www.astrosociety.org/uitc

No. 40 - Fall 1997

Lord of the Rings

Terence Dickinson
SkyNews

It would be the ultimate backpacking trip: an exploration of Saturn's rings. The astronauts squeeze into their space suits, strap on their rocket-powered backpacks, and load their cameras. Their spaceship brings them within a few kilometers of the rings. So long as the ship remains in a circular orbit, its speed is identical to that of the chunks of ice and rock which make up the rings. A collision with any ring material under these conditions is just a gentle nudge.

Stepping outside, the backpackers -- using brief rocket bursts -- slowly glide toward the glittering golden plain. The explorers touch down on a large boulder, and in one smooth push of the foot, propels themselves onto the next big piece. In between this slow-motion ballet toe-step, the explorers feel the blizzard of tiny particles gently bouncing off the front of their space suits.

Floating in the silvery gravel is intoxicating. The partly hidden Sun glinting off the field of ring chunks, the gentle gravitational symphony of collective motion that carries both chunks and explorers safely around the planet, the feeling of being surrounded yet freely floating -- all disguise the fact that everything is whirling around Saturn at tens of thousands of kilometers per hour.

Jewel of the Solar System

You don't have to travel millions of kilometers to visit Saturn. It comes to you. Of all the celestial sights available to backyard telescopes, only Saturn and the Moon are sure to elicit an exclamation of delight from those who have never looked through a telescope before. And one look is seldom enough. No photograph or description can duplicate the beauty of the colossal ringed planet floating against the black velvet of the night sky.

Dark side of the ringed planet. This is most people's favorite picture of Saturn. With the Sun off to the right, Saturn casts a shadow on its rings; its daytime hemisphere looks like a crescent. To see a planet or moon as a crescent, you need to be looking from the side -- a perspective on Saturn which Voyaer 1 achieved in 1980, but which is impossible from Earth. Photo courtesy of NASA JPL.

People have been watching Saturn for millennia, but Galileo Galilei was the first to point a telescope at the planet and see its rings. From his discovery, in 1610, until the 19th century, astronomers debated whether Saturn's rings were a solid disc or a swarm of objects. In a telescope, the rings look solid, yet Saturn's gravity should tear a solid structure apart. American astronomer James Edward Keeler resolved the dilemma in 1895. Using a spectroscope to study sunlight reflected off different parts of the rings, he found that they do not all move at the same speed, as they would if they were solid. Instead, the parts closest to Saturn are moving faster than the parts farther out. Keeler concluded that the rings must consist of individual objects revolving around Saturn just like tiny moonlets.

These objects range from tiny crystals, like those in an ice fog, to flying icebergs. Each has its own orbit about Saturn, but occasionally jostles its neighbors. The gentle collisions gradually grind down the larger particles. Meanwhile, the smallest particles tend to stick to one another and create larger clumps. These competing actions have established an equilibrium of sizes. For every house-sized boulder, there are a million baseball-sized chunks and trillions of sand-sized grains.

In the denser rings, the baseball-sized particles are separated by a meter or so; the house-sized ones are kilometers apart. In fact, most of the rings are empty space. If they could be melted and refrozen as a solid body, they would be a solid disc less than 2 feet thick.

The rings are enormous. From one edge to the other, they span a distance equivalent to two-thirds of the gulf between Earth and the Moon. Yet the ring particles seldom stray more than a few hundred meters from a perfectly flat plane, making the rings the height of a 30-story building. If the rings were the size of a football field, they would be paper-thin.

