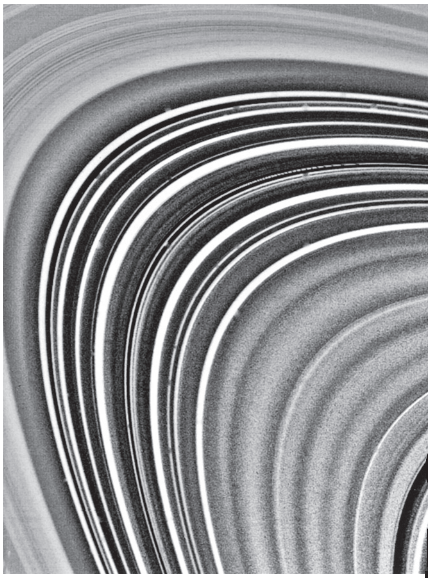
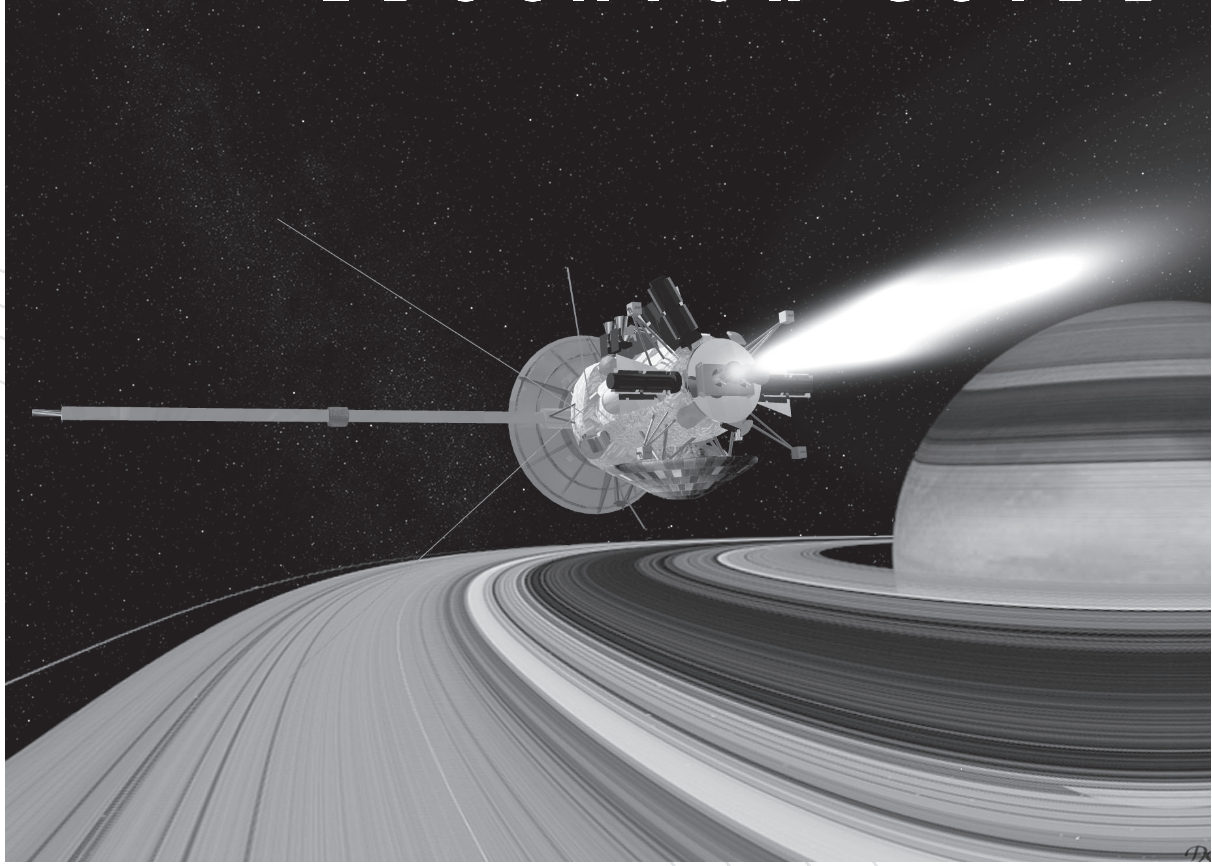


Educational Product	
Educators	Grades 5–8

EG-1999-12-008-JPL

Saturn

EDUCATOR GUIDE



TEACHER RESOURCES

AND STUDENT LESSONS

IN SPACE SCIENCE

(Suggested Grades 5–8)

How to Use the Guide

Overview

The *Saturn Educator Guide* consists of three major sections — *Lessons*, *Enrichments*, and *Appendices*. There are six standards-based lessons, all grounded in constructivist learning theory. We recommend that you do Lesson 1 — *The Saturn System* — before any of the others. To prepare for each lesson, review *Background for Lesson Discussion* at the beginning of each lesson; *Appendix 1, Questions & Answers* (101 well-organized questions posed as students would ask them); and *Appendix 2, Glossary* (over 90 technical terms). Use the *Enrichments* to enliven your teaching with relevant references to art, language, and mythology. To extend your classroom activities, see *Appendix 3, Observing Saturn in the Sky*; *Appendix 4, The Electromagnetic Spectrum*; *Appendix 5, Resources*.

Lesson Design

The first page of each lesson lists the topics, activities, standards, time required, prerequisite student skills, and equipment and materials needed. The second page — *Background for Lesson Discussion* — provides important information for the teacher. (See *Lesson Summaries* for a brief description of all the lessons.) While the lessons are focused on science standards for grades 5 though 8, they may be tailored to higher and lower grade levels.

The lessons are designed to reflect the ideals of constructivist learning theory. Students' prior knowledge, whether or not it is accurate, is the foundation of their learning. Therefore, it is critical for teachers to find out what students already "know" so that misconceptions can be addressed. In the learning process, students construct new meaning through their experiences. Challenging students' understanding allows them to build knowledge and understanding of the new concepts. Students must be assessed authentically within the context of their learning and have an opportunity to reflect on what they have learned.

Each lesson is divided into four parts:

Part I explores the students' understanding of the fundamental concept of the lesson. Headings give the teacher a quick reference about the focus of the lesson.

Part II challenges the students to make connections between the concept being explored in Part I and either Saturn or the Cassini–Huygens mission. Students' preconceptions are challenged through hands-on activities, problem solving, or design projects. As students complete the activity, the teacher guides them to focus on what they learned as a result of their experience.

Part III offers an assessment activity for the lesson. Modeling and demonstration of the activity are built into each lesson prior to the assessment. Criteria for assessing the students' responses are included. Teachers may want to create rubrics or otherwise quantify the criteria according to their particular students or teaching situation.

Part IV provides questions for reflection, which can be used for closure to the lesson, journal responses, or discussion prompts. They can also be used for individual assessment.

Note — for the sake of simplicity and convenience, in *Lessons* 1–6 and *Enrichments* 1–4, the materials a teacher must reproduce have been generically identified as numbered "figures," which may be conventional figures, illustrations, tables, and so forth. All such figures follow each "Materials" divider page at the end of the lesson or discussion.

Lesson Theme, Number, & Name

Time Required *(Varies with grade level)*

Lesson Overview

Content Standards

Student Skills

Common Questions

Items Needed for the Lesson

Note to the Teacher

GETTING TO KNOW SATURN

LESSON 1

The Saturn System

3 hrs

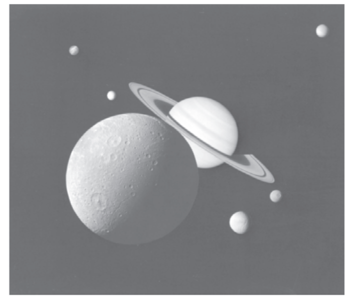
Students learn the concept of a system and apply it to learning about the Saturn system. They work with a ready-made scale diagram of the Saturn system, including the planet, rings, and moons.

The lesson prepares students to complete a Venn diagram that compares and contrasts the Saturn and Earth–Moon systems in terms of the systems' components and interactions.

MEETS NATIONAL SCIENCE EDUCATION STANDARDS:

Unifying Concepts and Processes
• *Systems, order, and organization*

Earth and Space Science
• *Earth in the Solar System*



Composite of Voyager images of Saturn and some of the moons.

PREREQUISITE SKILLS

Working in groups
Drawing and interpreting system diagrams
Measuring in millimeters
Computation (multiplication and division)
Completing a Venn diagram

BACKGROUND INFORMATION

Background for Lesson Discussion, page 2
Questions, page 7
Answers in *Appendix 1*, page 225
1–21: Saturn
22–34: Rings
35–50: Moons
51–55: Observing Saturn in the Sky

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher

Photocopier (for transparencies & copies)
Overhead projector
Chalkboard, whiteboard, or easel with paper; chalk or markers
Color image or video of Saturn (optional)
Basketball (optional)

For each group of 3 to 4 students

Chart paper (18" x 22"); color markers
Notebook paper; pencils; clear adhesive tape; scissors; ruler with millimeter divisions
Meter stick (optional)

Materials to reproduce

Figures 1–8 are provided at the end of this lesson.

FIGURE	TRANSPARENCY	COPIES
1	1	1 per group
2	1	
3		1 per group
4		1 per group
5		1 per group
6		1 per group
7		optional
8		1 per student

1

Saturn Educator Guide • Cassini Program website http://www.jpl.nasa.gov/cassini/educatorguide • EG-1999-12-008-JPL

According to the National Science Education Standards, a system is an organized group of related objects or components that form a whole. For example, systems can consist of organisms, machines, fundamental particles, galaxies, ideas, numbers, transportation, and education. Systems have boundaries, components, flow (input and output), and interactions.

inputs, outputs, organizing principles, or forces.)

6 Have each group share their diagrams with the whole class. Discuss with students their understanding of systems. Guide them to recognize the various aspects of a system and the pervasive nature of "systems" in our world, in the Solar System, and in the Universe.

3

Saturn Educator Guide • Cassini Program website http://www.jpl.nasa.gov/cassini/educatorguide • EG-1999-12-008-JPL

Lesson Summaries

ESTIMATED TIME *Varies by grades*	LESSON TITLE	CONTENT STANDARDS	LESSON DESCRIPTION
	GETTING TO KNOW SATURN		
3 hrs	**1) The Saturn System**	**Unifying Concepts and Processes** • Systems, order, and organization **Earth and Space Science** • Earth in the Solar System	Students learn the basic concept of a system and work with a scale model of the Saturn system.
3 hrs	**2) Saturn's Moons**	**Unifying Concepts and Processes** • Systems, order, and organization **Science as Inquiry** • Abilities necessary to do scientific inquiry **Earth and Space Science** • Earth in the Solar System	Students use data on the 18 moons known to be orbiting in the Saturn system to discover patterns and important relationships between physical quantities in a planet–moon system.
3–4 hrs	**3) Moons, Rings, and Relationships**	**Science as Inquiry** • Abilities necessary to do scientific inquiry **Physical Science** • Motion and forces **Earth and Space Science** • Earth in the Solar System	Students explore the fundamental force of gravity and how it acts to keep objects like moons and ring particles in orbit.
3 hrs	**4) History of Saturn Discoveries**	**History and Nature of Science** • Science as a human endeavor • History of science **Science and Technology** • Understandings about science and technology	Students examine how scientists throughout human history have explored Saturn. They learn how scientific knowledge evolves and how technology has improved our ability to solve Saturn's mysteries.
	THE CASSINI–HUYGENS MISSION		
3–4 hrs	**5) The Cassini Robot**	**Unifying Concepts and Processes** • Form and function **Science and Technology** • Abilities of technological design	Students explore the capabilities of a robot like the Cassini spacecraft. They compare its robotic functions to human functions.
1.5–2 hrs	**6) People of the Cassini Team**	**History and Nature of Science** • Science as a human endeavor **Science in Personal and Social Perspectives** • Science and technology in society	Students use a diverse collection of profiles of people who work on the Cassini mission to learn about science as a human endeavor, and to reflect on their own career goals.

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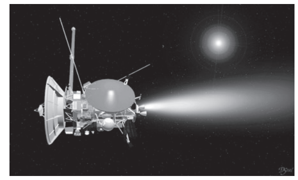

Lessons

GETTING TO KNOW SATURN

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THE CASSINI–HUYGENS MISSION

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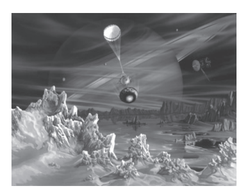

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Space Administration

Jet Propulsion Laboratory
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Pasadena, California

JPL 400-864 12/99

The Jet Propulsion Laboratory (JPL) of the California Institute of Technology is the nation's lead center for the robotic exploration of space. The Cassini–Huygens mission to Saturn and Titan is managed by JPL for the National Aeronautics and Space Administration (NASA).

The Saturn Educator Guide *was produced in collaboration with the Space Science Institute (SSI), a nonprofit corporation located in Boulder, Colorado, where researchers and educators work together to expand knowledge of the space sciences and communicate that knowledge to the public.*

SSI also manages the Western Region Education and Outreach Broker/Facilitator Program for NASA's Office of Space Science (OSS). This program is responsible for assisting the space science community (including existing and proposed space exploration projects and research programs) in identifying and implementing high-leverage partnerships with education and public outreach (E/PO) organizations.

The Education and Outreach Broker/Facilitator Program is a key element of the Space Science Education and Public Outreach "Ecosystem." The other main element of the Ecosystem is the set of four NASA/OSS education Forums, which consists of four national centers for space science education and outreach. The Forums provide education and public outreach support for space exploration missions and research programs that are within the four OSS scientific theme areas:

Astronomical Search for Origins and Planetary Systems
Solar System Exploration
Structure and Evolution of the Universe
Sun–Earth Connection

To learn more about SSI and the NASA/OSS Space Science Education and Public Outreach strategy, visit the following websites:

http://www.spacescience.org/
http://spacescience.nasa.gov/education/ecosystem.htm

Dear Fellow Educators:

One of the most remarkable gifts of being human is the ability to experience the beauty, the richness, and the insights that accompany the fields of literature, art, music, architecture, and the sciences. Indeed, these areas of human endeavor are like vast oceans that meet and mingle in many places. Several streams of interconnection between mathematics and music, or between art and architecture, are well known, but there are yet new voyages that lead us from the currents in one ocean to those in another. NASA's Cassini–Huygens mission to the magnificent ringed planet Saturn is such a voyage.

The Cassini spacecraft's 4-year scientific tour of gigantic Saturn and its 18 presently known moons will reveal new beauty, richness, and insights on behalf of all humankind. Cassini was launched in October 1997 and will arrive at the Saturn system in 2004. The Saturn Educator Guide *calls upon teachers and students of widely varying interests to come along on this extraordinary journey. You are invited to explore the role Saturn has played in our culture over time and across the diverse oceans of human interest. The Guide is the product of a collaborative venture among scientists, engineers, teachers, and education researchers. We hope we have synthesized the cutting edge of science, the cutting edge of educational research, and practicality of use in the classroom.*

The Guide includes opportunities to use the contexts of Saturn and the Cassini–Huygens mission to enrich your curricular units in science. The lessons are grounded in the National Science Education Standards and constructivist learning theory, as well as enhanced by the excitement of real-life space science and engineering. The Guide also offers highlights of the interconnections between Saturn and other areas of human endeavor, such as art, language, history, and mythology. We hope this unique blend will enable a grander diversity of learners to share and benefit from the excitement of Cassini–Huygens mission discoveries.

The international Cassini–Huygens mission is an exciting culmination of centuries of human interest in Saturn. The mission will no doubt resolve some of the most intriguing mysteries of the Saturn system, and perhaps even provide insight into how our own Solar System was formed. The mission team will receive electronic signals from the spacecraft that our computers will interpret to produce artful images for us all to explore and enjoy, of scenes never before observed by human eyes as Cassini extends our earthly senses to worlds that are a billion miles away. Meanwhile, in keeping with the nature of the scientific enterprise, the mission's investigations will raise many new questions. You may rest assured that there will be many compelling mysteries left for the Saturn explorers of the future!

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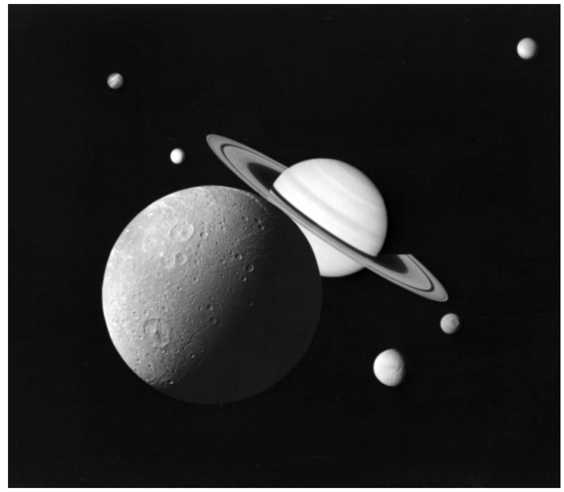
LESSON 1

3 hrs

The Saturn System

Students learn the concept of a system and apply it to learning about the Saturn system. They work with a ready-made scale diagram of the Saturn system, including the planet, rings, and moons.

The lesson prepares students to complete a Venn diagram that compares and contrasts the Saturn and Earth–Moon systems in terms of the systems' components and interactions.



Composite of Voyager images of Saturn and some of the moons.

MEETS NATIONAL SCIENCE EDUCATION STANDARDS:

Unifying Concepts and Processes
• *Systems, order, and organization*

Earth and Space Science
• *Earth in the Solar System*

PREREQUISITE SKILLS

Working in groups
Drawing and interpreting system diagrams
Measuring in millimeters
Computation (multiplication and division)
Completing a Venn diagram

BACKGROUND INFORMATION

Background for Lesson Discussion, page 2
Questions, page 7
Answers in *Appendix 1,* page 225
1–21: Saturn
22–34: Rings
35–50: Moons
51–55: Observing Saturn in the Sky

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher

Photocopier (for transparencies & copies)
Overhead projector
Chalkboard, whiteboard, or easel with paper; chalk or markers
Color image or video of Saturn (optional)
Basketball (optional)

For each group of 3 to 4 students

Chart paper (18" x 22"); color markers
Notebook paper; pencils; clear adhesive tape; scissors; ruler with millimeter divisions
Meter stick (optional)

Materials to reproduce

Figures 1–8 are provided at the end of this lesson.

FIGURE	TRANSPARENCY	COPIES
1	1	1 per group
2	1	optional
3		1 per group
4		1 per group
5		1 per group
6		1 per group
7		optional
8		1 per student

Background for Lesson Discussion

LESSON 1

Comparing the Saturn system to Earth's system

(See Procedures & Activities, Part II, Step 3)

- The Saturn system is farther from the Sun.
- The planet in the Saturn system is bigger.
- Saturn is a different color (butterscotch yellow).
- Saturn is made mostly of gas instead of rock.
- The Saturn system has rings.
- The Saturn system has more than one moon.
- The Saturn and Earth systems are both subsystems of the Solar System.
- Both systems receive and reflect sunlight.
- Both systems have at least one moon.
- In both systems, gravity acts to keep the moon(s) orbiting around the planet.
- In both systems, there are tidal forces between the planet and moon(s).

Examples of interactions in the Saturn system

(See Procedures & Activities, Part II, Step 10)

The basic parts of the Saturn system are the planet, rings, and moons. The relationships and interactions among them are defined predominantly by gravity. The moons and ring particles of the Saturn system orbit Saturn just like the planets and asteroids of the Solar System orbit the Sun. Fundamental properties of a system arise from the interaction of its parts, not from the properties of the individual parts.

- Moon–ring interaction include:
  - — Prometheus and Pandora "shepherding" the F ring
  - — Pan "clearing" the Encke Gap at the outer edge of the A ring
  - — Enceladus possibly having ice geyers that create the E ring
- Moon–moon interactions include Epimetheus and Janus swapping orbits.
- Moon–planet interactions include tidal forces between the moons and the planet.

