, the spacecraft will continue orbiting Saturn. If all goes well during the mission, there should be enough attitude-control propellant and electrical power for the spacecraft to continue to relay data back to Earth for many years (just as Magellan did and the two Voyagers still do). However, budget constraints may limit how long NASA is able to operate the spacecraft after the end of the mission in 2008. Cassini will continue to orbit Saturn until the spacecraft runs out of propellant. Before it runs out of propellant, flight controllers will probably place Cassini in an orbit that minimizes its chances of colliding with any of the moons for a long time.



A sample Saturn orbital tour. The view is from above Saturn's north pole. This type of diagram is called a petal plot because each orbit resembles the petal of a flower. The range of orbit orientations allows a detailed survey of Saturn's magnetosphere and atmosphere.





Data flow from Saturn to Cassini to Earth.

## Communications and Science Data

### 95. How long does it take for a radio signal to travel between Earth and Saturn?

A signal takes between 70 and 90 minutes to reach Earth from Saturn. The exact time depends on the ever-changing locations of Earth and Saturn in their orbital laps around the Sun. Radio waves travel at the speed of light, or 300,000 km/sec (186,000 mi/sec).

### 96. Has anything been learned from the failure of the high-gain antenna on the Galileo spacecraft which has altered the design of Cassini's high-gain antenna?

The Galileo spacecraft's high-gain (or main) antenna was designed to unfurl itself like an umbrella while in flight to Jupiter. When flight controllers commanded it to open, it opened partially but not enough for it to be of use transmitting data between the spacecraft and the ground. The Cassini mission had already

planned to use a fixed antenna before the failure of Galileo's folding antenna. The Cassini high-gain antenna, which was provided by the Italian Space Agency, has no moving parts. The failure of Galileo's antenna triggered an intense analysis of the Cassini spacecraft to avoid other types of mechanical failures.

### 97. How much power do Cassini's radio transmitters put out?

Cassini's radio transmitters send out about 20 watts of power — about the same amount of power it takes to operate a refrigerator's light bulb.

### 98. What is the Deep Space Network?

The Deep Space Network (DSN) is a collection of huge, dish-shaped radio antennas distributed around the world that send and receive messages to and from spacecraft like Cassini.







If you could place one of NASA's 70-m Deep Space Network antennas inside the Rose Bowl in Pasadena, California, it would look like this.

Cassini will regularly use the Deep Space Network's largest antennas, which are 70 m (230 ft) in diameter — nearly the size of a football field. The DSN's large radio dishes must be pointed to within a small fraction of a degree of a spacecraft's location to be able to communicate with it.

**99. What if something goes wrong with the spacecraft? Do we have to wait an hour to learn about it?**

Yes, we would have to wait to learn about a problem, but Cassini might be able to take care of itself in the meantime. Much planning has been done for times when things don't go as planned. Many of Cassini's parts have backups that can be activated from Earth, or in some cases turned on automatically by the spacecraft. For example, Cassini has two radio receivers. If one should fail, the spacecraft's computers would realize that they haven't heard from Earth recently, and automatically switch to the backup receiver to listen for further instructions. Cassini's capabilities for detecting and handling problems by itself are collectively called "fault protection."

**100. How much science data will Cassini return?**

On a busy day at Saturn, Cassini could transmit up to 500 megabytes (500,000,000 bytes, or about a CD-ROM's worth) of information to Earth. More than 300 gigabytes of science data will be sent back to Earth during the mission. This would fill more than 400 CD-ROMs — a stack of CDs that would be higher than 4 m (13 ft). It is also about the amount of information in 2,400 sets of the Encyclopedia Britannica.

**101. How many pictures will be sent back from Cassini-Huygens?**

Engineers estimate that the Cassini mission will return as many as a million images of Saturn, the rings, Titan, and the other moons. This includes more than a thousand images taken by the Huygens probe of scenes never before seen by humans.