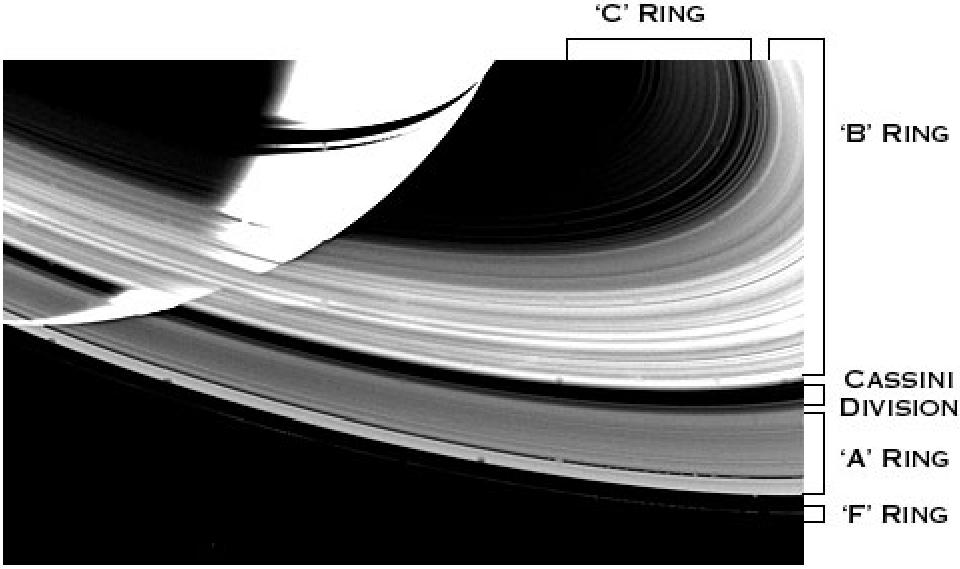
The reason why the rings are so flat -- rather than a random haze -- has to do with Saturn itself. Saturn is the least dense of the gaseous giant planets, yet a day on Saturn is only 11 hours long. This rapid rotation has bulged the planet at the equator and compressed it at the poles. As a result, there is more material at the equator, so the gravity is stronger there. A body orbiting Saturn feels a greater gravitational pull as it passes over the equator, compared with the poles. Over time, this difference distorts the orbits of the ring particles, causing them to collide and settle into a circular orbit above the equator.

Although astronomers are still trying to determine exactly where the rings came from, they think a collision, either between two of Saturn's moons or between a moon and a comet, blasted debris into orbit around the planet. The debris became the rings; it could not regroup into a moon because, near the planet, gravity rips large objects to shreds. Some scientists think the rings are less than a billion years old -- fairly young by astronomical standards -- while others think they date back to the early days of the solar system.

Lord of the Rings

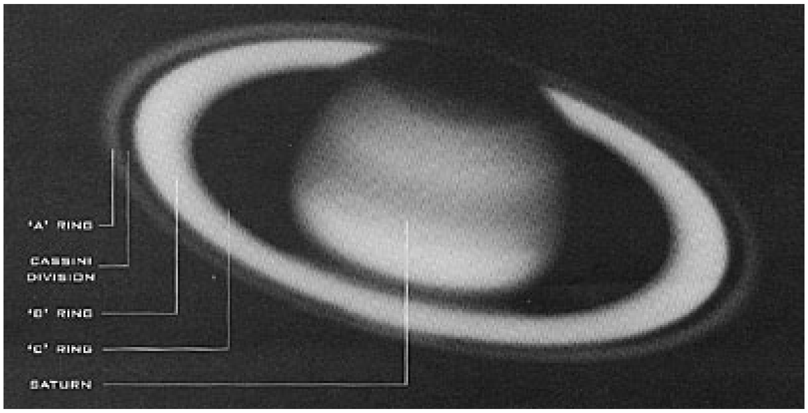
Know Your ABCs

Even the most modest telescope reveals the beauty of Saturn's rings. A 60-millimeter (3-inch) refractor at 50-power will clearly show them. [For details on observing the rings, see "Running Rings Around a Planet," *Mercury*, September/October 1996, p. 9.]



Eerie rings. This is, in effect, a blow-up of the photo above. The black stripe in the outer part of the 'A' ring is the Encke division. The white stripe just outside the 'A' ring is the infamous 'F' ring, discovered by the Pioneer 11 space probe in 1979. 'F' might as well stand for "flummox", because unlike other rings, which are generally smooth and curved, the 'F' ring has lumps, knots, and kinks -- perhaps due to electromagnetic forces and the influence of little moonlets. Photo courtesy of NASA JPL.

From Earth, we can see the three main rings. Ring 'A', the outer band, and 'B', the widest and brightest section, are both visible in any telescope (see photo below). They are separated by the Cassini division, a broad gap that may seem narrow, but is about as wide as North America. The division looks as black as the sky, but does contain some particles. The gap is caused by the gravity of Saturn's moon Mimas. Ring particles orbiting in the gap have what is called a "resonance" with Mimas -- they complete exactly two orbits for every one Mimas makes. On each orbit, the gravity of Mimas pulls the particles a slight amount, and over time these nudges accumulate, largely clearing out the area.