(Note: This can be discussed further if students have learned something previously about tidal forces between Earth and the Moon. See the Glossary.*)*

Examples of inputs and outputs in the Saturn system

(See Procedures & Activities, Part II, Step 10)

Sunlight is both an input to and an output of the Saturn system. As an input, the Sun heats the system, but because Saturn is so far away from the Sun, it is very cold compared with Earth. As an output, reflected sunlight is seen when we observe Saturn and its rings and moons. In the same way, we see the reflected light of the Moon from Earth.

It is possible that Saturn's gravity captures asteroids, comets, and meteorites from time to time. These events are considered inputs to the system. The moon farthest from Saturn (Phoebe) may be a captured asteroid. Comets that passed near Saturn may have collided with and broken up a moon, and played a role in the formation of Saturn's rings.

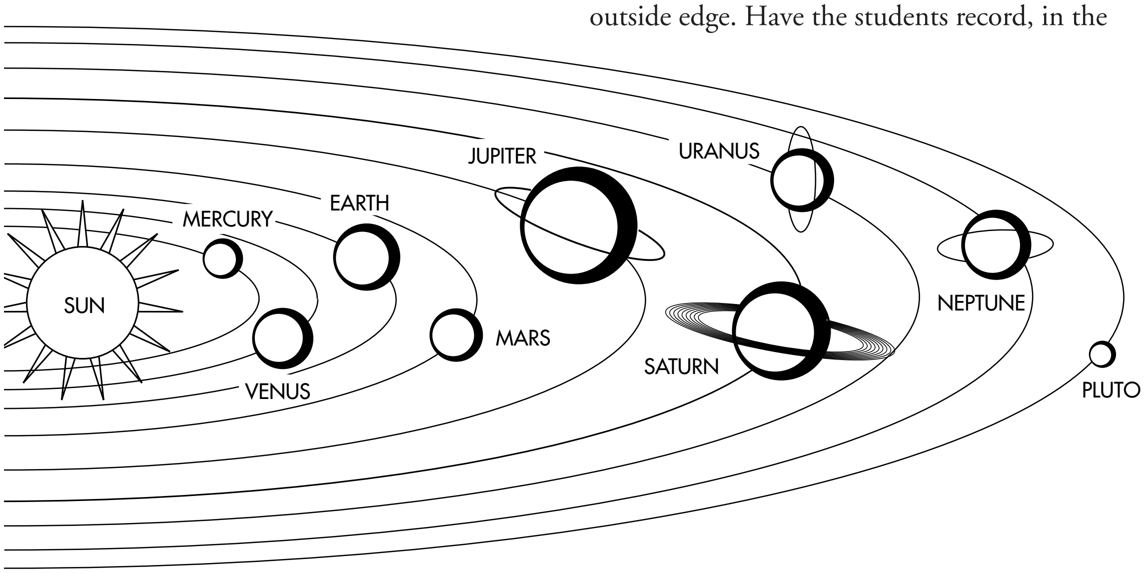
Radio waves are another output of the Saturn system. The mechanisms behind some of Saturn's emission of "light" in the radio-wave portion of the electromagnetic spectrum are unknown.

LESSON 1

Lesson Plan

Part I: What Is a System?

1 Tell the students that diagrams are simple drawings that can show the basic organization of a system. Demonstrate how to make diagrams by drawing the Solar System, including the Sun and planets with their labels, and the planets' orbital paths. For completion, title the diagram (of course, it is not to scale).



The Solar System (not to scale).

2 Ask students this question: How have you heard the word "system" used? List their responses on the chalkboard. Possible student responses include: Solar System, school system, computer system, stereo system, digestive system, and so on.

According to the National Science Education Standards, a system is an organized group of related objects or components that form a whole. For example, systems can consist of organisms, machines, fundamental particles, galaxies, ideas, numbers, transportation, and education. Systems have boundaries, components, flow (input and output), and interactions.

3 Have the students select and diagram on notebook paper a system other than the Solar System.

4 Have students form groups with those who have drawn different system diagrams. Limit group size to four students.

5 Give each group a sheet of chart paper, and have them attach their diagrams around the outside edge. Have the students record, in the center of the paper, all the similarities they can find in their system diagrams. Guide students to consider questions such as — What do all the diagrams have in common? (For example: titles, labels, or objects.) What do all the systems have in common? (For example: parts, interconnections and interactions among parts, boundaries, inputs, outputs, organizing principles, or forces.)

6 Have each group share their diagrams with the whole class. Discuss with students their understanding of systems. Guide them to recognize the various aspects of a system and the pervasive nature of "systems" in our world, in the Solar System, and in the Universe.

Part II: Making Connections to Saturn

1 Have the students focus on the planet Saturn in the Solar System diagram you drew for them. Note that Saturn is the sixth planet from the Sun and that it has rings (as do all of the giant planets in the outer Solar System which are composed primarily of gases). Remind them that the Solar System diagram is not to scale, that Saturn is really much larger than Earth, and that Saturn is approximately 10 times farther from the Sun than is Earth. Inform the students that NASA has a spacecraft called Cassini that will study Saturn (it was launched in 1997 and will arrive at Saturn in 2004).

2 Display the transparency of the *Voyager Image of Saturn* (Figure 1) to introduce the look of Saturn and its rings. Tell students that Saturn is a large ball of gas and does not have a solid surface like Earth's. Ask students to guess what size Earth would be if placed next to Saturn in this image (they will work out the answer during a later activity).

Note: If you have a color image or video of Saturn, it can be used to further motivate students' interest in Saturn. If you have access to the World Wide Web, the Cassini website is an excellent source of Saturn images (http://www.jpl.nasa.gov/cassini/). There are also other exceptional websites — please see *Appendix 5, Resources*.

3 Ask students to consider how Saturn's system is different from or the same as Earth's system. For example: How are the parts of the two systems different or the same? How might the interactions between the parts be different or the same? How are the inputs and outputs different or the same? (See information in *Background for Lesson Discussion.*)

4 Display the *Saturn Ring System* (Figure 2) transparency. Discuss students' observations of the ring illustration. For example: How many rings are there? Do the rings appear in alphabetical order from Saturn outward? How wide are the rings relative to the planet and to the Earth–Moon system?

5 Explain that the next part of the lesson will involve looking at a close-up of a smaller section of the rings, and show students the four pages of the *Saturn System Diagram* (Figure 4). Detailed instructions for assembling the diagram are shown in Figure 3. Tell students that the scaled Saturn on the diagram is about the size of a basketball. Show them how to tape together the *Saturn System Diagram:*

- Line up the center lines of each section (labeled A, B,C, and D).
- Use the arc of the G ring to estimate the connection between Sections A and B.
- Tape A and B together.
- Line up C and D to B and tape together.

Note: Older or more advanced students can achieve a more accurate depiction of scaled distances to the moons outside the A ring by following the directions in *How to Assemble the Saturn System Diagram.* (For lower grade levels, this degree of care in assembly is likely to take too much time away from the main concept of the lesson.)

6 Put students in an even number of small groups of 3 or 4. Give each group a copy of the 4-page *Saturn System Diagram* and a paper copy of the *Voyager Image of Saturn* (Figure 1). Have students carefully tape together their diagrams.

7 Ask the students to look at their assembled *Saturn System Diagram* and review it briefly. Ask them to share their immediate observations — for example, the number of rings, gaps, or divisions; location of moons; size of Earth relative to Saturn and Titan; special notes about various elements of the system, etc. *Optional: Pass a basketball around to each group so that students can compare its size to Saturn in their diagram.*

8 Distribute a copy of the *Saturn System Scavenger Hunt* (Figure 5) pages to each group. Point out that it is important for students to read all the information for each question to learn more about the Saturn system. Explain that each section of the scavenger hunt includes questions for the students to answer by using the *Saturn System Diagram.* Some sections include space for students to generate additional questions that can be answered by using the diagram. Advise students that their classmates will be asked to answer the questions they create using the diagram.

9 After students have completed the *Saturn System Scavenger Hunt*, have them trade scavenger hunts with another group. Each group will then try to find answers to the questions created by their partner group.

10 Review and discuss the scavenger hunt. (See the *Saturn System Scavenger Hunt Answer Key* [Figure 6] at the end of this lesson.) Guide students to see how the Saturn system is an example of a system. What are the parts of a system? How do they relate and interact with each other? What are the inputs and outputs of the system? (See information in *Background for Lesson Discussion*.) Figure 7, the *Saturn System Table*, can be provided to students for additional information in working with the *Saturn System Diagram* (see *Additional Exercises*).

Part III: Assessment

1 Give each student a copy of the *Earth/Saturn Systems Venn Diagram* (Figure 8). Ask students to think about how the two systems are alike and how they are different in terms of their definition of a system. Explain the three different areas on the Venn diagram — the region where the circles intersect should contain aspects that both systems have in common, and the regions that do not overlap should contain aspects that are unique to each system.

2 Have students record system aspects in the appropriate areas on the Venn diagram. Ask students to record at least three system aspects in each area.

3 Have students write a paragraph or two on the back of their Venn diagram sheets that explains how the Saturn system is a system. Tell them that their explanations should include specific examples to illustrate various properties of the system.

Assessment Criteria

1. The student should identify differences and similarities between the two systems and write them in the correct areas of the Venn diagram. Some included items might be:

EARTH SYSTEM
- *Inner part of Solar System*
- *One moon*
- *Inhabited by humans and other life forms*
- *Moon has been visited by humans*
- *Earth and Moon made mostly of rock*
- *Planet does not have rings*

SATURN SYSTEM
- *Outer part of Solar System*
- *Many moons*
- *Uninhabited*
- *Planet is a ball of gas instead of rock*
- *Planet has rings*

BOTH EARTH AND SATURN SYSTEMS

- *Have parts that interact*
- *Are subsystems of the Solar System*
- *Orbit the Sun*
- *Have at least one moon*
- *Have been explored by spacecraft*
- *Are held together by the force of gravity*

2. In the student's paragraph, the Saturn system is explained as a system composed of several elements, including a planet, rings, and moons. There should be two to three examples of how the system's components interact with or relate to each other, and at least one example of an input and output to the system. (See information in Background for Lesson Discussion.*)*

Part IV: Questions for Reflection

- How would the night sky be different if you lived in the Saturn system instead of the Earth–Moon system?
- What are the similarities and differences between the Saturn system and the Solar System?
- What are the similarities and differences between the Saturn system and the system you diagrammed at the beginning of the lesson?

Part V: Lesson Extensions

1. Ask students to do additional measurements and computations of distances on the *Saturn System Diagram*. See the *Saturn System* table for measurements and scale factors.

2. Ask the students to make a 3-D scale model of Saturn and its main rings using a 3-inch-diameter styrofoam ball and other basic materials. You can download classroom-tested directions for making the model at this website — http://lyra.colorado.edu/sbo/mary/Cassini/scale_saturn.html

LESSON 1

Questions

These questions and their answers can be used to provide background for teachers or to explore prior knowledge and facilitate discussions with students. The answers are found in Appendix 1*, starting on page 225.*

Saturn

1. When did we discover Saturn?
2. How did Saturn get its name?
3. Where is Saturn located?
4. How old is Saturn?
5. How big is Saturn?
6. If Saturn is so much more massive than Earth, why is it said that Saturn could float in water?
7. What is Saturn made of?
8. Could we breathe Saturn's atmosphere?
9. Pictures of Saturn show that it sort of flattens out near the poles and is wider at the equator. Why is that?
10. Why is Saturn so much larger and more massive than Earth?
11. Since Saturn does not have a solid surface, would I sink to the middle of the planet if I tried to walk there?
12. What's gravity like on Saturn? Would I weigh the same on Saturn as on Earth?
13. What is the temperature on Saturn?
14. Does Saturn have winds and storms?
15. Since Saturn and Jupiter are both made up of mostly hydrogen and helium, why isn't Saturn the same color as Jupiter?
16. Is there life on Saturn?
17. Does Saturn have a magnetic field like Earth's?
18. How long is a day on Saturn?
19. How long is a month on Saturn?
20. How long is a year on Saturn?
21. Does Saturn have seasons like Earth?

Rings

22. How did we first find out about Saturn's rings?
23. What are the rings of Saturn made of ? Are they solid?
24. How many rings are there?
25. Do the rings move?
26. In the opening sequence of the TV show *Star Trek: Voyager*, a ship passes through the rings of Saturn from bottom to top. Do the rings contain more empty space or more solid particles?
27. How big are the rings?
28. How much stuff is in the rings?

LESSON 1

29. Do ring particles collide?

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

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

32. Are there other planets with rings?

33. Why doesn't Earth have rings?

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

Moons

35. How many moons does Saturn have?

36. Who discovered all these moons?

37. How did the moons get their names?

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

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

40. Are Saturn's moons in the rings? Do the moons collide with the ring particles?

41. What is the difference between a moon and a ring particle?

42. What's gravity like on Saturn's moons? Could we walk there?

43. Are there volcanoes on any of Saturn's moons?

44. How cold are Saturn's moons?

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

46. Is there water on Titan?

47. Is there life on Titan?

48. What is the weather like on Titan?

49. Cassini carries a probe that is going to Titan, not Saturn or any other moons? Why Titan?

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

Observing Saturn in the Sky

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

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

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

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

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

Materials

LESSON 1

Figure 1	**Voyager Image of Saturn**
Figure 2	**Saturn Ring System**
Figure 3	**How to Assemble the Saturn System Diagram**
Figure 4	**Saturn System Diagram (4 pages)**
Figure 5	**Saturn System Scavenger Hunt (4 pages)**
Figure 6	**Saturn System Scavenger Hunt Answer Key**
Figure 7	**Saturn System Table — Optional**
Figure 8	**Earth/Saturn Systems Venn Diagram**

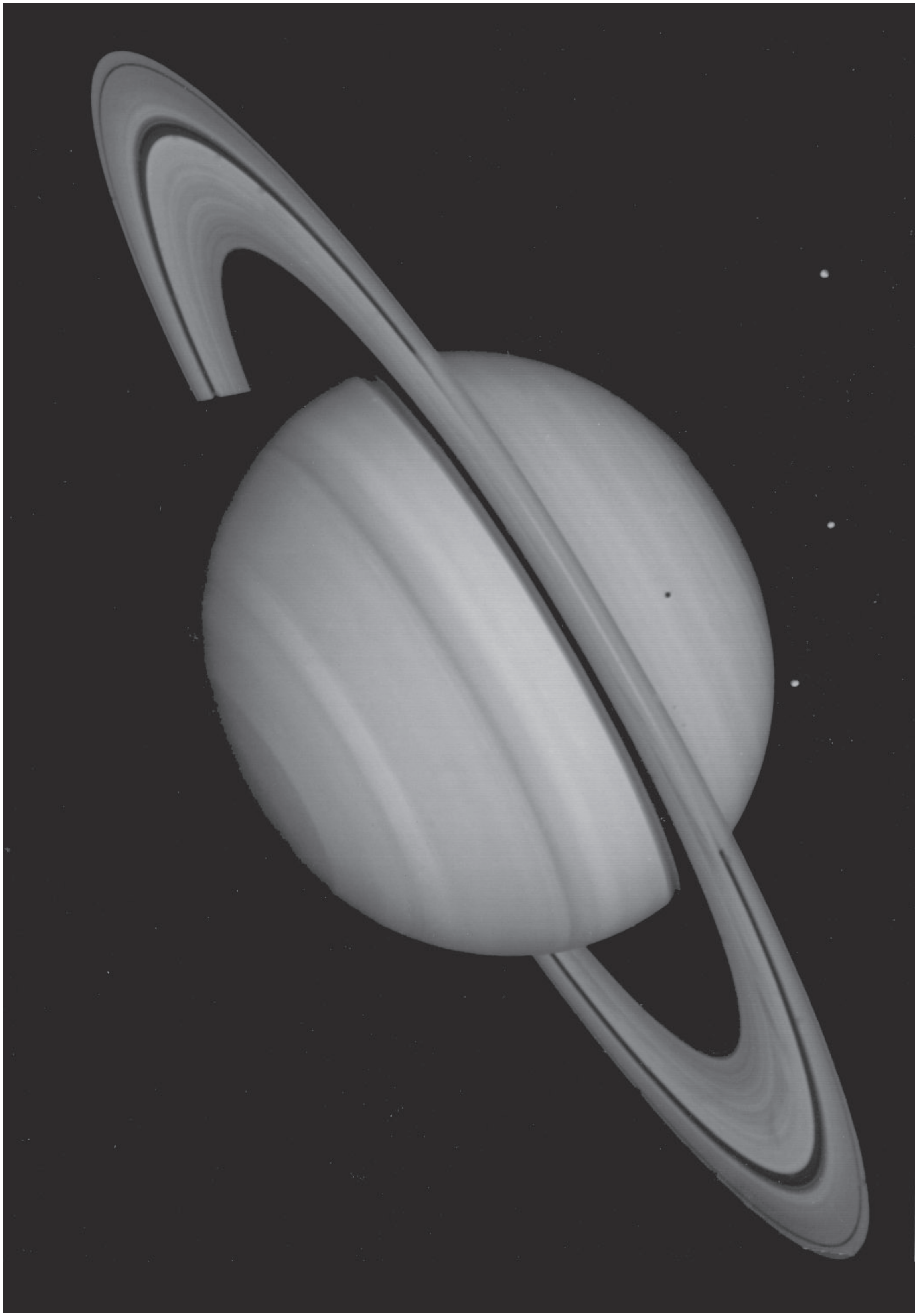
Voyager Image of Saturn

LESSON 1

Figure 1

It appears that three moons are scattered about Saturn, but in reality, all of Saturn's known moons except the two outermost ones orbit in the same plane as do Saturn's rings. In images, a moon may appear outside Saturn's ring plane because of the moon's position in its orbit and the angle from which the Saturn system is being viewed. The small dark shadow on the surface of Saturn is that of a fourth moon, which does not appear in the image.

A similar image of Saturn may be found at <http://www.jpl.nasa.gov/cassini/Images/astro/23887.html>.



TOP ←

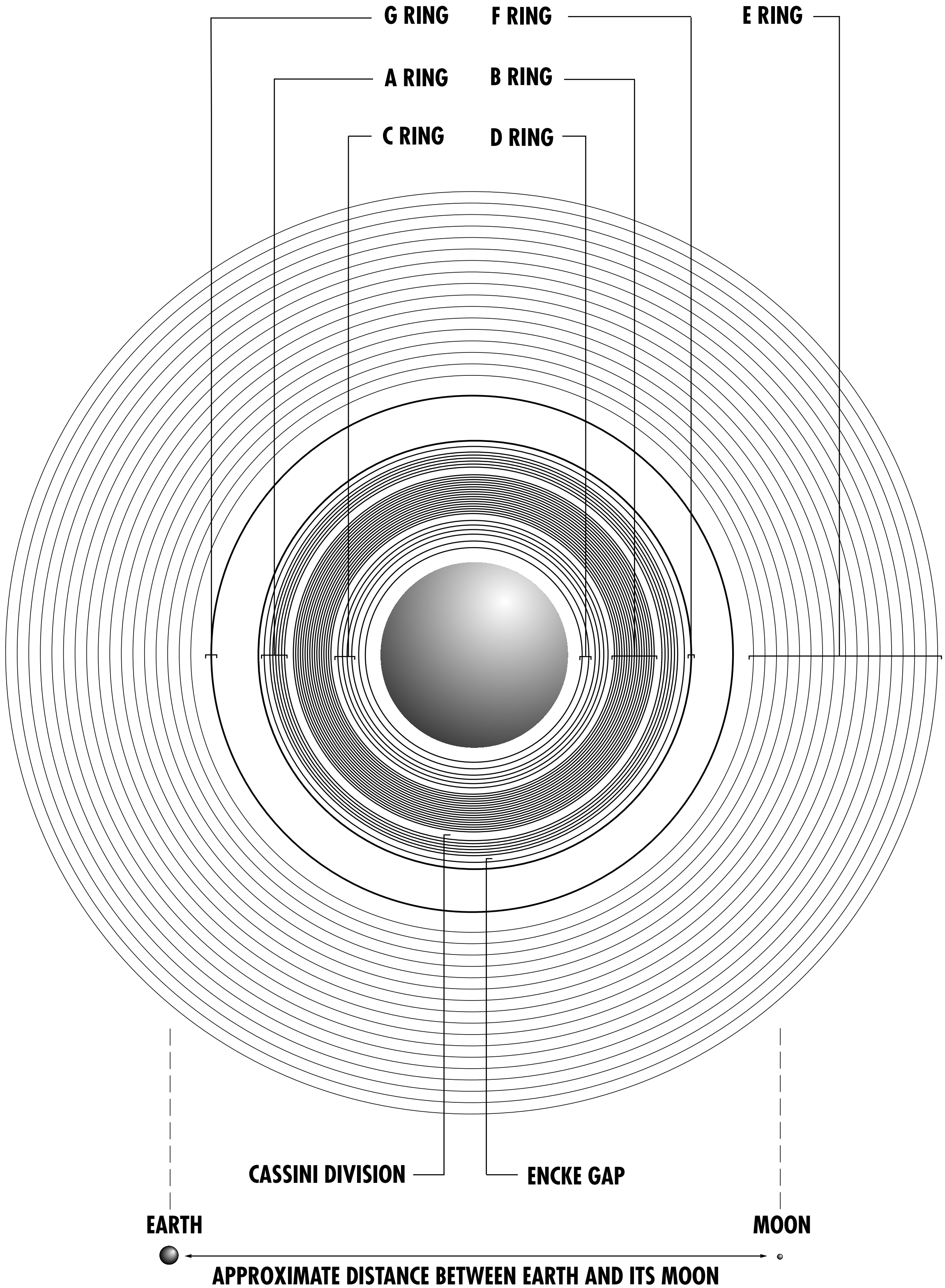
LESSON 1

Figure 2

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

Colored markers can enchance the visual distinction between rings.

Saturn Ring System (shown to scale)

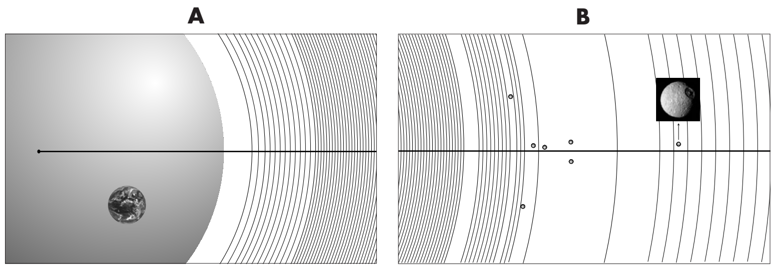


Saturn's rings are not located in alphabetical order outward from the planet because they were named in order of their discovery. From inner to outer, the rings are — D, C, B, A, F, G, E.

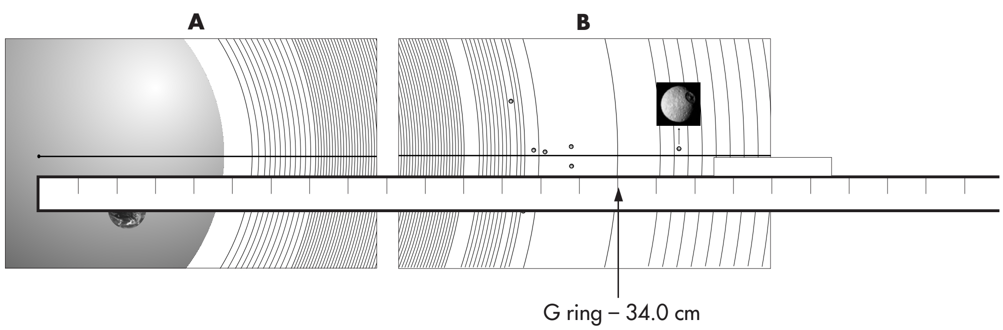
Figure 3

How to Assemble the Saturn System Diagram

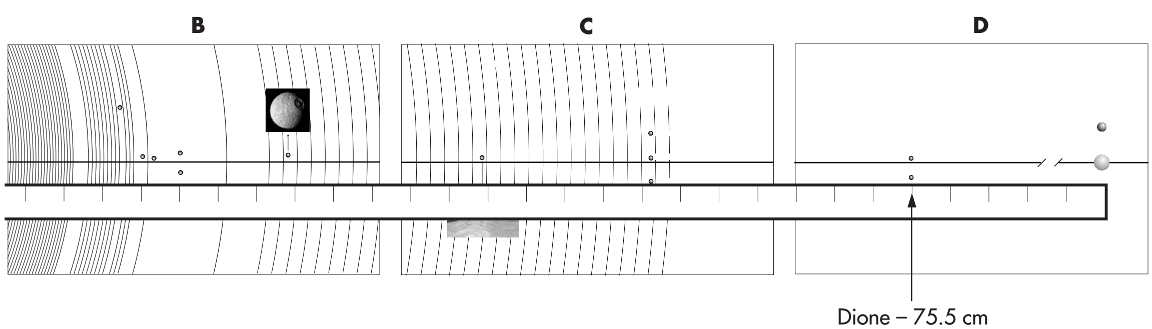
1. Be sure you have all 4 sections (A, B, C, and D) of the *Saturn System Diagram*. Place Section B to the right of Section A so they are lined up along the center line, as illustrated below.



2. Place the meter stick over the two sections so that the end “0” mark of the meter stick lines up with the center of Saturn located near the left edge of Section A. Now align your meter stick with the black line running from left to right across the center of each section of the diagram. Adjust the position of Section B to the left or right as needed so that the G ring crosses the center line at 34 cm on the meter stick. When you are certain that it is in position, tape the two sections together. (When the pages are correctly positioned, the horizontal edges may or may not overlap.) Tape them together so that the center lines are continuous, aligned, and straight. Don’t tape the meter stick to the sections!



3. Place Section C to the right of Section B; then place D next to C. Adjust Section D to the left or right so that the moon Dione is located at 75.5 cm on the meter stick. When you have Dione in position, tape Sections B, C, and D together. As before, the edges may or may not align. You have now assembled your *Saturn System Diagram* and you are ready to begin your scavenger hunt!



LESSON 1

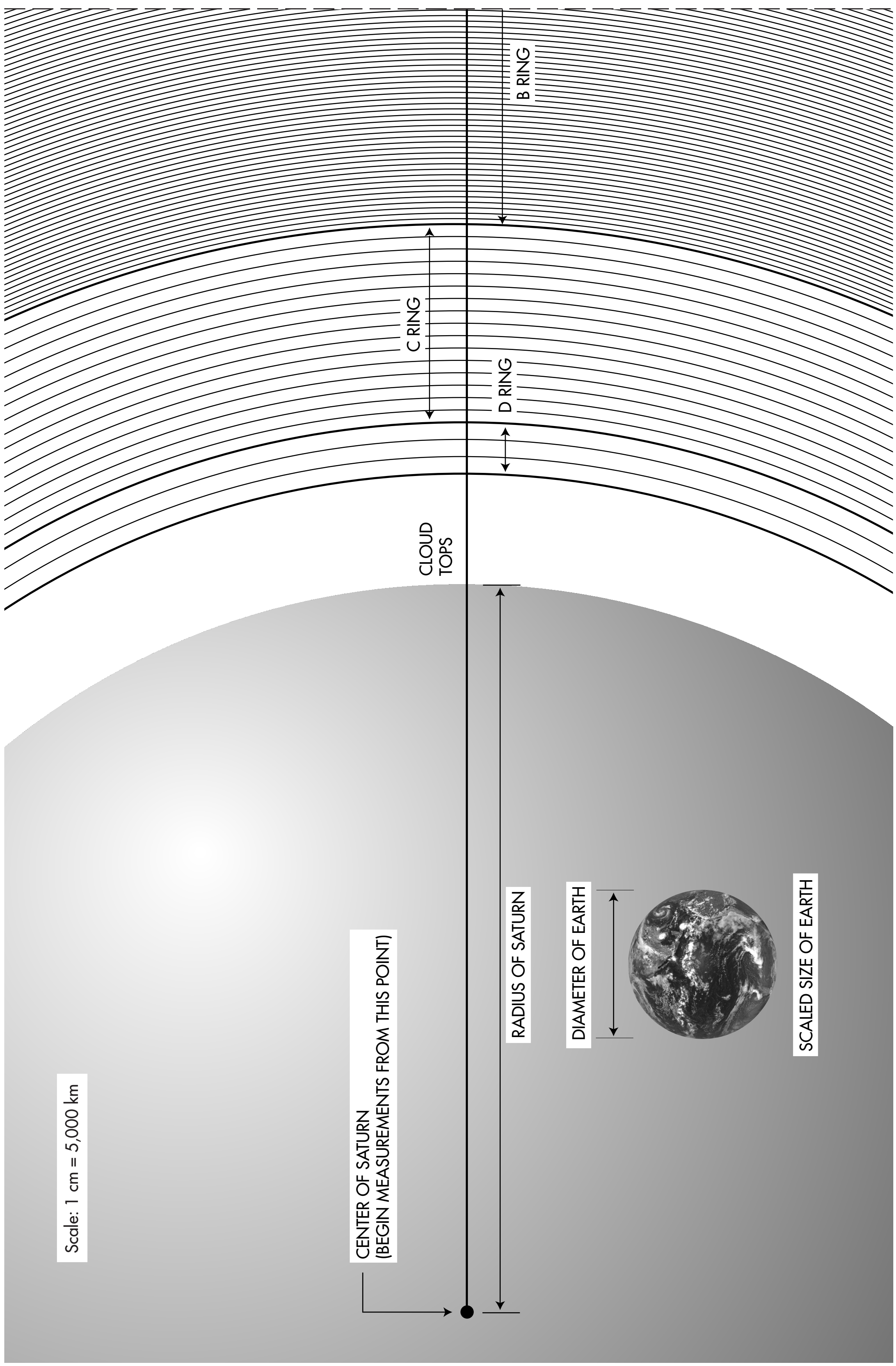
Saturn System Diagram (A) (1 of 4)

LESSON 1

Figure 4

Scale: 1 cm = 5,000 km. The radius of Saturn corresponds to the radius of a basketball in this scale diagram.

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

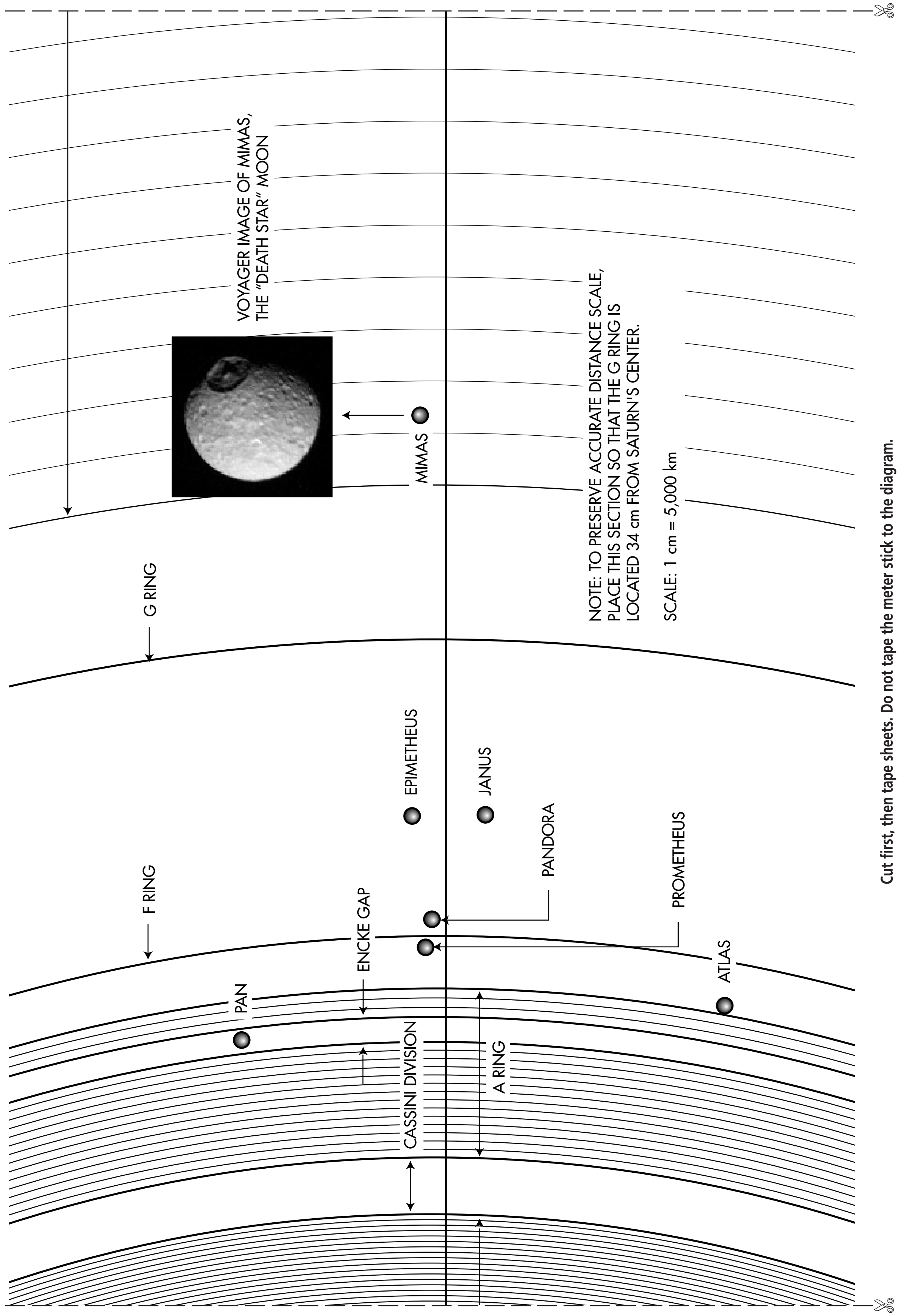


Cut first, then tape sheets. Do not tape the meter stick to the diagram.

Figure 4

Saturn System Diagram (B) (2 of 4)

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

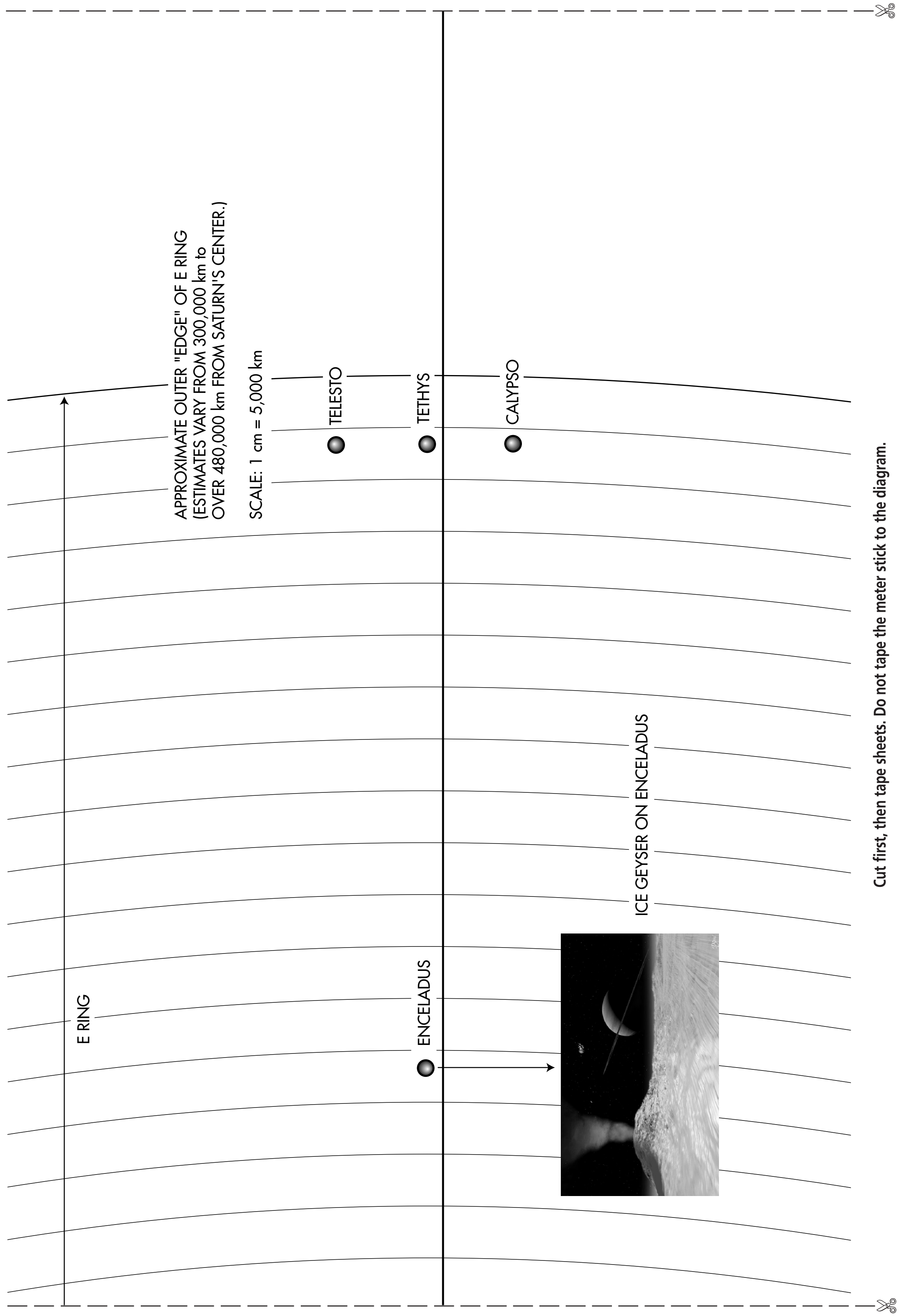


LESSON 1

Figure 4

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 System Diagram (C) (3 of 4)

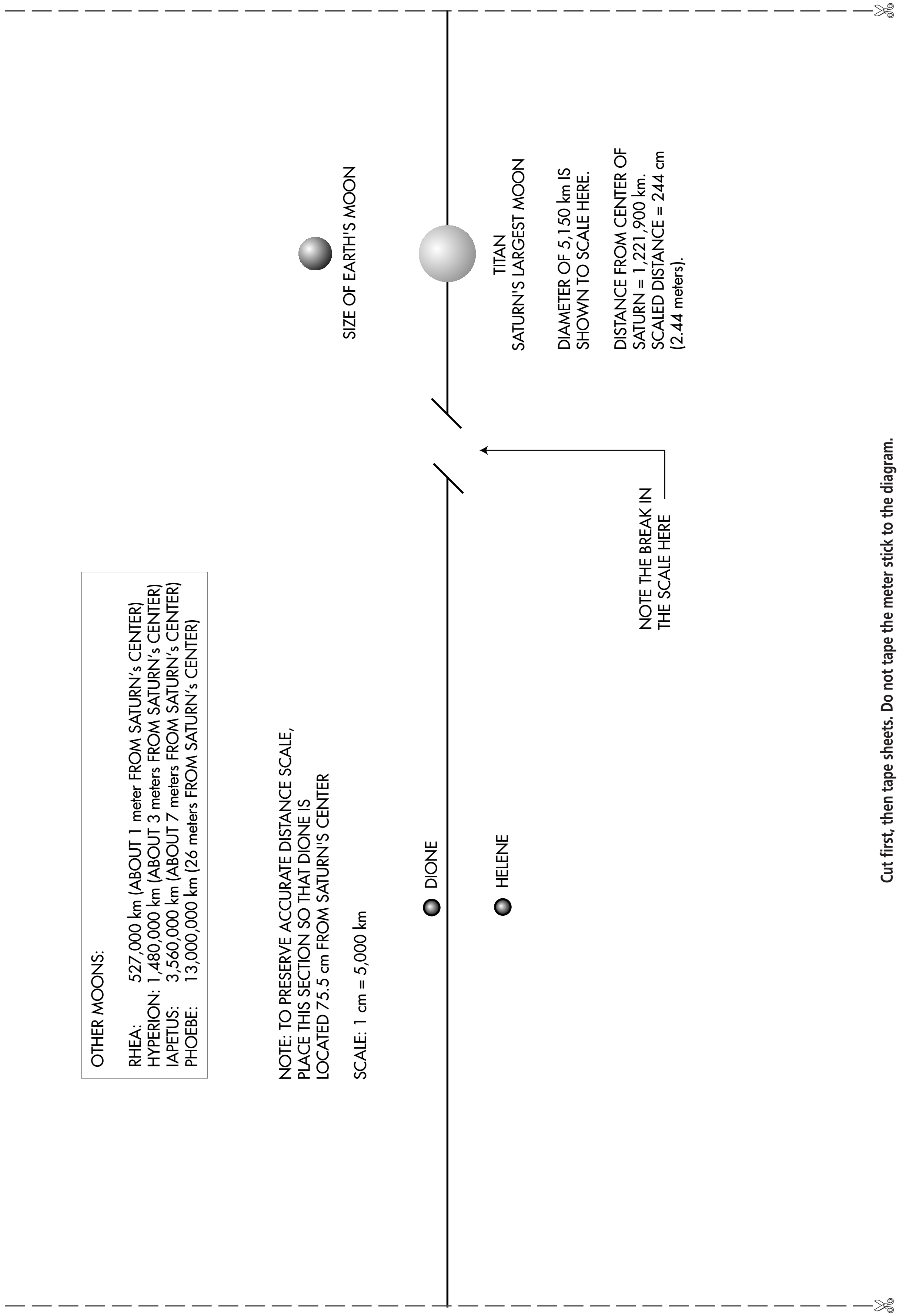


LESSON 1

Figure 4

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 System Diagram (D) (4 of 4)



Saturn System Scavenger Hunt (1 of 4)

LESSON 1

Figure 5

Student group members: Use the information in the assembled *Saturn System Diagram* scale model to find answers to the following questions. In Sections A and B below, use the space provided to create two or three of your own questions. You must be able to answer the questions using the diagram. *Your classmates will be asked to answer the questions you create.*

Section A: Rings and Gaps

1. Saturn's rings are not solid, but are composed of many chunks of ice and rock that range in size from a grain of sand to a house. The names of the rings in the order they appear from the cloud tops of Saturn outward toward the moon Titan are:

_____ _____ _____ _____ _____ _____ _____.

2. Jean-Dominique Cassini is the person who discovered a division (gap) in Saturn's rings in 1659. The _______ and _______ rings are on either side of the Cassini Division.