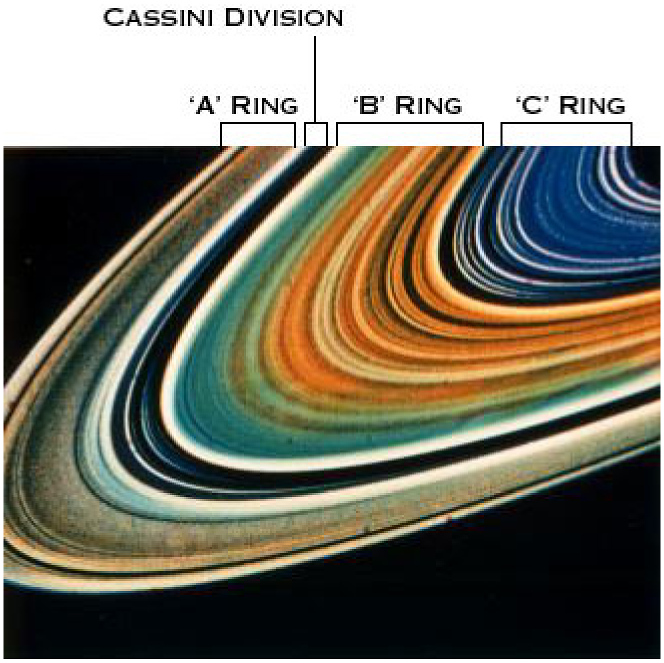
With this ring I thee amaze. From the ground, a telescope can make out the basic structure of Saturn and its rings. The dim 'C' ring barely appears on this image, but is easier to spot on other ground-based images. From above, the rings would look circular, but from our viewing angle they are tilted. Photo courtesy of Lick Observatory.

Ring 'C', the innermost of the main rings, is so dim that it takes a large telescope to reveal it. Also known as the "crepe ring," ring 'C' is a phantomlike structure extending about halfway toward the planet from the inner edge of ring 'B'.

Conveniently for observers on Earth, the rings are tipped by Saturn's 27-degree tilt. Because the rings ride exactly above Saturn's equator, we would only ever see their edge if Saturn had a tilt of, say, 3 degrees, as Jupiter does. As it is, we are treated to a majestic cycle of ring visibility during Saturn's 29-year orbit of the Sun. The current cycle began with the rings seen edge-on last year. They will be fully open with the south side presented to our view in 2002, then edge-on again in 2009. The north side of the rings is at maximum tilt toward us in 2016, then edge-on in 2025.

Saturn itself is not wobbling around to create these changes. Like Earth, Saturn's rotation axis is essentially fixed in space over the centuries. What we are seeing is Saturn's seasons -- first spring and summer in the southern hemisphere, then spring and summer in the northern hemisphere [see "To Every Season There is a Reason," *The Universe in the Classroom*, winter/spring 1995].

As smooth and simple as the rings seem from Earth, they look much more complicated close-up. When the twin *Voyager* spacecraft flew by Saturn in the early 1980s, they discovered that the main rings consist of hundreds of ringlets (see photo below). Many of gaps between these ringlets are generated in much the same way as the Cassini division [see "Rally Around the Ring," *Mercury*, March/April 1995].



Looking groovy. If you still remember what the grooves on a phonograph record look like, then Saturn's rings will remind you of them. The rings consist of hundreds of narrow ringlets and gaps, as shown in this Voyager 2 image, which looks down on the rings at an angle. Most of the ringlets are several hundred kilometers wide. They, in turn, consist of trains of rocks and icy chunks in orbit about Saturn. Photo courtesy of NASA JPL.

A few years before the *Voyager* flybys, astronomers discovered that the other giant planets -- Jupiter, Uranus, and Neptune -- also have rings, though they are pale facades compared to the sparkling beauty of Saturn's adornment. If any one of these other ring systems surrounded Saturn, it would be almost invisible to us on Earth. The rings of Jupiter are dull and diffuse, those of Uranus and Neptune downright dark -- among the least reflective objects in the solar system. On the other hand, those other ring systems have their own subtle beauty. Uranus's rings, for example, are slender and oval in shape, which indicates that they are engaged in a complex gravitational dance with nearby moonlets.