3. The narrowest rings by far are the _______ ring and the ______ ring.

4. Compare the projected *Voyager Image of Saturn* and the *Saturn System Diagram* (and/or the *Saturn Ring System* illustration) and explain which of Saturn's rings you think we are seeing in the Voyager image.

5. Student questions about the rings and gaps:

Saturn System Scavenger Hunt (2 of 4)

Section B: Moons

1. There are _______ (a number) moons orbiting Saturn at distances closer to the planet than the G ring.

2. There are ________ (a number) moons orbiting Saturn at distances farther from the planet than the G ring. (HINT: Don't forget to count the moons that are farther away than Titan. All of Saturn's moons, except the two most distant ones, orbit Saturn in the same plane as the rings.

3. The farthest moon from Saturn is actually orbiting very slowly in the opposite direction from all the other moons and ring particles. It may be an asteroid captured by Saturn's gravity. The Cassini spacecraft will investigate this possibility. This moon is called _______________.

4. Student questions about the moons:

Section C: Relationships and Interactions

1. ____________________ is the force that holds the moons and the ring particles in orbit around Saturn.

2. The widest ring of Saturn has a moon called Enceladus orbiting where the ring is densest. Enceladus may have ice volcanoes that supply the _______ ring with small ice particles. Cassini will observe Enceladus to see if the science instruments on board can detect any ice volcanoes.

Saturn System Scavenger Hunt (3 of 4)

3. The ______ ring has a gap near its outer edge caused by the tiny moon named Pan. Cassini may discover other moons like Pan that orbit within the A and B rings.

4. The narrow _______ ring is held together ("shepherded") by the gravity of the moons Prometheus and Pandora, which orbit on either side of the ring.

5. The tiny moons Janus and Epimetheus are between the ______ ring and the ______ ring. The gravitational forces between these small, odd-shaped moons cause them to trade orbits with one another.

Section D: Compare the Size of Earth with the Size of Saturn

For the following, make measurements to the nearest millimeter wherever possible.

1. Measure the scaled diameter of the Earth on the *Saturn System Diagram*:

__________ cm

Use your measurement to compute the diameter of Earth:

__________ cm	×	5,000 km/cm	=	______________ km
(scaled diameter)		*(scale factor)*		*(actual diameter)*

2. Measure the scaled radius of Saturn on the *Saturn System Diagram*:

__________ cm

Use your measurement to compute the actual radius of Saturn:

__________ cm	×	5,000 km/cm	=	______________ km
(scaled radius)		*(scale factor)*		*(actual radius)*

Saturn System Scavenger Hunt (4 of 4)

3. What is the actual diameter of Saturn?

Actual diameter of Saturn = 2 × (radius of Saturn) = __________ km

4. Compare the diameter of Saturn with the diameter of Earth by forming the ratio of Saturn's diameter to Earth's diameter:

$$\frac{\text{Saturn diameter}}{\text{Earth diameter}} = \underline{\qquad\qquad} = \underline{\qquad\qquad}$$

Therefore, Saturn's diameter is __________ times bigger than Earth's diameter.

Note: Use the problem set above as a model to construct a problem that compares the size of Titan (the largest moon in the Saturn system) with the size of Earth's Moon.

LESSON 1

Figure 6

Saturn System Scavenger Hunt Answer Key

Section A: Rings and Gaps

1. D, C, B, A, F, G, and E

2. A and B

3. F and G

4. Not all the rings are visible in the Voyager image of Saturn. The F, G, and E rings, and most of the D and C rings, are too faint to be seen. Considering the sizes of the observable features in the Voyager image and their distances from the Saturn cloud tops, we are seeing the bright B and A rings with the Cassini Division in between. It is possible we are seeing a bit of the C ring, but it is difficult to tell because there is no gap between the B ring and the C ring.

5. Possible student question about rings and gaps: The brightest and densest ring is the ___________ ring. (Answer — B ring)

Section B: Moons

1. Six moons — Pan; Atlas; Prometheus and Pandora; Epimetheus and Janus.

2. Twelve moons — Mimas; Enceladus; Tethys, Telesto, and Calypso; Dione and Helene; Titan; Rhea; Hyperion; Iapetus; Phoebe.

3. Phoebe.

4. Possible student question about the moons: The largest moon in the Saturn system is ________________. (Answer — Titan)

Section C: Relationships and Interactions

1. Gravity

2. E ring

3. A ring

4. F ring

5. F ring and G ring

Section D: Compare the Size of Earth with the Size of Saturn (Optional)

1. Scaled diameter of Earth = 2.5 cm; 2.5 cm × 5,000 km/cm = 12,500 km (actually, 12,800 km)

2. Scaled radius of Saturn = 12.0 cm; 12.0 cm × 5,000 km/cm = 60,000 km (actually, 60,300 km)

3. Actual diameter of Saturn = 120,000 km (diameter = 2 × radius — actually, 120,600 km)

4. Ratio of Saturn's diameter to Earth's diameter = 9.6 (in reality, the ratio is about 9.4)

LESSON 1

Figure 7

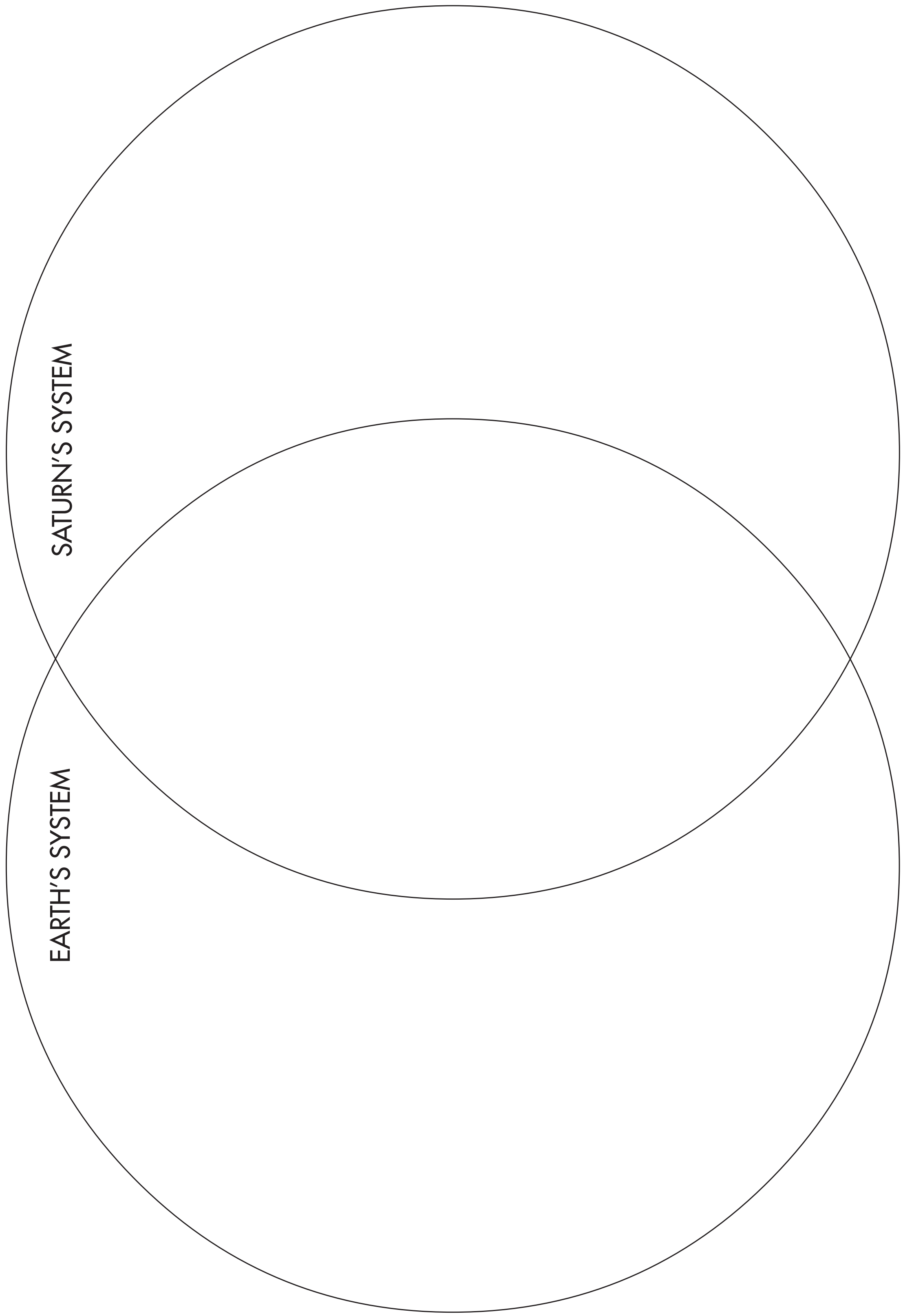
Saturn System Table

Moon/Ring	Distance from Saturn's Center (cm)	Scale Factor (km/cm)	Approximate Distance from Saturn's Center (km)
D Ring (inner edge)	13.4	× 5,000	67,000
C Ring (inner edge) D Ring (outer edge)	14.9	× 5,000	74,500
B Ring (inner edge) C Ring (outer edge)	18.4	× 5,000	92,000
B Ring (outer edge) Cassini Division (inner edge)	23.5	× 5,000	117,500
A Ring (inner edge) Cassini Division (outer edge)	24.4	× 5,000	122,000
Encke Gap and Pan	26.7	× 5,000	133,500
A Ring (outer edge)	27.4	× 5,000	137,000
Atlas	27.5	× 5,000	137,500
Prometheus	27.9	× 5,000	139,500
F Ring	28.0	× 5,000	140,000
Pandora	28.3	× 5,000	141,500
Epimetheus and Janus	30.3	× 5,000	151,500
G Ring	34.0	× 5,000	170,000
E Ring (approx. inner edge)	36.2	× 5,000	181,000
Mimas	37.1	× 5,000	185,500
Enceladus	47.6	× 5,000	238,000
Tethys, Telesto, and Calypso	58.9	× 5,000	294,500
Dione and Helene	75.5	× 5,000	377,500
E Ring (approx. outer edge)	96.6	× 5,000	483,000
Rhea	105.0	× 5,000	525,000
Titan	244.0	× 5,000	1,220,000

Optional: Students can measure the shaded items using the Saturn System Diagram.

Figure 8

Earth/Saturn Systems Venn Diagram

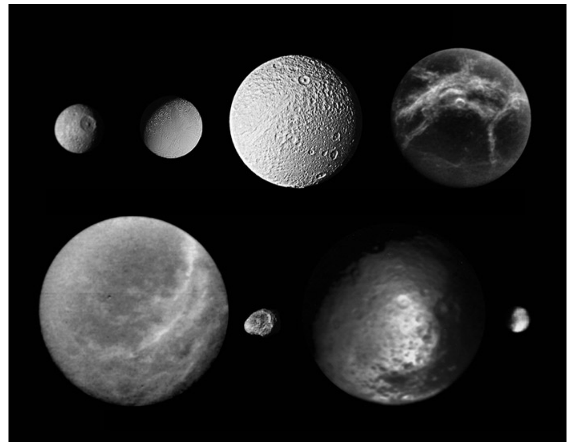


LESSON 2

3 hrs

Saturn's Moons

Students use the data provided on a set of *Saturn Moon Cards* to compare Saturn's moons with Earth's Moon, and to explore moon properties and physical relationships within a planet–moon system. For example, the farther the moon is from the center of the planet, the slower its orbital speed, and the longer its orbital period. The lesson enables students to complete their own *Moon Card* for a mystery moon of Saturn whose size, mass, and distance from the center of Saturn are specified.



Saturn's eight large icy moons.

MEETS NATIONAL SCIENCE EDUCATION STANDARDS:

Unifying Concepts and Processes
• *Systems, order, and organization*

Science as Inquiry
• *Abilities necessary to do scientific inquiry*

Earth and Space Science
• *Earth in the Solar System*

PREREQUISITE SKILLS

Working in groups

Reading in the context area of science

Basic familiarity with concepts of mass, surface gravity, orbital period, and orbital speed

Interpreting scientific notation

Using Venn diagrams

Sorting and ordering data

BACKGROUND INFORMATION

Background for Lesson Discussion, page 32

Questions, page 37

Answers in *Appendix 1,* page 225

1–21: Saturn

35–50: Moons

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher

Photocopier (for transparencies & copies)

Overhead projector

Marker to write on transparencies

Chalkboard, whiteboard, or easel with paper; chalk or markers

For each group of 2–3 students

Clear adhesive tape

Notebook paper; pencils

Materials to reproduce

Figures 1–21 are provided at the end of this lesson.

FIGURE	TRANSPARENCY	COPIES
1	1	1 per student
2–19		1 set per group
20	1	optional
21		1 per student

Background for Lesson Discussion

LESSON 2

Students may ask about the quantities listed on the *Saturn Moon Cards*.

Radius and size: To determine the actual size of a moon or a planet, scientists make images of it and use the known distance to the object and the resolution of the camera to fix a "scale" for the image (e.g., 1 picture element or "pixel" = 10 km). For example, if a round moon covers 6 pixels in the image, the moon's diameter is 6 pixels × 10 km/pixel = 60 km. Some moons have nonspherical shapes and so there may be more than one size. If a moon is round, then one size (radius) is sufficient.

Distance from the center of Saturn: Careful measurements of the position of a moon in the sky are used to compute a mathematical expression for the orbit of the moon, including its distance from the center of Saturn. For a quick, less accurate estimate, astronomers make images of the moon and Saturn together and use the scale of the image, just as for determining size.

Orbital speed: Orbital speed is the speed of an object in orbit around another object. To determine the orbital speed of a moon around Saturn, astronomers can take pictures of the moon over a period of time, and measure how far it moves in its orbit around Saturn during that time. This information can be used to compute a speed (speed = distance/time). If you already know the moon's distance from the center of Saturn, then you can use mathematical equations (Newton's Laws) to calculate orbital speed. Orbital speed is the same for all objects orbiting the same central body at the same distance from the center. The mathematical expression for a moon's orbit permits easy computation of its orbital speed.

Orbital period: The orbital period of a moon is the time it takes the moon to go once around in its orbit of a planet. The orbital period can be observed directly or calculated using the moon's distance from the center of Saturn (Kepler's Laws — see *Glossary*), and is part of the mathematical expression for the orbit.

Mass: Mass is a measure of the amount of "stuff" that constitutes an object. The most direct way to measure the mass of a moon works only for the larger moons. It involves a spacecraft flying very close to the moon to see how the moon's gravity influences the speed and direction of travel of the spacecraft. Less easily, the effect of the mass of one moon on the motion of another moon can be used to determine a moon's mass. From these methods, a mass can be calculated (using Newton's Laws). These methods do not work well for the smallest moons because they do not have strong enough gravity to have a measurable effect on the speed of a spacecraft or the speed of another moon at long distances. Thus, the masses of the smallest moons are largely unknown.

Surface gravity: Surface gravity of a planet or moon is a measure of the acceleration of gravity at the surface. For Earth, acceleration of gravity is about 9.8 meters/sec^2. For Earth's Moon, it is 0.17 times this value, or about 1.7 meters/sec^2. To calculate surface gravity, you must know the moon's size (R) and mass (M). Surface gravity = GM/R^2, where R is the radius of the moon, M is the mass of the moon, and G is the universal gravitational constant. Because the masses of the smaller moons are unknown, their surface gravities are also unknown.

Lesson Plan

Part I: What Do We Know about Earth's Moon?

1 Display a transparency of the *Profile of Earth's Moon* (Figure 1). Cover up the half that displays Moon data, showing only the top half of the transparency.

2 Ask students the following questions: What do you know about the Moon? Why do we call it a moon? What have we done to explore the Moon? What Moon mysteries do we still want to solve? Record their responses on the lines on the top half of the transparency.

3 Give each student a copy of the *Profile of Earth's Moon*. Allow students time to record responses about the Moon data collected on the transparency. Share the other half of the transparency, briefly review the provided Moon data, and review the terminology used, including terms such as "period of orbit" and "surface gravity." (See *Background for Lesson Discussion*.)

Part II: Making Connections to Saturn

1 Tell the students that this lesson will take a closer look at one of the elements of the Saturn system — the moons. Tell them that, until just recently, Saturn's known moons numbered more* than any other planet's. Draw a line down the center of the chalkboard. At the top of the first column, write "What We Know." Ask students what they already know about Saturn's moons. Record their responses in the first column.

***As of September 1999, Uranus may be the moon champion — recent discoveries indicate that Uranus may have as many as 21 moons, compared with Saturn's 18 moons. The Cassini mission may discover more moons of Saturn.**

2 At the top of the second column, write "Questions We Have." Ask students what they want to learn about Saturn's moons. Record their questions in the second column.

Make a set of *Saturn Moon Cards* (Figures 2–19) for each student group prior to the next portion of the lesson. To make one set, copy the *Saturn Moon Cards* and cut them along the dashed lines, or in half. You may want to use the completed Venn diagram from Lesson 1 to introduce similarities and differences between the Saturn system and the Earth–Moon system. You may want to use Greek mythology to introduce the names of Saturn's moons. See the *Cultural Connections* section or other resources such as children's literature or videos.

3 Arrange students in groups of two or three. Give each group a complete set of *Saturn Moon Cards* (Figures 2–19). Review the meaning of the properties listed on the cards (see *Background for Lesson Discussion*, and the *Glossary*).

4 Instruct the groups to study the cards and to select the Saturn moon they believe is most like Earth's Moon. Remind them to use the information on Earth's Moon for comparison. Guide students to consider properties other than surface features and physical appearance, such as distance from the center of the planet, orbital speed and period, radius, mass, and surface gravity. Compute density when possible, and compare it with the Moon's density.

5 When the groups find the moon they believe is most like Earth's Moon, have the students create a *Moon Comparison Chart*. Have the group tape their chosen *Saturn Moon Card* to the top half of a sheet of notebook paper and fill in corresponding properties for Earth's Moon on the bottom half. Ask one member of the group to record the explanation of how the group determined that the two moons are alike.

LESSON 2

6 Have the groups share the *Moon Comparison Charts* they created and explain how they determined that the two moons are alike.

According to the National Science Education Standards, "Abilities necessary to do scientific inquiry" include designing and conducting a scientific investigation (i.e., students should be able to formulate questions, design and execute experiments, interpret data, synthesize evidence into explanations, propose alternative explanations for observations, and critique explanations and procedures).

7 Gather the students in an open area in the classroom and tell them that the next part of the lesson is to use the *Saturn Moon Cards* to look for relationships among the various properties of Saturn's moons. Model how to arrange the cards according to a property listed on their *Saturn Moon Cards*. For example, ask the students to order the cards from least to greatest distance from the center of Saturn. Check to be sure each group has done this properly.

8 Explain that relationships can be determined by looking at the other data on the cards when the cards are ordered or sorted in a particular way. For example, ask the students to examine the ordered cards to try to determine what happens to the orbital period as a moon's distance from the center of Saturn increases.

9 Guide students to see that as the distance from the center of Saturn increases, the orbital period also increases. In other words, the farther the moon is from Saturn, the longer the moon takes to orbit the planet.

10 Record on the chalkboard: "As the distance from the center of Saturn increases, the orbital period also increases." Tell students that there are many other relationships to be discovered from the data on the *Saturn Moon Cards*.

11 Point to the other properties listed on the cards to show how to look for a pattern of increasing or decreasing quantity. Explain that this is one way to look for relationships. As one set of values increases, does another increase or decrease? How does it change?

12 List the following items on the chalkboard:

- Mass — Size
- Size — Shape
- Date of Discovery — Size
- Distance from Center of Saturn — Orbital Speed
- Distance from Center of Saturn — Mass
- Orbital Speed — Mass
- Size — Orbital Speed

13 Tell the students that they need to arrange the *Saturn Moon Cards* in different ways to test for the relationships between the pairs of properties listed on the board. Have them record their conclusions about the relationships on a separate sheet of paper. Inform the students that a clear relationship may not exist between some of the pairs of properties.

14 Once all the groups have recorded their discoveries, discuss the relationships observed by each group. See the *Saturn Moon Relationships Table* (Figure 20) for a sample of correct answers. Use the figure as a transparency or make copies for the students.

From the National Science Education Standards: "Knows that scientific inquiry includes evaluating results of scientific investigations, experiments, observations, theoretical and mathematical models, and explanations proposed by other scientists (e.g., reviewing experimental procedures, examining evidence, identifying faulty reasoning, identifying statements that go beyond the evidence, suggesting alternative explanations)."

LESSON 2

Part III: Assessment

1 Tell students that other moons may exist in the Saturn system. Tell them that the next part of the lesson is hypothetical and that they will be creating a *Mystery Moon Card*. They will model their card after the *Saturn Moon Cards*.

2 Write the following information about the mystery moon on the chalkboard: 1) The mystery moon is located in the Saturn system. 2) The mystery moon's distance from the center of Saturn is the same as the distance between Earth and the Moon. 3) The radius, mass, and surface gravity of the mystery moon are the same as those of Earth's Moon.

3 Give each student a copy of the *Mystery Moon Card* (Figure 21). Tell students they should use the *Saturn Moon Cards*, the *Profile of Earth's Moon*, and what they have learned about discovering relationships in the Saturn system to estimate the unknown data on the *Mystery Moon Card*. A helpful hint is to suggest that students order the cards and include the *Profile of Earth's Moon*. Each student should prepare his or her own unique *Mystery Moon Card*.

4 Allow time for the students to work with the *Saturn Moon Cards* and the *Profile of Earth's Moon*. Have the students complete the *Mystery Moon Card*, giving the mystery moon a unique name, drawing the mystery moon, naming himself or herself as discoverer, estimating when the moon would have been discovered by real astronomers, estimating an orbital period and orbital speed, and writing a paragraph about the moon's features.

Assessment Criteria

- *The drawing of the mystery moon is spherical in shape. (Earth's Moon is similar in size to the moons of Saturn that are spherical in shape.)*
- *The* Mystery Moon Card *data for the date of discovery, orbital period, and orbital speed fall within these ranges:*

DATE OF DISCOVERY: *Between 1655 (Titan) and 1672 (Rhea). The size of Earth's Moon (1,738 km) is between the size of Titan (2,575 km) and Rhea (764 km). Using the relationship between the size and the date of discovery, students can infer that the mystery moon would have been discovered between 1655 and 1672.*

ORBITAL PERIOD: *Between 2.74 days (Dione) and 4.52 days (Rhea). The distance of 384,000 km falls between the orbits of Dione (377,400 km) and Rhea (527,040 km). Because the orbital period increases with distance from the center of the planet, the orbital period of the mystery moon should fall between the orbital period of Dione (2.74 days) and Rhea (4.52 days).*

ORBITAL SPEED: *Between 8.49 km/sec (Rhea) and 10.03 km/sec (Dione). Since orbital speed decreases as distance from the center of the planet increases, the orbital speed of the mystery moon should fall between the orbital speed of Rhea (8.49 km/sec) and Dione (10.03 km/sec).*

- *The mystery moon distance from the center of Saturn is 384,000 km (same as Earth–Moon distance).*
- *The mystery moon data for radius, mass, and surface gravity are:*

  RADIUS: *1,738 km (same as Earth's Moon)*

  MASS: 735×10^{20} *kg (same as Earth's Moon)*

  SURFACE GRAVITY: *0.17 of Earth's (same as Earth's Moon)*

- *The student has written a paragraph that describes the surface features of a mystery moon.*

Part IV: Questions for Reflection

- Would the relationships between physical properties (e.g., between orbital speed of a moon and distance from the center of the planet it orbits) be the same for Jupiter and its many moons?
- If you were to send a probe to one of Saturn's moons, which one would it be? Why? What would you hope to discover?

LESSON 2

Questions

These questions and their answers can be used to provide background for teachers or to explore prior knowledge and facilitate discussions with students. The answers are found in Appendix 1*, starting on page 225.*

Saturn

1. When did we discover Saturn?
2. How did Saturn get its name?
3. Where is Saturn located?
4. How old is Saturn?
5. How big is Saturn?
6. If Saturn is so much more massive than Earth, why is it said that Saturn could float in water?
7. What is Saturn made of?
8. Could we breathe Saturn's atmosphere?
9. Pictures of Saturn show that it sort of flattens out near the poles and is wider at the equator. Why is that?
10. Why is Saturn so much larger and more massive than Earth?
11. Since Saturn does not have a solid surface, would I sink to the middle of the planet if I tried to walk there?
12. What's gravity like on Saturn? Would I weigh the same on Saturn as on Earth?
13. What is the temperature on Saturn?
14. Does Saturn have winds and storms?
15. Since Saturn and Jupiter are both made up of mostly hydrogen and helium, why isn't Saturn the same color as Jupiter?
16. Is there life on Saturn?
17. Does Saturn have a magnetic field like Earth's?
18. How long is a day on Saturn?
19. How long is a month on Saturn?
20. How long is a year on Saturn?
21. Does Saturn have seasons like Earth?

Moons

35. How many moons does Saturn have?
36. Who discovered all these moons?
37. How did the moons get their names?
38. Are Saturn's moons like Earth's Moon?
39. Why does Saturn have so many moons, but Earth has only one?
40. Are Saturn's moons in the rings? Do the moons collide with the ring particles?
41. What is the difference between a moon and a ring particle?
42. What's gravity like on Saturn's moons? Could we walk there?
43. Are there volcanoes on any of Saturn's moons?
44. How cold are Saturn's moons?
45. Do any of Saturn's moons have an atmosphere? Could we breathe it?
46. Is there water on Titan?
47. Is there life on Titan?
48. What is the weather like on Titan?
49. Cassini carries a probe that is going to Titan, not Saturn or any other moons. Why Titan?
50. Will there be a mission that takes humans to Titan in the near future?

Materials

LESSON 2

Figure 1	**Profile of Earth's Moon**
Figures 2–19	**Saturn Moon Cards**
Figure 20	**Saturn Moon Relationships Table**
Figure 21	**Mystery Moon Card**

LESSON 2

LESSON 2

Figure 1

Profile of Earth's Moon

Distance from Earth

384,500 km (238,900 mi)

Orbital Period

27.32 days (655.73 hrs)

Orbital Speed

1.02 km/sec (0.67 mi/sec)

Radius

1,738 km (1,080 mi)

Mass

735×10^{20} kg

Density

3.34 g/cm^3

Surface Gravity

0.166 of Earth's

Other Features

- Rocky, cratered, mountainous.
- One side always faces Earth.
- Prominent flat, dark areas known as *maria* on Earth-facing side — lava flows filled gigantic meteorite craters called impact basins.
- Humans first landed there in 1969.

LESSON 2

Figure 2

Saturn Moon Card

Pan

Discovered by Mark Showalter, 1990

One of the tiniest moons in the Saturn system, Pan orbits in the narrow Encke Gap near the outer edge of the A ring and actually clears out ring particles to form the gap. If Pan disappeared, so would the Encke Gap. Voyager took pictures of Pan during the flybys of 1980–81, but the moon was not found until 10 years later, when astronomer Mark Showalter carefully hunted through the Voyager images to see if he could find a moon. *Cassini might answer...* Are there more undiscovered moons like Pan, clearing areas like the Encke Gap in the main rings?

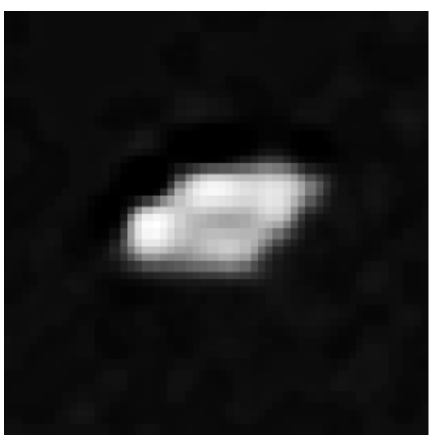
Distance from Center of Saturn 133,583 km (83,000 mi)	**Radius** 10 km (6 mi)
Orbital Period 0.577 days (13.85 hrs)	**Mass** Unknown
Orbital Speed 16.84 km/sec (10.46 mi/sec)	**Surface Gravity** Unknown

Figure 3

Saturn Moon Card

Atlas

Discovered by Richard Terrile and the Voyager team, 1980



Atlas (AT-less) is the second innermost of Saturn's known moons. Astronomers believe it may be maintaining the sharp outer edge of the A ring. *Cassini might answer...* How could a moon like Atlas keep the outer edge of the A ring so sharp?

Distance from Center of Saturn 137,640 km (85,530 mi)	**Radius** 18.5 × 17.2 × 13.2 km avg. = 16 km (10 mi)
Orbital Period 0.601 days (14.42 hrs)	**Mass** Unknown
Orbital Speed 16.63 km/sec (10.3 mi/sec)	**Surface Gravity** Unknown

LESSON 2

LESSON 2

Figure 4

Saturn Moon Card

Prometheus

Discovered by Stewart Collins and the Voyager team, 1980

Moving outward from Saturn, Prometheus (pro-MEE-thee-uss) is the third moon. Together with Pandora (the fourth moon), Prometheus acts as a shepherd moon for the F ring. This means the moons' gravity nudges the F ring particles into a thinner ring, much like shepherds keep their flocks of sheep together. Prometheus is extremely elongated, much more so than an egg. *Cassini might answer*... What could have caused Prometheus' odd shape? How do Prometheus and Pandora shepherd the F ring? Are there other moons playing shepherding roles?

Distance from Center of Saturn
139,350 km (86,590 mi)

Orbital Period
0.613 days (14.71 hrs)

Orbital Speed
16.53 km/sec (10.27 mi/sec)

Radius
74 × 50 × 34 km avg. = 53 km (33 mi)

Mass
Unknown

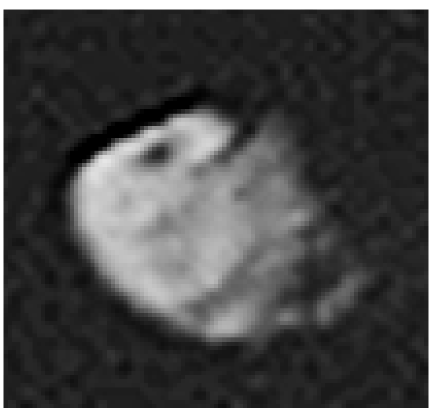
Surface Gravity
Unknown

Figure 5

Saturn Moon Card

Pandora

Discovered by Stewart Collins and the Voyager team, 1980



Moving outward from Saturn, Pandora (pan-DOR-uh) is the fourth moon. Together with Prometheus (the third moon) it acts as a shepherd moon for the F ring. This means the moons' gravity nudges the F ring particles into a thinner ring, much like shepherds keep their flocks of sheep together. *Cassini might answer*... How do Prometheus and Pandora shepherd the F ring? Are there other moons playing shepherding roles?

Distance from Center of Saturn
141,700 km (88,050 mi)

Orbital Period
0.628 days (15.07 hrs)

Orbital Speed
16.38 km/sec (10.18 mi/sec)

Radius
55 × 44 × 31 km avg. = 43 km (27 mi)

Mass
Unknown

Surface Gravity
Unknown

LESSON 2

Figure 6

Saturn Moon Card

Epimetheus

Discovered by Telescope Observation, 1966

The moon Epimetheus (epp-ee-MEE-thee-uss) shares its orbit with its neighbor, Janus. Both moons are in circular orbits around Saturn, with one of them slightly inward of the other. As the inner moon passes the outer one, they swap orbits! The new inner moon — which used to be the outer one — then begins to pull away from its companion, and the whole process begins again. In the image, note the shadow of one of Saturn's rings, like a stripe on the surface. *Cassini might answer...* Are there other moons that swap orbits like these two moons?

Note: The orbital periods for Epimetheus and Janus are slightly different but round off to the same value.

Distance from Center of Saturn
151,422 km (94,090 mi)

Orbital Period
0.695 days (16.68 hrs)

Orbital Speed
15.87 km/sec (9.86 mi/sec)

Radius
69 × 55 × 55 km avg. = 60 km (37 mi)

Mass
Unknown

Surface Gravity
Unknown

Figure 7

Saturn Moon Card

Janus

Discovered by Telescope Observation, 1966

The moon Janus (JANE-uss) shares its orbit with its neighbor, Epimetheus. Both moons are in circular orbits around Saturn, with one of them slightly inward of the other. As the inner moon passes the outer one, they swap orbits! The new inner moon — which used to be the outer one — then begins to pull away from its companion, and the whole process begins again. *Cassini might answer...* Are there other moons that swap orbits like these two moons?

Note: The orbital periods for Epimetheus and Janus are slightly different but round off to the same value.

Distance from Center of Saturn
151,472 km (94,120 mi)

Orbital Period
0.695 days (16.68 hrs)

Orbital Speed
15.85 km/sec (9.85 mi/sec)

Radius
97 × 95 × 77 km avg. = 90 km (56 mi)

Mass
Unknown

Surface Gravity
Unknown

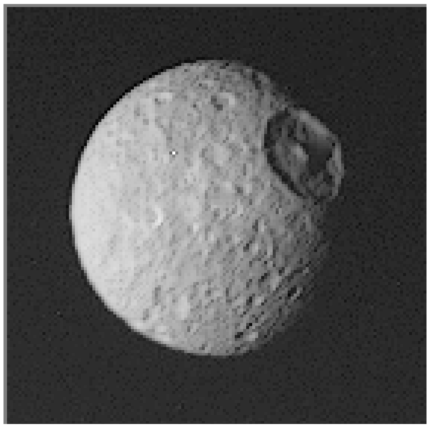
LESSON 2

Figure 8

Saturn Moon Card

Mimas

Discovered by William Herschel, 1789



Mimas (MY-muss), the so-called "Death Star" moon, may have been hit and nearly shattered by a large asteroid or another moon. The massive crater caused by the impact is 130 kilometers (80 miles) in diameter, and in the center of the crater is a mountain more than 10 kilometers (6 miles) high — almost a mile higher than Mt. Everest! Astronomers think that even though Mimas does not orbit in the Cassini Division, its gravity is responsible for making this division (between the bright A and B rings) clear of ring material. *Cassini might answer*... How does the gravity of Mimas clear out the Cassini Division?

Distance from Center of Saturn
185,520 km (115,277 mi)

Radius
199 km (124 mi)

Orbital Period
0.942 days (22.61 hrs)

Mass
0.4×10^{20} kg

Orbital Speed
14.32 km/sec (8.90 mi/sec)

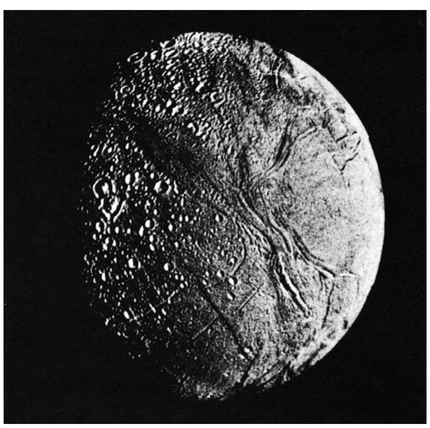
Surface Gravity
0.007 of Earth's

Figure 9

Saturn Moon Card

Enceladus

Discovered by William Herschel, 1789



Much of the bright surface on Enceladus (en-SELL-uh-duss) consists of water ice. Some parts of the surface are smooth and have only a few impact craters, suggesting that events heated up and melted large areas of the icy surface, erasing many craters. It may even be possible that the gravitational tug of tidal forces from Saturn and other moons have caused the surface of Enceladus to warm and melt, occasionally triggering geysers of ice and water to erupt from the surface! *Cassini might answer*... Are ice geysers from this moon spewing material that becomes the tiny ice particles of the E ring?

Distance from Center of Saturn
238,020 km (147,900 mi)

Radius
249 km (155 mi)

Orbital Period
1.37 days (32.88 hrs)

Mass
0.8×10^{20} kg

Orbital Speed
12.63 km/sec (7.85 mi/sec)

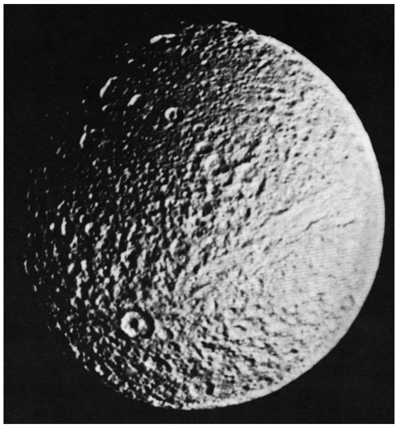
Surface Gravity
0.009 of Earth's

Figure 10

Saturn Moon Card

Tethys

Discovered by Jean-Dominique Cassini, 1684



Tethys (TEE-thiss) is full of impact craters, including a large crater over 400 kilometers (250 miles) across — nearly half the diameter of the moon itself. On the opposite side, a giant crack extends over 3/4 of the way around the moon! This enormous canyon on Tethys is many times longer and deeper than the Grand Canyon on Earth. *Cassini might answer...* What more can we learn about the giant crack, named Ithaca Chasma, on this moon? What more can we learn about the giant crater, named Odysseus, on the opposite side? Are they linked?