Once upon a time, Earth might have had a ring, too. But without nearby moonlets to resupply the ring with new material, the ring would have disappeared slowly but steadily as material fell into our atmosphere or was blown out into space.

Blandness is Skin-Deep

Though Saturn's rings steal the show, the planet and its moons also fascinate astronomers. Saturn is almost identical to Jupiter in overall structure -- a giant globe of gas, mostly hydrogen and helium. Its cream-colored surface is but the visible skin of an atmosphere that, deep down, becomes dense enough to crush any astronaut foolish enough to parachute in. Because Saturn is so remote from the Sun's warmth, a high-altitude haze veils the planet, giving it a far blander appearance than Jupiter's. The highly reflective chunks of water ice which make up the rings outshine the ammonia clouds that top Saturn's atmosphere.

There is much yet to be learned about Saturn, which is why the *Cassini* spacecraft is now on its way there. Built by an American and European partnership and launched in October, *Cassini* is due to reach Saturn in 2004 and swing into orbit for a four-year tour [see "Saturn and Titan on the Eve of Cassini-Huygens," *Mercury*, September/October 1997]. Soon after it arrives, it will drop a set of scientific instruments into the atmosphere of Titan, Saturn's largest moon.

Titan is the only satellite in the solar system with a substantial atmosphere. In many ways, it is a deep-freeze version of Earth. Its air is much like ours: primarily nitrogen, with almost the same surface pressure, but with the rather brisk temperature of -180 degrees Celsius (-290 degrees Fahrenheit). High up in the atmosphere are thick, orangish clouds -- a smog produced by natural chemical reactions of methane and other compounds. These clouds cloak Titan's surface, so no one knows for sure what is down there. It is probably a mix of methane and water-ice glaciers, with lakes of liquid ethane, a form of liquid natural gas. Given the Earth-like atmosphere and carbon-based compounds, some scientists think living organisms, or lifelike chemical reactions, might lurk on the surface.

Cassini will take tens of thousands of close-up images of Saturn, its rings, and moons. It's safe to say that the exploration of Saturn has just begun.

TERENCE DICKINSON is the editor of *SkyNews*, the astronomy magazine of Canada's National Museum of Science and Technology. Since he got interested in astronomy -- he says a meteor did it, at age 5 -- he has written a dozen books, produced a weekly astronomy column for the *Toronto Star*, worked at planetariums in Toronto and Rochester, appeared on numerous radio and TV shows, and served as editor of *Astronomy* magazine. Last year Dickinson received the ASP's Klumpke-Roberts Award for his efforts to bring astronomy to the public. His email address is arcturus@istar.ca.

Classroom Activity: A Grapefruit Saturn

Lynda Filip
John Percy
University of Toronto

Objectives

- To construct a scale model of Saturn and its rings
- To explain how shadows on Saturn are formed
- To discover how light travels
- To calculate sizes for the scale model from real data (optional)

Preconceptions

It is crucial that students first understand that light is an entity that travels through space outward from its source. Many 10- and 11-year-old students think of light as a source (light bulb, stars), an effect (bright patches on the ground) or a state (brightness). These are all associated with light, but they are not the light itself.

To determine what your students think about the behavior of light, ask these questions before the activity:

1. What is light?

2. Where is light in this room?

3. How does light from the Sun get to Saturn?

It also helps for students to draw a picture of how light from a lamp causes a shadow.

Materials

- photocopies of Voyager image of Saturn
- photocopies of handout (click here for printable pdf handout)
- blank acetates or transparencies
- scissors
- paint (pearl, beige, pale yellow, cream-colored, gold, or silver)
- glitter paint, glitter glue, or loose glitter (optional)
- paint brushes (half-inch, 1-centimeter)
- toothpicks (preferably clear plastic)
- flashlight or other point-like light source

Grade Level

This activity is designed for students in grades 7 to 9, but can be simplified for grades 5 or 6. Younger students can eyeball the distances, rather than calculate them.

Summary

Students will construct a scale model of Saturn; use it to explain a Voyager image of Saturn's shadow on its rings; and, by trial and error, discover that light moves through space in straight lines.