Distance from Center of Saturn
294,660 km (183,090 mi)

Orbital Period
1.888 days (45.31 hrs)

Orbital Speed
11.34 km/sec (7.04 mi/sec)

Radius
530 km (329 mi)

Mass
7.55×10^{20} kg

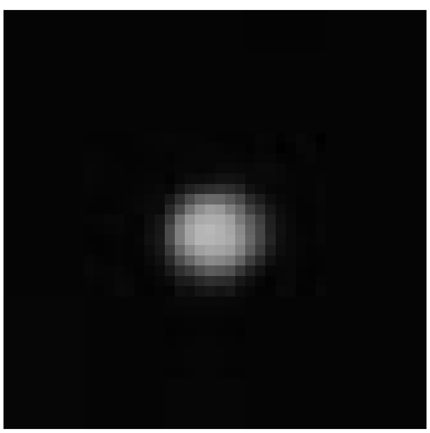
Surface Gravity
0.018 of Earth's

Figure 11

Saturn Moon Card

Telesto

Discovered by Brad Smith, Steve Larson, and Harold Reitsema, 1980



The orbit of this moon has a special relationship to that of the large moon Tethys. Telesto (tel-LESS-toe) and Calypso orbit at the same distance from Saturn as Tethys as they travel around Saturn. Telesto always remains 60° behind Tethys at the L5 point, while Calypso is always 60° ahead at the L4 point. Can you draw a labeled diagram to show this? *Cassini might answer...* How did the moons get into this type of shared orbit?

Distance from Center of Saturn
294,660 km (183,090 mi)

Orbital Period
1.888 days (45.31 hrs)

Orbital Speed
11.34 km/sec (7.04 mi/sec)

Radius
$15 \times 12.5 \times 7.5$ km avg. = 12 km (7 mi)

Mass
Unknown

Surface Gravity
Unknown

LESSON 2

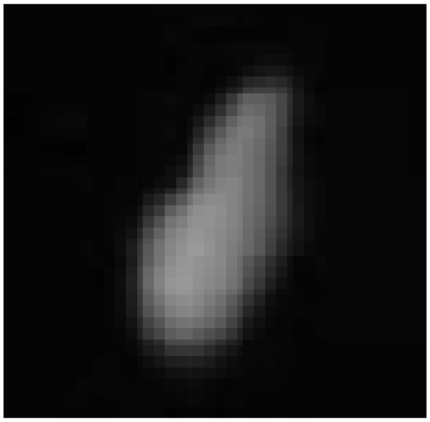
Figure 12

Saturn

Moon Card

Calypso

Discovered by Dan Pascu, 1980



The orbit of this moon has a special relationship to that of the large moon Tethys. Calypso (kuh-LIP-soh) and Telesto orbit at the same distance from Saturn as Tethys as they travel around Saturn. Telesto always remains 60° behind Tethys at the L5 point, while Calypso is always 60° ahead at the L4 point. Can you draw a labeled diagram to show this? *Cassini might answer*... How did the moons get into this type of shared orbit?

Distance from Center of Saturn
294,660 km (183,090 mi)

Orbital Period
1.888 days (45.31 hrs)

Orbital Speed
11.34 km/sec (7.04 mi/sec)

Radius
$15 \times 8 \times 8$ km avg. = 10 km (6 mi)

Mass
Unknown

Surface Gravity
Unknown

Figure 13

Saturn

Moon Card

Dione

Discovered by Jean-Dominique Cassini, 1684

Dione (die-OH-nee) appears to be covered with water ice and many impact craters. Floods may have filled many of the craters. Bright streaks cover one side of this moon. Dione also appears to control the intensity of radio waves generated by Saturn's magnetic field. *Cassini might answer*... What caused the floods? Why might Dione be affecting Saturn's radio emissions? Does Dione have a magnetic field of its own?

Distance from Center of Saturn
377,400 km (234,500 mi)

Orbital Period
2.737 days (65.69 hrs)

Orbital Speed
10.03 km/sec (6.23 mi/sec)

Radius
560 km (348 mi)

Mass
10.5×10^{20} kg

Surface Gravity
0.023 of Earth's

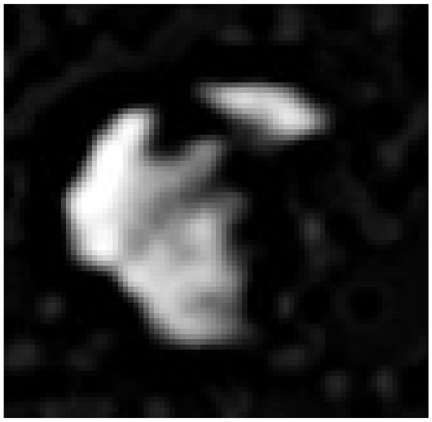
LESSON 2

Figure 14

Saturn Moon Card

Helene

Discovered by Pierre Laques and Jean Lecacheux, 1980



Helene (huh-LEE-nee) is a small moon orbiting at the exact same distance from Saturn at the L4 point, 60° ahead, of the large moon Dione. Saturn seems to have a long history of "adopting" moons. Most of the smaller moons like Helene are not round, but instead have strange or irregular shapes. *Cassini might answer...* Why do so many of Saturn's moons share orbits?

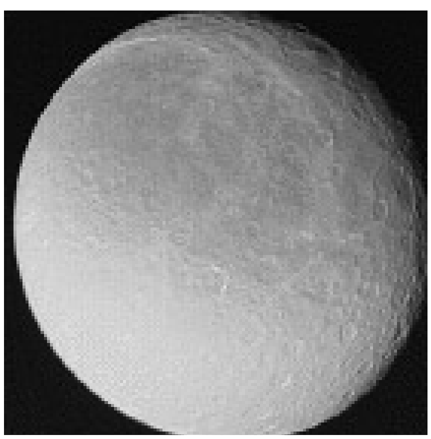
Distance from Center of Saturn 377,400 km (234,500 mi)	**Radius** 17.5 km (11 mi)
Orbital Period 2.737 days (65.69 hrs)	**Mass** Unknown
Orbital Speed 10.05 km/sec (6.25 mi/sec)	**Surface Gravity** Unknown

Figure 15

Saturn Moon Card

Rhea

Discovered by Jean-Dominique Cassini, 1672



Rhea (REE-uh) is Saturn's second largest moon. Like Dione and Tethys, astronomers think it is composed of rock covered by water ice. It has more impact craters than any other moon orbiting Saturn. In the Voyager pictures, we also see wispy, light-colored streaks on one side of the moon. *Cassini might answer...* Why does Rhea have so many craters compared with the other moons? Does it have any connection with geologic activity such as earthquakes or erupting volcanoes? Could the wispy streaks be water released from the interior and frozen on the surface in the distant past? Why are the streaks only on one side?

Distance from Center of Saturn 527,040 km (327,490 mi)	**Radius** 764 km (475 mi)
Orbital Period 4.517 days (108.42 hrs)	**Mass** 24.9×10^{20} kg
Orbital Speed 8.49 km/sec (5.27 mi/sec)	**Surface Gravity** 0.029 of Earth's

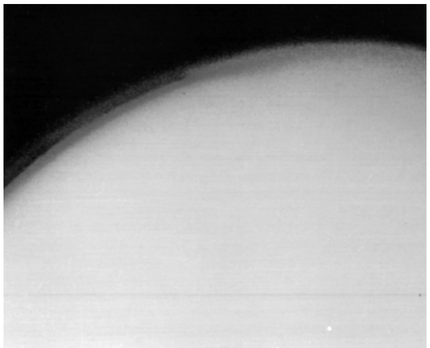
LESSON 2

Figure 16

Saturn Moon Card

Titan

Discovered by Christiaan Huygens, 1655



Titan (TIE-ten), Saturn's largest moon, is one of the few bodies in the Solar System besides Earth with a dense atmosphere. Like Earth, its atmosphere is made mostly of nitrogen. Scientists believe Titan's atmosphere may be similar to that of the early Earth, before life began. Titan's atmosphere is extremely cold and so hazy that very little sunlight reaches the surface. Titan's temperatures hover around –180 °C (–292 °F). The Cassini mission's Huygens probe will descend through Titan's atmosphere, taking the first close-up pictures of Titan's surface. *Cassini might answer...* Does Titan have mountains of ice or rock? What color is Titan's surface?

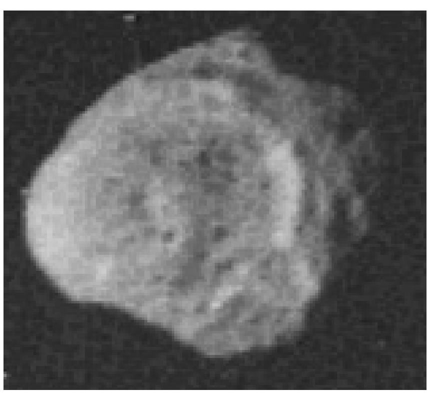
Distance from Center of Saturn 1,221,850 km (759,220 mi)	**Radius** 2,575 km (1,600 mi)
Orbital Period 15.945 days (382.7 hrs)	**Mass** 1,346 × 10^{20} kg
Orbital Speed 5.57 km/sec (3.46 mi/sec)	**Surface Gravity** 0.138 of Earth's

Figure 17

Saturn Moon Card

Hyperion

Discovered by William Bond, George Bond, and William Lassell, 1848



Little Hyperion (high-PEER-ee-on) is especially interesting. It orbits just beyond Saturn's giant moon, Titan. Why is Hyperion shaped like a dented hamburger? Could it be a fragment of a large moon that was split apart by collision with an asteroid? It tumbles unpredictably in its orbit, causing its north pole to point in different directions. Sometimes it spins slowly, and sometimes quickly! *Cassini might answer...* Could the gravitational tug of Titan be causing Hyperion's wild tumbling?

Distance from Center of Saturn 1,481,100 km (920,310 mi)	**Radius** 180 × 140 × 112.5 km avg. = 144 km (90 mi)
Orbital Period 21.276 days (510.6 hrs)	**Mass** Unknown
Orbital Speed 5.06 km/sec (3.15 mi/sec)	**Surface Gravity** Unknown

LESSON
2

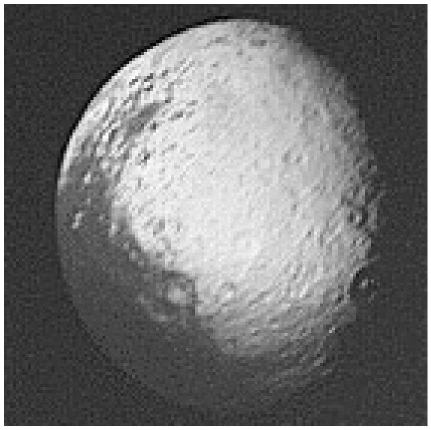
LESSON 2

Figure 18

Saturn Moon Card

Iapetus

Discovered by Jean-Dominique Cassini, 1671



Iapetus (eye-APP-eh-tuss) is a strange moon that appears bright white on one side and dark, almost black, on the other. The bright area may be water ice, while the dark area — called Cassini Regio — is a mystery! *Cassini might answer...* Why is Iapetus' surface half bright and half dark? Could it come from dark material bubbling out from volcanoes? Or might it come from dust in space being swept up by the moon, like a cosmic broom?

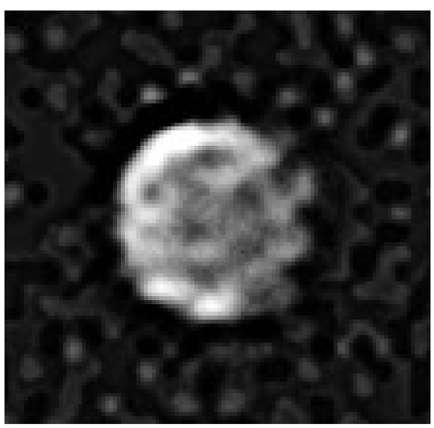
Distance from Center of Saturn 3,561,300 km (2,212,900 mi)	**Radius** 718 km (446 mi)
Orbital Period 79.331 days (1,904 hrs)	**Mass** 18.8×10^{20} kg
Orbital Speed 3.26 km/sec (2.03 mi/sec)	**Surface Gravity** 0.025 of Earth's

Figure 19

Saturn Moon Card

Phoebe

Discovered by William Pickering, 1898



Little Phoebe (FEE-bee) is the farthest moon from Saturn yet discovered. Unlike the others, Phoebe and neighboring moon Iapetus have significantly tilted orbits. This means these moons pass above, then below the plane of the rings during their journey around Saturn. Phoebe is a strange, dark moon that orbits Saturn in a direction opposite that of all of the other moons. We don't know why Phoebe is "backwards." *Cassini might answer...* Is Phoebe a captured asteroid? Why is it orbiting backwards compared with the rest of the moons? Will it still be there far in the future?

Distance from Center of Saturn 12,952,000 km (8,048,000 mi)	**Radius** $115 \times 110 \times 105$ km avg. = 110 km (68 mi)
Orbital Period 550.46 days (13,211 hrs)	**Mass** Unknown
Orbital Speed 1.71 km/sec (1.06 mi/sec) (reversed)	**Surface Gravity** Unknown

LESSON 2

Figure 20

Saturn Moon Relationships Table

Compared Properties	Relationship
Mass–Size	As the radius/size of the moon increases, the mass of the moon also increases. This does not mean, however, that larger things are always more massive. Compare a beach ball and a cannonball. Which is larger? Which is more massive?
Size–Shape	As the moons increase in size, the shape becomes spherical. The smaller moons tend to have more irregular shapes.
Date of Discovery–Size	As the size of the moon decreases, the date of discovery is more recent. Bigger moons were discovered before smaller moons. Ask students why they think this is the case. Better technology?
Distance from Center of Saturn–Orbital Speed	As the distance from the center of Saturn increases, the orbital speed decreases. Moons farther away from Saturn move around more slowly. This is a consequence of Newton's Law of Gravity.
Distance from Center of Saturn–Mass	There is no simple physical relationship between a moon's distance from the center of Saturn and its mass.
Orbital Speed–Mass	There is no relationship between the orbital speed of the moons and the mass of the moons. In fact, orbital speed is not at all dependent on mass.
Size–Orbital Speed	There is no physical relationship between the size of the moons and the orbital speed of the moons.

LESSON
2

LESSON 2

Figure 21

Mystery Moon Card

Name of Moon

Discovered by

Date of Discovery

Drawing of My Mystery Moon

Description of My Mystery Moon

Distance from Center of Saturn

Radius

Orbital Period

Mass

Orbital Speed

Surface Gravity

LESSON 3

3–4 hrs

Moons, Rings, and Relationships

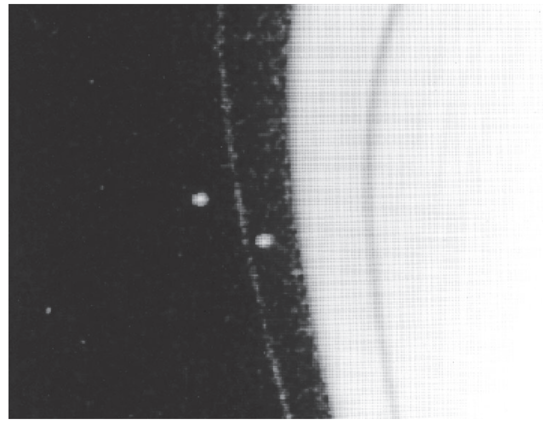
MEETS NATIONAL SCIENCE EDUCATION STANDARDS:

Science as Inquiry
• *Abilities necessary to scientific inquiry*

Physical Science
• *Motions and forces*

Earth and Space Science
• *Earth in the Solar System*

Students design their own experiments to explore the fundamental force of gravity, and then extend their thinking to how gravity acts to keep objects like moons and ring particles in orbit. Students use the contexts of the Solar System and the Saturn system to explore the nature of orbits. The lesson enables students to correct common misconceptions about gravity and orbits and to learn how orbital speed decreases as the distance from the object being orbited increases.



Prometheus and Pandora, two of Saturn's moons, "shepherd" Saturn's F ring.

PREREQUISITE SKILLS

Working in groups
Reading a chart of data
Plotting points on a graph

BACKGROUND INFORMATION

Background for Lesson Discussion, page 66
Questions, page 71
Answers in *Appendix 1*, page 225
1–21: Saturn
22–34: Rings
35–50: Moons

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher

Photocopier (for transparencies & copies)
Overhead projector
Chalkboard, whiteboard, or large easel with paper; chalk or markers

For each group of 3 to 4 students

Large plastic or rubber ball
Paper, markers, pencils

Materials to reproduce

Figures 1–10 are provided at the end of this lesson.

FIGURE	TRANSPARENCY	COPIES
1	1	
2	1	
3	1	
4		1 per student
5	1	1 per student
6		1 for teacher
7	1 (optional)	1 for teacher
8		1 per student
9	1 (optional)	1 per student
10	1 (optional)	1 for teacher

Background for Lesson Discussion

Science as inquiry

(See Procedures & Activities, Part I, Steps 1-6)

Part I of the lesson offers students a good opportunity to experience science as inquiry. Various aspects of inquiry can be highlighted and discussed as they arise in the context of learning about gravity. Such aspects include making predictions, designing and conducting an investigation involving systematic observations, interpreting data while avoiding bias, using logic to synthesize evidence into explanations, proposing alternative explanations for observations, and critiquing explanations and procedures.

Earth's Moon and the nature of gravity

(See Procedures & Activities, Part I, Step 12)

Students may ask whether the Moon itself has gravity. This is an opportunity to explain that every object having mass also has gravity and exerts gravitational force on every other object. The strength of the gravitational force depends on the masses of the objects and their distances from one another. So, not only does Earth's gravity pull on the Moon, but the Moon's gravity pulls back on Earth (as demonstrated by ocean tides).

The nature of Saturn's rings and how they move

(See Procedures & Activities, Part IIa, Step 3)

Most students are likely to imagine Saturn's rings as solid, unmoving disks, when in reality the rings are made up of individual particles that orbit Saturn like small moons. The rings are made mostly of water ice and range from the size of houses to that of grains of sand and smaller. Students should understand that if the ring particles were not moving in orbit around Saturn, they would fall in toward the planet.

Variations of orbital speed in the Saturn system

(See Procedures & Activities, Part IIb)

Considering how orbital speed varies in a system like Saturn's is a prelude to learning more about Newton's Law of Gravity and Kepler's Third Law in later grades. The orbital speed of a moon or ring particle decreases with distance from the center of Saturn. The orbital speed is the same for any two bodies at the same distance from the center of Saturn, even if they have very different masses (e.g., Tethys and Telesto). Two common misconceptions are: 1) orbital speed is the same for all moons, and thus the more distant moons require a longer time to complete their orbits because they have farther to travel (in reality, the more distant moons not only have greater circumferences to travel but in fact they also are moving more slowly); and 2) that more-massive moons have greater orbital speeds than less-massive moons.

Lesson Plan

LESSON 3

This section is adapted from "Is There Gravity in Space?" by V. Bar, C. Sneider, and N. Martimbeau, Science and Children, *April 1997.*

Part I: What Do We Know about Objects in Orbit?

1. Arrange students in groups of 3 to 4. Ask the students to discuss, predict, and draw what they think will happen to a ball after it rolls off the edge of a table — first when it's rolling slowly, then when it's rolling quickly.

2. Lead a class discussion that identifies student ideas. Invite students to post their drawings or draw their ideas on the chalkboard.

3. Have students vote for the ideas that they believe represent what will happen to the ball. Make sure they understand that they can change their votes if someone presents a convincing argument that differs from their own. Record the students' votes on the chalkboard.

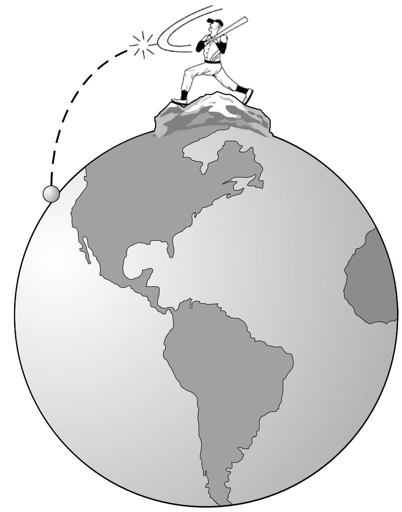
4. To test their predictions, have each student group devise an experiment. When they have completed their planning, distribute one large plastic or rubber ball per group and have them conduct the experiments.