Instructions

Part 1: Pre-Activity Announcement

During the previous class, announce, mysteriously, that everyone will need to bring in a drawing compass, pencil, ruler, calculator, flashlight, and...grapefruit. The grapefruit should have a circumference of about 11 1/4 inches (28.5 centimeters). When they go shopping, students can measure circumference by taking an 11 1/4-inch piece of string to the store and wrapping the string around the grapefruits on display. Students can cut the strings in class and take them home. (From now on, we will use metric units, as astronomers do.)

Part 2: Discussion of Saturn

Hand out photocopies of the image that the Voyager 1 space probe took after its flyby of Saturn. It shows the planet at an angle impossible to see from Earth. Have your students write a brief, but detailed, description of what they see. Draw a picture of Saturn on the board or overhead and ask a few students to share their observations while you label the following: lit side, dark side, 'A', 'B', and 'C' rings, and so-called Cassini division. If the students correctly identify the ring's shadow on the planet and the planet's shadow on the rings, label these as well. If not, leave these features as a mystery that students will solve by constructing their own Saturns.

You can also show a video clip from the opening of Star Trek: Voyager, in which the starship glides along the icy rings of a planet, or a NASA animation of the Voyager flyby of Saturn.

Part 3: Constructing the Model

1. Break into groups of 4 or 5. Have two materials-managers from each group pick up handouts, transparencies, scissors, paint, brushes, and toothpicks for the whole group. Have each student tape his or her transparency to a blank piece of paper in order to make their pencil markings more visible.

2. For older students: Go over the handout. Explain that they will have to calculate the widths of the rings of their grapefruit Saturn so that their models will be proportioned correctly.The proportionality equation is:

$$\frac{\text{radius of Saturn}}{\text{width of ring}} = \frac{\text{radius of grapefruit}}{\text{width of model ring}}$$

So, the width of the model ring is:

$$\frac{\text{radius of grapefruit} \times \text{width of ring}}{\text{radius of Saturn}}$$

The radius of Saturn is 60,330 kilometers. The radius of the 28.5-centimeter grapefruit is 4.5 centimeters. For larger or smaller grapefruits, use the formula:

$$\text{radius} = \text{circumference} \div 2 \div 3.1416.$$

For younger students: Write the precalculated widths of Saturn's rings on the board (see chart below) and have students copy the numbers onto their handouts. These figures apply to the 28.5-centimeter grapefruit:

Feature	Scaled width (cm)
'A' ring	1.1
Cassini division	0.3

'B' ring	1.9
'C' ring	1.3
Space between Saturn and 'C' ring	1.0

3. Students must now figure out the sizes of the circles they will draw with their compasses. For example:

- radius of first circle = radius of grapefruit + width of space between grapefruit and 'C' ring = 4.5 + 1.0 = 5.5 centimeters
- radius of second circle = radius of first circle + width of 'C' ring = 5.5 + 1.3 centimeters

4. Advise your students to place their compass points in the very center of the transparency and proceed to draw the five concentric circles (see handout). They should then cut away the transparency on the outside and inside.

5. Next, students paint their rings. They should place each ring on a scrap piece of paper. The 'C' and 'A' rings need one thin coat of paint, and the 'B' ring a very thick coat of paint. Sprinkle glitter on the rings before the paint dries. If you are using glitter paint or glitter glue, let the first coat dry for 20 minutes and then add another.

6. Finally, they can assemble their models. Stick four toothpicks equidistant around the "equator" of the grapefruit. Then place the ring system on the toothpicks. To prevent the ring from falling off, use glue, staples, or small pieces of folded plastic to hold it in place.

Part 4: Casting Shadows

This part of the activity may be done in the next class period.

1. Draw students' attention to the *Voyager* image of Saturn. Find out what they think is going on by asking:

- What is the large black area? (Answer: the shadow of the planet on its rings)
- What is the thin black line on the planet? (shadow of rings on the planet)
- Where is the Sun? (towards the lit side)
- Where is Earth? (towards the lit side) Why? (Earth is much closer to the Sun than Saturn, so Earth is always in the general direction of the Sun if you are standing on Saturn)
- What causes shadows? What causes the shadows in this image? For these two questions, brainstorm answers and then tell the class they will determine the best answer by experimenting with their grapefruits.

2. Turn off all the lights in the classroom and cover the windows. Break into groups of 2 to 4. Each group should have one flashlight, which represents the Sun. Have students explore different flashlight and grapefruit positions, recording what happens. Challenge them to recreate the shadow in the Voyager image by tilting their models and positioning them relative to the flashlight.

3. Students should find that:
(i) Only a slight tilt of the face of Saturn towards the Sun will produce a shadow as in the *Voyage*r image. What does this tell them about Saturn? (Answer: It is tilted in its orbit around the Sun.)
(ii) As they raise or lower the flashlight relative to the grapefruit, the shadow of Saturn on its rings changes. When the flashlight is high, the shadow is a semicircle falling on the rings. As the flashlight is lowered, the shadow stretches out until it no longer appears curved, but straight -- as in the *Voyager* image. Have your students hold a piece of paper perpendicular to the planet as an extension of the ring system. This will catch the top part of the shadow, showing it is actually still curved.
(iii) When the shadow of the planet on the rings is straight, as in the *Voyager* image, it falls on the equator.

4. Your students may enjoy making shadows of Saturn on the walls. Point out that the shadows of Saturn on its rings and on the classroom wall are caused by the same property of light -- the fact it travels in straight lines.

5. Have the groups discuss and answer the following question: What causes the shadows? Suggest that the groups make a series of drawings that show the shadow for different flashlight heights. The drawings should also show the light rays from the flashlight.

Light usually travels in perfectly straight lines. For this reason, when sunlight reaches Saturn, it doesn't curve -- it either hits the planet or misses. If you look behind the planet, the area where light is blocked by the planet is dark (the shadow).

6. After a few groups have shared their answers, ask: What does the shape of the shadows tell you about the path of light? (It is a straight line.)

Extensions

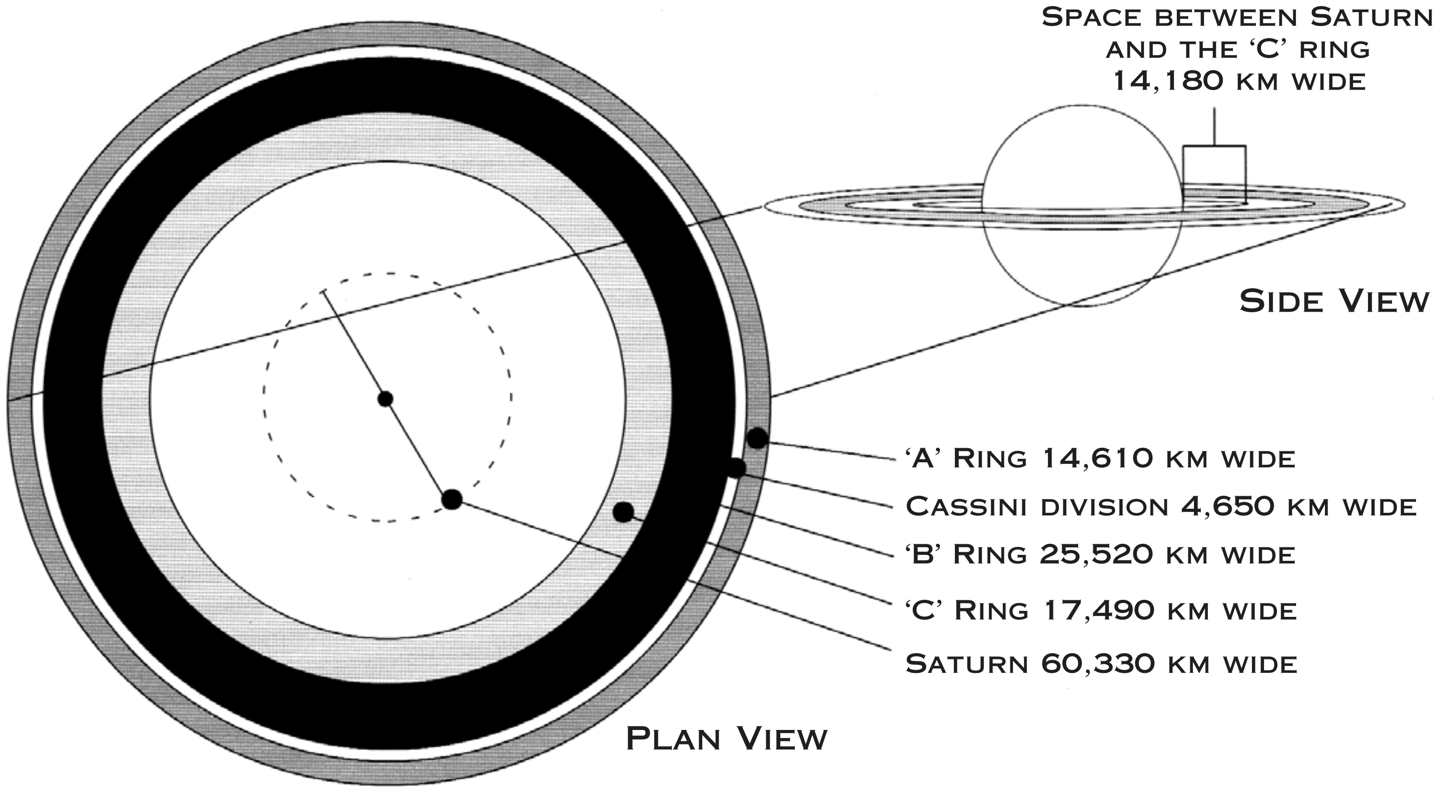
1. How long does it take for sunlight to reach Saturn? Light travels at 300,000 kilometers per second and Saturn is 1,427,000,000 kilometers from the Sun. (Answer: 1.3 hours.)