5. When the students finish their experiments, lead a discussion of the results and ask them to revisit the original predictions and vote on them again. (See *Background for Lesson Discussion* for helpful background on science as inquiry.)

At this point there should be much broader agreement among the students about how the ball moves. Most students will conclude correctly that the ball's trajectory had the shape of an arc (technically speaking, a parabola), and that the faster the ball moved, the farther out from the edge of the table it went before hitting the floor.

6. Ask students to explain why the ball follows the path it does. (It is the result of the combination of the forward momentum when the ball is rolled and the downward force of gravity.)

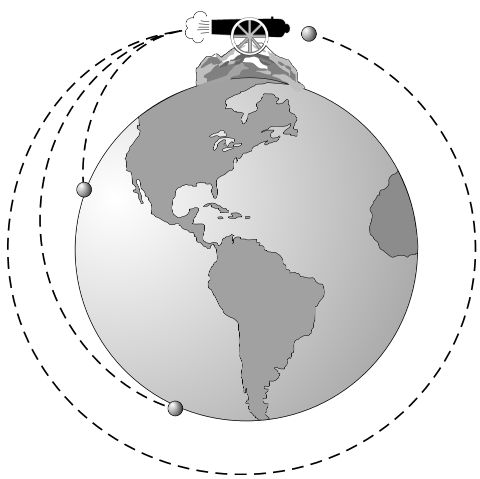
7. Display a transparency of Figure 1, which is the illustration of the baseball player (below) but without the complete trajectory of the baseball. Ask the students to imagine an enlarged mountain on Earth with a baseball player on top who hits a ball that is pitched from space. Tell students that the mountain is very high and that most of the atmosphere is below the mountain top. (This is important because many students have the misconception that gravity cannot act without an atmosphere.)



8. Ask students what happens when the baseball player hits the ball. Guide them to see that the ball follows the same sort of arcing path the students observed in their experiments, and that the baseball eventually falls to Earth, as you draw the correct baseball trajectory on the transparency. Ask the students to explain why the ball follows the path it does. Why doesn't it fly off into space after it is hit? (It is because gravity pulls it back to Earth.)

9 Ask students what would happen if the baseball were hit harder. (It would go somewhat farther around Earth and then land.)

10 Next, ask students to consider a cannon atop the mountain that can propel a cannonball with greater and greater force. Remind the students that the mountain is above most of Earth's atmosphere. Display a transparency of Figure 2, which is the illustration below but without the cannonball trajectories. Ask the students to predict what would happen if a cannonball were to be blown out of the cannon with more and more force. Guide the students (as you draw in the different trajectories on the transparency) to see that, with enough force, the cannonball would eventually "fall" all the way around Earth — in other words, it would go into orbit around Earth.



11 Ask the students what forces make the Space Shuttle go into orbit. (Rockets propel the shuttle upward, and then at an angle, to thrust it into space. Inertia keeps the shuttle moving in orbit around Earth as gravity pulls it downward, just balancing its forward speed.) Ask them what would happen if we could somehow "turn off" Earth's gravity. (The shuttle would fly off into space away from Earth.) Reinforce the idea that even where there is no air, the gravitational attraction of Earth keeps pulling at the shuttle to keep it in orbit.

12 Ask students what keeps Earth's Moon in orbit. (It is the Moon's forward speed and Earth's gravitational pull that keep the Moon in its orbit.)

Students will probably ask how the Moon obtained its forward speed. This is a subject of ongoing research about how the Moon formed. Many astronomers hypothesize that the Moon formed from a glancing collision by a large, Mars-sized object with the young, molten Earth. The matter dislodged from our planet went into orbit around Earth and eventually assembled as the Moon. Students may also ask whether the Moon itself has gravity. (See *Background for Lesson Discussion.*)

Part IIa: Making Connections to Saturn — the Nature of the Rings

1 Ask the students the following questions: What orbits Saturn? What do you know about the orbits of these objects? Record their responses on the chalkboard.

2 Display a transparency of Figure 3 (an illustration of a close-up view of Saturn's rings, a ring particle, and a house). Have students work in small groups to develop explanations of the illustration; then have each group share their theories about the meaning of the illustration.

Figure 3 shows a portion of Saturn's main rings viewed from just above the ring plane. The largest ring particles shown are house-sized. The large bodies are irregularly shaped and lie in a roughly flat layer; smaller particles are scattered about them. The ring particles orbit Saturn like tiny moons. This concept of Saturn's rings will be new to most students who are likely to have imagined Saturn's rings as solid, unmoving disks.

3 Explain that the illustration is an artist's idea of a close-up view of the rings of Saturn, and that the Cassini–Huygens spacecraft will not be able to get this close to the rings.

Ask students how they think the individual particles of Saturn's rings move. (See *Background for Lesson Discussion*.)

4 Ask the students again: What are the objects that orbit Saturn? (By this time, students should be saying ring particles as well as moons.) Ask students what keeps these objects in orbit (it is Saturn's gravity). See Lesson 1, *The Saturn System*, for a diagram of the relative positions of Saturn's rings and moons.

Part IIb: Making Connections to Saturn — Orbital Speed

1 Ask the students what they know about orbital speed. Is it different for different moons or ring particles? Does it depend on the mass of the orbiting object? Does it depend on how far away the orbiting body is from the object being orbited? Record student ideas.

2 Tell students that their ideas (or hypotheses) about orbital speed will be tested by graphing the orbital speeds of some of Saturn's moons and also ring particles at the inner and outer edges of the A ring. Give each student a copy of *Moon and A Ring Data* (Figure 4) and *Orbital Speed vs. Distance from the Center of Saturn* (Figure 5). For the teacher, Figure 6 lists the moon and A ring data but is a more complete list — the students will plot only the shaded items.

3 Display a transparency of Figure 5, *Orbital Speed vs. Distance from the Center of Saturn*. Use a marker to plot the first few points to show the students how to graph the data from Figure 4, *Moon and A Ring Data*. For the teacher, Figure 7 shows a completed plot. Have the students start graphing the data along with you, and then ask them to plot and label the rest of the data themselves.

Some students may be unfamiliar with the way numbers and units are used on the graph's axes; some review may be necessary to get them started. It may be helpful to demonstrate a unit conversion from a speed given in km/sec to a more familiar unit of speed like km/hr or mi/hr. Students will also ask about points that appear to be in virtually the same place on the plot (e.g., Tethys and Telesto). Respond by asking them to pay special attention to these cases.

4 When the students have finished plotting, ask them to draw a smooth curve through the points. Tell the students to work in pairs to examine their curves and answer the question: How does the orbital speed change as you go farther from the center of Saturn?

5 Have the students report out interpretations of their graphs. Show them how the graph shows that orbital speed decreases for objects that are orbiting farther from the center of Saturn. (See *Background for Lesson Discussion*.)

6 Ask students if there was a case where two points were plotted in the same position. Ask the student groups to use information from *Moon and A Ring Data* (Figure 4) to study this case carefully. Then ask them to compare the orbital speeds of two orbiting bodies located at the same distance from Saturn, where one has a larger mass. (See *Background for Lesson Discussion*.)

7 Have students report out and discuss interpretations of the data. Guide them so that they recognize that orbital speed is the same for objects that are the same distance from the center of Saturn, regardless of mass.

To illustrate this idea further, ask students to consider the case of the Space Shuttle in Earth orbit and an astronaut using a maneuvering unit outside the Shuttle. Do the Shuttle and the astronaut orbit at the same speed even though their masses are very different? (The answer is yes.) As long as objects are the same distance from the center of the object being orbited, they orbit at the same speed.

Part III: Assessment

1. Have each student write a description of the forces that keep the planets and asteroids of our Solar System in orbit about the Sun.

2. Ask students to write down their predictions of how the orbital speed of the planets in our Solar System changes with distance from the center of the Sun.

3. Give each student a copy of *Solar System Data* (Figure 8) and *Orbital Speed vs. Distance from Sun* (Figure 9).

4. Have each student graph the relevant data from *Solar System Data* onto *Orbital Speed vs. Distance from Sun*. You may wish to display a transparency of Figure 9 and demonstrate the first part of the plot. For the teacher, a completed plot is shown in Figure 10.

5. Ask students to interpret the graph and write down a summary of their discoveries about orbital speed. How does orbital speed depend on distance from the center of Saturn? For a given distance from the center of Saturn, does the orbital speed depend on mass or size? Ask them to point to specific data to support their discoveries. Ask them to compare their conclusions with their initial predictions, writing down how their ideas changed.

Assessment Criteria

- *Students apply learning about gravity in the contexts of rolling balls in the classroom, the Saturn system, and the Solar System.*
- *Students correctly infer that the Sun's gravity keeps the planets and asteroids in orbit, and that an orbiting planet is essentially falling around the Sun like a ball could fall around Earth.*
- *Students make predictions about orbital speed.*
- *Students plot data correctly from the chart.*
- *Students interpret data on the chart and graph to draw the correct conclusion that orbital speed decreases for planets that are more distant from the Sun.*

Part IV: Questions for Reflection

- In what respects are the Saturn system and the Solar System the same?
- What would happen to the orbital speed of Earth if it were twice as massive but remained in orbit at the same distance from the Sun?
- How is the orbital speed of a planet dependent on its distance from the Sun?

Questions

These questions and their answers can be used to provide background for teachers or to explore prior knowledge and facilitate discussions with students. The answers are found in Appendix 1*, starting on page 225.*

Saturn

1. When did we discover Saturn?
2. How did Saturn get its name?
3. Where is Saturn located?
4. How old is Saturn?
5. How big is Saturn?
6. If Saturn is so much more massive than Earth, why is it said that Saturn could float in water?
7. What is Saturn made of?
8. Could we breathe Saturn's atmosphere?
9. Pictures of Saturn show that it sort of flattens out near the poles and is wider at the equator. Why is that?
10. Why is Saturn so much larger and more massive than Earth?
11. Since Saturn does not have a solid surface, would I sink to the middle of the planet if I tried to walk there?
12. What's gravity like on Saturn? Would I weigh the same on Saturn as on Earth?
13. What is the temperature on Saturn?
14. Does Saturn have winds and storms?
15. Since Saturn and Jupiter are both made up of mostly hydrogen and helium, why isn't Saturn the same color as Jupiter?
16. Is there life on Saturn?
17. Does Saturn have a magnetic field like Earth's?
18. How long is a day on Saturn?
19. How long is a month on Saturn?
20. How long is a year on Saturn?
21. Does Saturn have seasons like Earth?

Rings

22. How did we first find out about Saturn's rings?
23. What are the rings of Saturn made of? Are they solid?
24. How many rings are there?
25. Do the rings move?
26. In the opening sequence of the TV show *Star Trek: Voyager*, a ship passes through the rings of Saturn from bottom to top. Do the rings contain more empty space or more solid particles?
27. How big are the rings?
28. How much stuff is in the rings?
29. Do ring particles collide?
30. Why does Saturn have rings? How were the rings made?
31. How old are the rings? Has Saturn always had rings? Will it always have rings?
32. Are there other planets with rings?
33. Why doesn't Earth have rings?
34. If Earth had rings like Saturn's what would they look like from the ground?

Moons

35. How many moons does Saturn have?
36. Who discovered all these moons?

37. How did the moons get their names?
38. Are Saturn's moons like Earth's Moon?
39. Why does Saturn have so many moons, but Earth has only one?
40. Are Saturn's moons in the rings? Do the moons collide with the ring particles?
41. What is the difference between a moon and a ring particle?
42. What's gravity like on Saturn's moons? Could we walk there?
43. Are there volcanoes on any of Saturn's moons?
44. How cold are Saturn's moons?
45. Do any of Saturn's moons have an atmosphere? Could we breathe it?
46. Is there water on Titan?
47. Is there life on Titan?
48. What is the weather like on Titan?
49. Cassini carries a probe that is going to Titan, not Saturn or any other moons? Why Titan?
50. Will there be a mission that takes humans to Titan in the near future?

LESSON 3

Materials

Figure 1	**Baseball Player Hitting a Baseball Pitched from Space**
Figure 2	**Cannon Shooting a Cannonball**
Figure 3	**Close-up of Saturn's Rings with Ring Particle and House**
Figure 4	**Moon and A Ring Data — for Students**
Figure 5	**Orbital Speed vs. Distance from Center of Saturn — for Students to Complete**
Figure 6	**Moon and A Ring Data — for Teacher (shading shows items for students to plot)**
Figure 7	**Orbital Speed vs. Distance from Center of Saturn — Completed Plot for Teacher**
Figure 8	**Solar System Data — for Students**
Figure 9	**Orbital Speed vs. Distance from Sun — for Students to Complete**
Figure 10	**Orbital Speed vs. Distance from Sun — Completed Plot for Teacher**

LESSON 3

Figure 1

Baseball Player Hitting a Baseball Pitched from Space

LESSON 3

Cannon Shooting a Cannonball

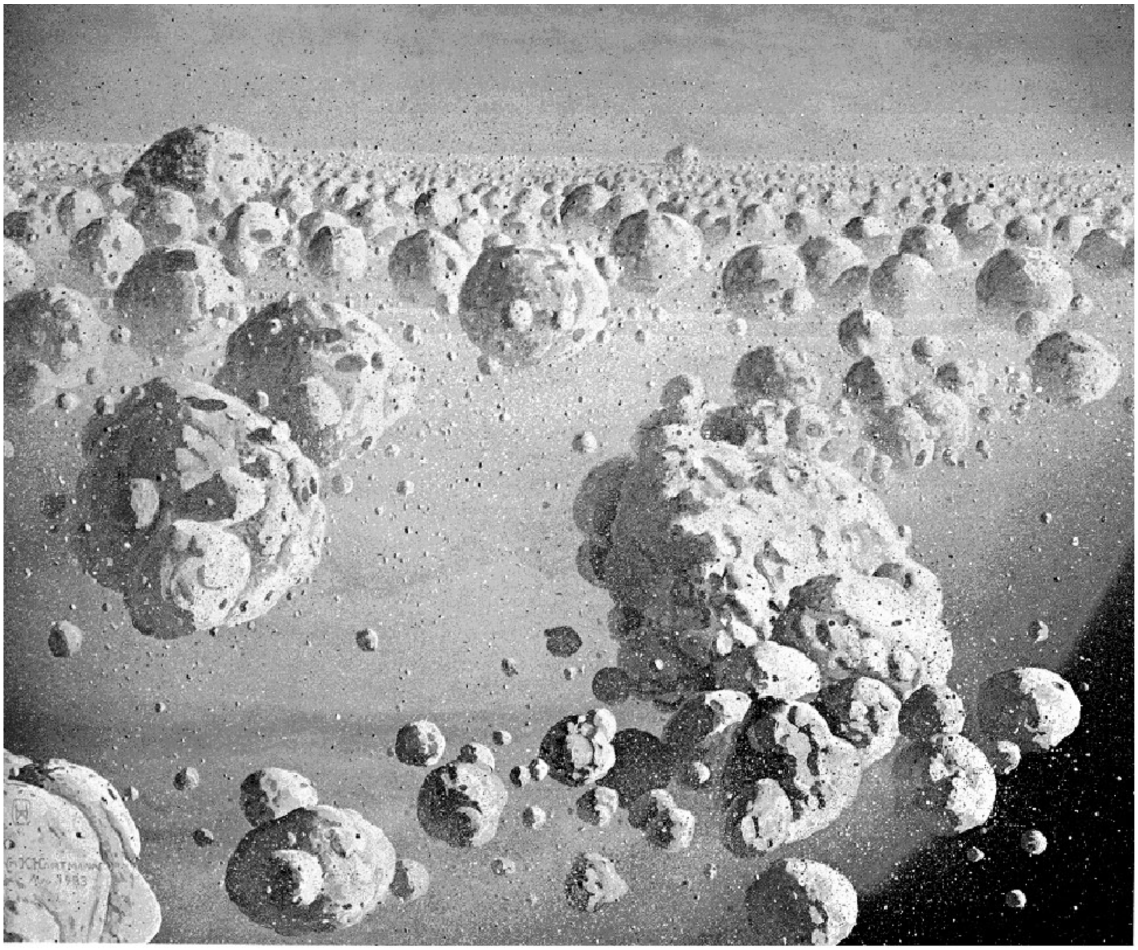
LESSON 3

Figure 2

LESSON 3

LESSON 3

Figure 3


Wm. K. Hartmann

LESSON 3

Figure 4

Moon and A Ring Data — for Students

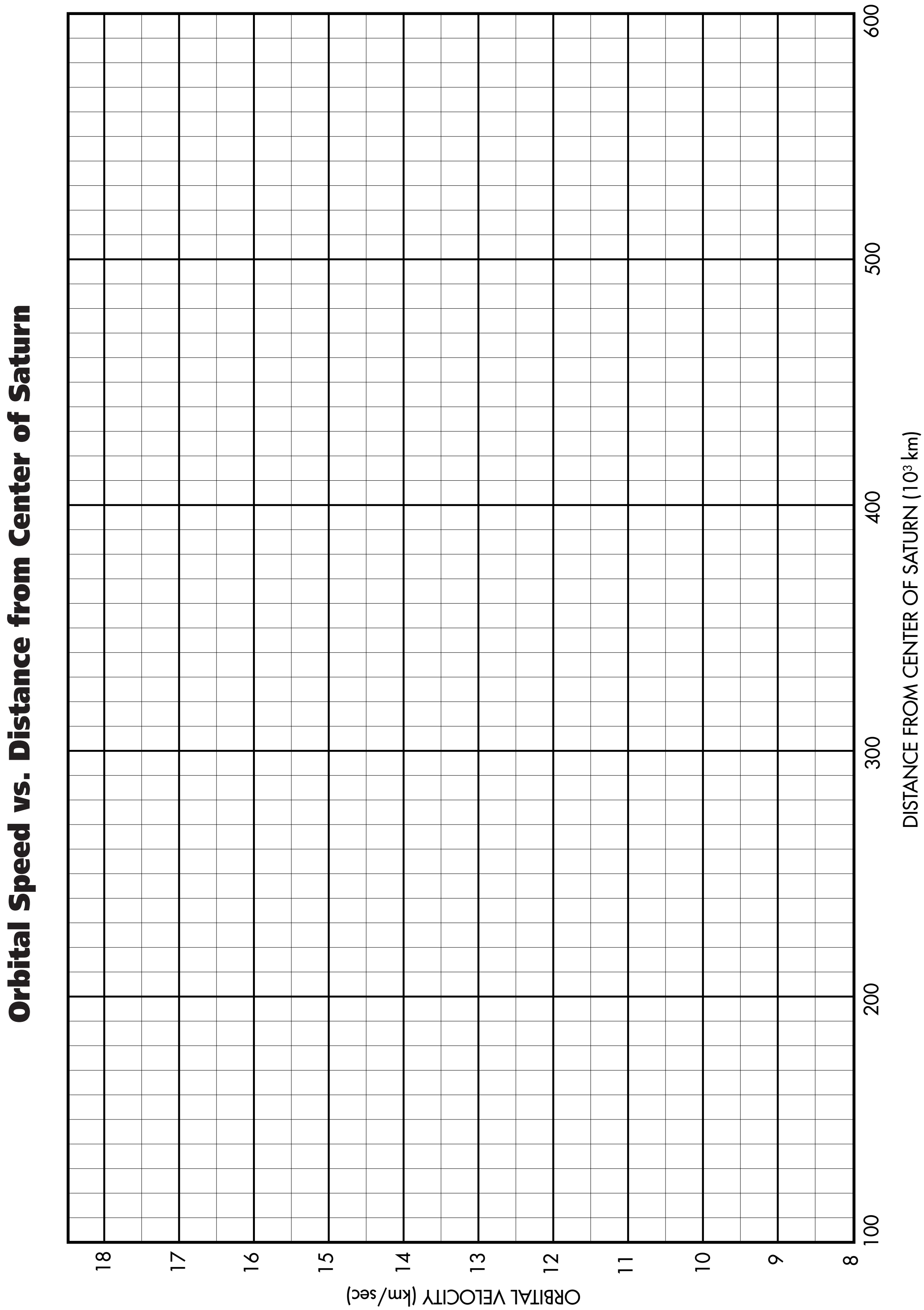
Use this information to complete your plot of Orbital Speed vs. Distance from Center of Saturn.