2. To find Saturn in the night sky, students can consult a star chart in the newspaper or magazines such as *Astronomy, Sky & Telescope,* or *Mercury.* The planet is often, but not always, visible at night.

3. Students can write a report about the *Voyager* missions to Saturn in the early 1980s. They can compare the trajectory of *Voyager 1* with that of *Voyager 2* and select the most important discoveries. They can also read up on the Cassini spacecraft that was launched on Oct. 15, 1997, and is due to arrive at Saturn in 2004. The November *Astronomy* and September/October *Mercury* had cover stories on *Cassini.*

LYNDA FILIP is an education graduate of the University of Toronto. She is now teaching in Chapel Hill, N.C. JOHN R. PERCY is an astronomy professor at the University of Toronto. His email address is jpercy@erin.utoronto.ca.

Making Saturn's Rings



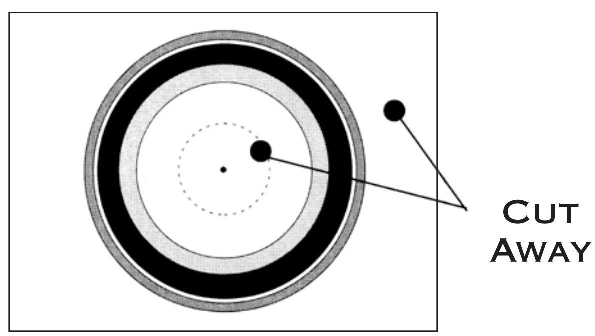
1 To draw your model's rings with the same proportions as Saturn's actual rings, you must scale down the size of the rings from kilometers to centimeters. Your teacher will either ask you to calculate the scaled size of Saturn's rings or give the numbers to you.

Name of feature	Actual width km	Scaled width cm
'A' ring	14,610	
Cassini division	4,650	
'B' ring	25,520	
'C' ring	17,490	
Space between Saturn and 'C'ring	14,180	↗ **1.0** example

3 Paint your rings to look like Saturn's rings as follows:

- The 'A' ring is translucent, so paint it lightly
- The Cassini division is almost empty, so don't paint it at all.
- The 'B' ring is almost opaque, so paint it heavily.
- The 'C' ring is translucent, so paint it lightly, like the 'A' ring.

2 Use the scaled widths in the chart to draw Saturn's rings on a transparency with a pencil and compass. They should look like this when your are finished:



As you can see from this diagram, you must draw five circles. The radius of the first (smallest) circle will be the radius of your grapefruit Saturn (4.5 centimeters) plus the space between Saturn and the 'C' Ring (1.0 centimeter). So, set your compass to draw a circle of radius 5.5 centimeters. The radius of the second circle will be the radius of the first circle (5.5 centimeters) plus the scaled width for the 'C' Ring. What is the radius of the third circle?