Moon or Ring	Special Features or Behavior	Distance from Center of Saturn (10^3 km)	Speed of Moon in Orbit (km/sec)
A Ring — Inner Edge	Forms outer edge of Cassini Division	122.2	17.63
Pan	Orbits in Encke Gap, sweeping it clean	133.6	16.84
A Ring – Outer Edge	"Guarded" in its outer edge by the moon Atlas	136.8	16.66
Atlas	May keep the outer edge of the A ring well defined	137.6	16.63
Pandora	Shepherd moon; helps keep the F ring narrow	141.7	16.38
Epimetheus	Irregular; may have been joined with Janus	151.4	15.87
Mimas	Has giant crater called Herschel; looks like "Death Star" moon	185.5	14.32
Enceladus	Icy, shiny; may have ice geysers that feed E ring	238.0	12.63
Tethys	Has large trench called Ithaca Chasma; large crater called Odysseus	294.7	11.34
Telesto	Same orbit as Tethys (60° behind); less massive than Tethys	294.7	11.34
Dione	Cratered leading face; wispy features on trailing hemisphere	377.4	10.03
Rhea	Largest icy satellite; densely cratered	527.0	8.49

LESSON 3

Figure 5

Orbital Speed vs. Distance from Center of Saturn — for Students to Complete



LESSON 3

Figure 6

Moon and A Ring Data — for the Teacher (shading shows items for students to plot)

Use this information to complete your plot of Orbital Speed vs. Distance from Center of Saturn.

Moon or Ring	Special Features or Behavior	Distance from Center of Saturn (10^3 km)	Speed of Moon in Orbit (km/sec)
A Ring — Inner Edge	Forms outer edge of Cassini Division	122.2	17.63
Pan	Orbits in Encke Gap, sweeping it clean	133.6	16.84
A Ring – Outer Edge	"Guarded" in its outer edge by the moon Atlas	136.8	16.66
Atlas	May keep the outer edge of the A ring well defined	137.6	16.63
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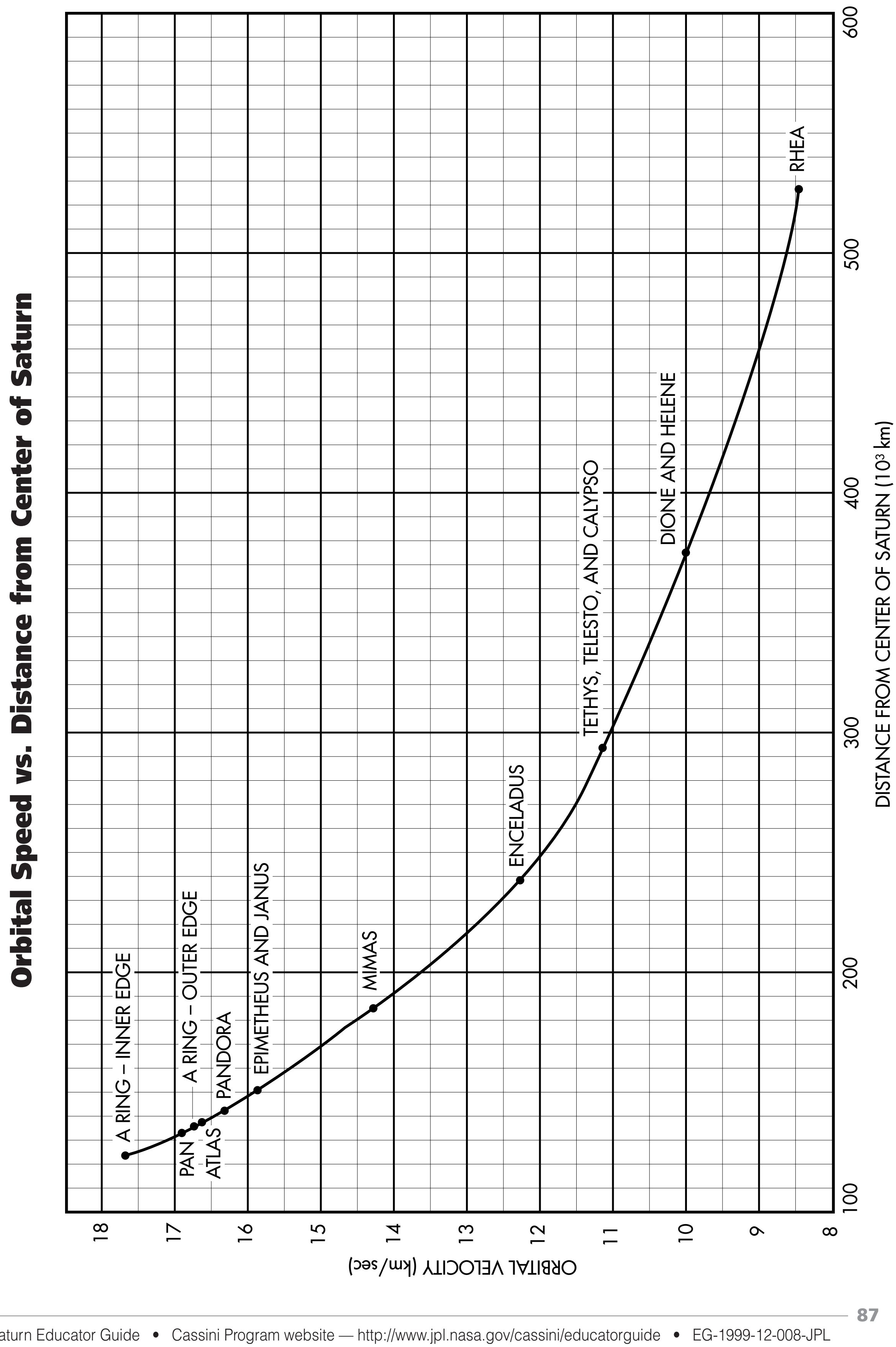
Pandora	Shepherd moon; helps keep the F ring narrow	141.7	16.38
Epimetheus	Irregular; may have been joined with Janus	151.4	15.87
Janus	Irregular; trades orbits with Epimetheus	151.5	15.85
Mimas	Has giant crater called Herschel; looks like "Death Star" moon	185.5	14.32
Enceladus	Icy, shiny; may have ice geysers that feed E ring	238.0	12.63
Tethys	Has large trench called Ithaca Chasma; large crater called Odysseus	294.7	11.34
Telesto	Same orbit as Tethys (60° behind); less massive than Tethys	294.7	11.34
Calypso	Same orbit as Tethys (60° ahead); less massive than Tethys	294.7	11.34
Dione	Cratered leading face; wispy features on trailing hemisphere	377.4	10.03
Helene	Same orbit as Dione (60° ahead); less massive than Dione	377.4	10.03
Rhea	Largest icy satellite; densely cratered	527.0	8.49

Figure 7

Orbital Speed vs. Distance from Center of Saturn — Completed Plot for Teacher



LESSON
3

LESSON 3

Figure 8

Solar System Data — for Students

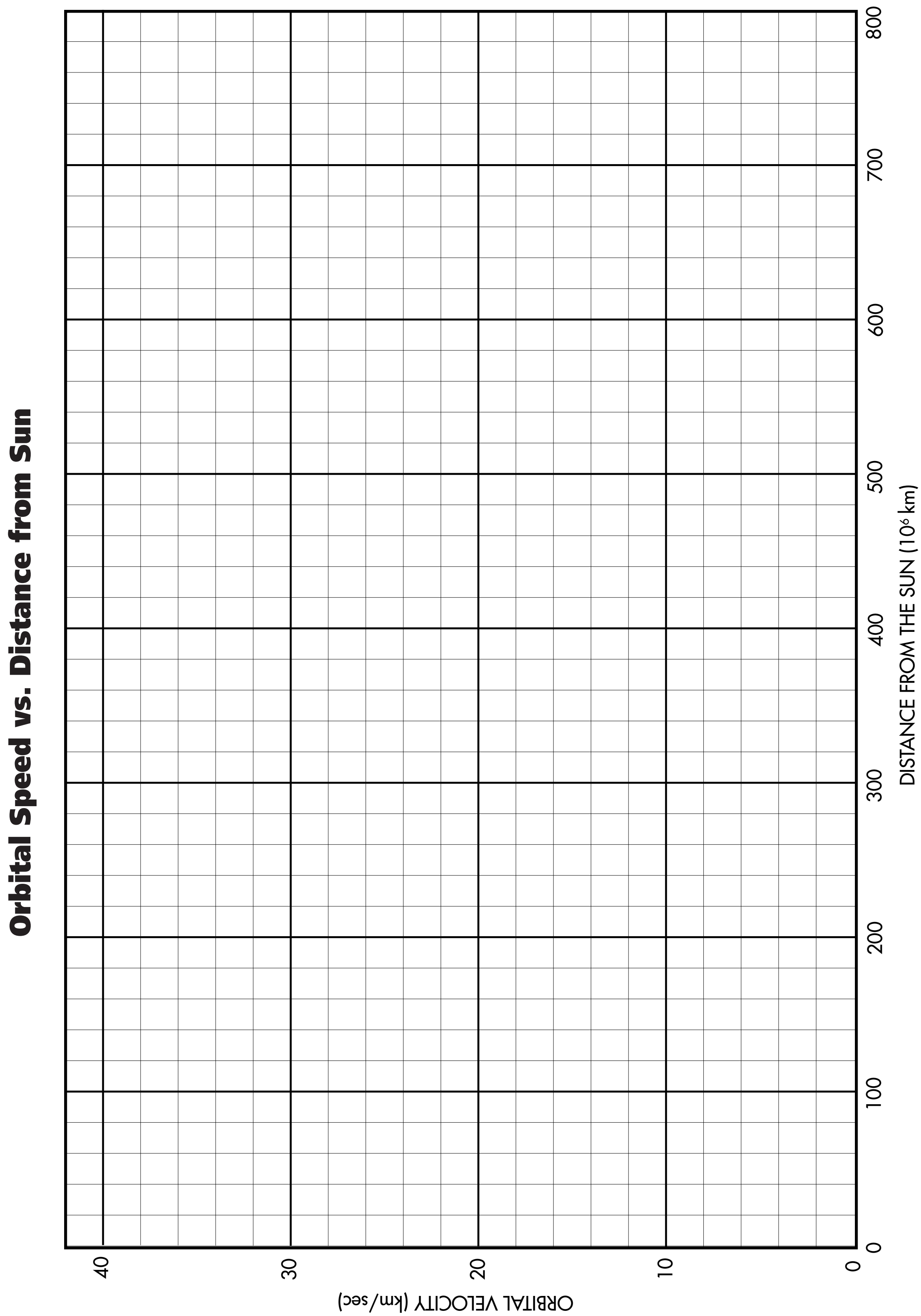
Use this chart to plot Orbital Speed vs. Distance from Sun.

Object	Distance from Sun ($\times 10^6$ km)	Orbital Speed (km/sec)	Mass ($\times 10^{24}$ kg)	Diameter (km)
Venus	108.2	35.0	4.87	12,104
Earth	149.6	29.8	5.97	12,756
Mars	227.9	24.1	0.642	6,794
Asteroid Ceres	414	17.9	Unknown	1,000
Jupiter	778.3	13.1	1,900	142,984

LESSON 3

Figure 9

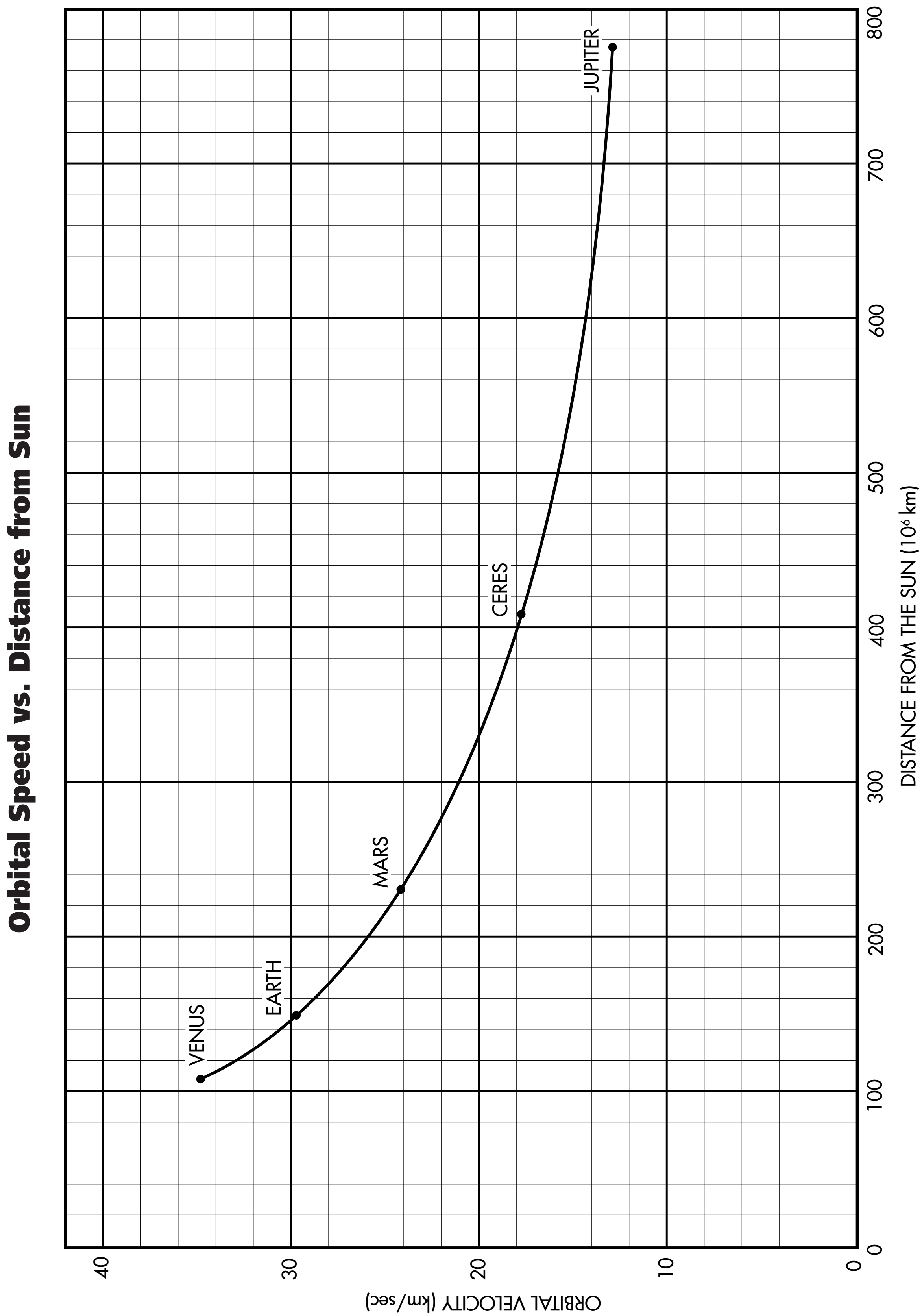
Orbital Speed vs. Distance from Sun — for Students to Complete



LESSON 3

Figure 10

Orbital Speed vs. Distance from Sun — Completed Plot for Teacher



LESSON 3

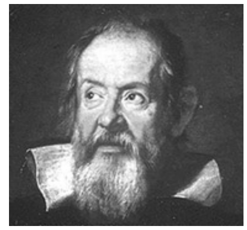
LESSON 4

3 hrs

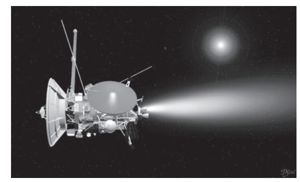
History of Saturn Discoveries

Students use *History of Discovery* cards and interpretive skits to examine how scientists throughout history have explored Saturn. The lesson enables students to discern the multicultural nature of scientific inquiry and to see how the improvement of technology increases our ability to solve scientific mysteries.

The lesson also prepares students to create and interpret their own timelines spanning the years 1610 to 2010. The timelines depict scientists, technologies, and discoveries.



1610 - 2010



MEETS NATIONAL SCIENCE EDUCATION STANDARDS:

History and Nature of Science
- *Science as a human endeavor*
- *History of science*

Science and Technology
- *Understandings about science and technology*

PREREQUISITE SKILLS

Measuring in centimeters
Reading science content
Recording key information
Creating timelines

BACKGROUND INFORMATION

Background for Lesson Discussion, page 96
Questions, page 99
Answers in *Appendix 1*, page 225
35–50: Moons
56–63: The Cassini–Huygens Mission

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher

Photocopier (for transparencies & copies)
Overhead projector
Chalkboard, whiteboard, or easel with paper; chalk or markers
1-meter (or 2-meter) strip of adding-machine tape or butcher paper

For each of 10 student groups

Chart paper (18" × 22"); markers

For each student

1-meter (or 2-meter) strip of adding-machine tape or butcher paper
Markers
Notebook paper; pencil

Materials to reproduce

Figures 1–14 are provided at the end of this lesson.

FIGURE	TRANSPARENCY	COPIES
1	1	
2–11		1 card per group
12		1 per group
13		1 per student
14		1 for teacher

Background for Lesson Discussion

History of discovery

(See Procedures & Activities, Part II, Step 6)

Here are some questions *(with answers)* to help students in interpreting the data they collect on their *History of Discovery* tables.

- What do you notice about technology over time?

Answer — The type of technology changed from small refracting telescopes to larger reflecting telescopes, then to spacecraft that flew by Saturn, and finally, to a spacecraft (Cassini–Huygens) that will orbit Saturn and tour the Saturn system.

- What do you notice about the dates of discoveries?

Answer — There were long periods of time between discoveries. More discoveries have been made in recent years.

- What do you notice about the discoveries as technology improves?

Answer — The discoveries are more numerous and more detailed as technology improves. Technology improved dramatically within the last century, so the discoveries increased dramatically as well.

Ancient astronomers

(See Procedures & Activities, Part II, Step 3)
Students may want to know more about ancient astronomers. Here is some background information: People in ancient cultures — as long as 5,000 years ago, according to the records they left us — followed the motions of the Sun, the Moon, stars, and planets. The earliest recorded observations of Saturn appear to have been made by astrologer-priests during the reign of King Esar-haddon of Assyria in about 700 B.C.

Early observers watched the sky for omens. They realized that while the stars generally traversed the night sky in unchanging patterns, there were some points of light that appeared to wander across the starry background. In fact, the name given by early Greek astronomers to these points of light was "planetes," which meant "wandering stars."

People all over the world have given their own names to the Sun, the Moon, the stars, and the planets. The Greeks named one of the bright "planetes" after their god Cronos. The Romans considered Cronos to be the same as their god Saturn. Almost 1,500 years after the ancient Roman culture flourished, European astronomers explained the motions of the wandering lights in terms of a system with planets orbiting the Sun — a Solar System. European astronomers generally accepted the Roman names for the planets and selected Roman names for new celestial objects found with the aid of telescopes.

According to the National Science Education Standards, students should know that:

- **People of all backgrounds — with diverse interests, talents, qualities, and motivations — engage in science and engineering. Some of these people work in teams and others work alone, but all communicate extensively with others.**
- **Throughout history, many scientific innovators have had difficulty breaking through accepted ideas of their times to reach conclusions that are now accepted as common knowledge.**
- **Technology drives science because it provides the means to gain access to outer space; collect and analyze samples; collect, measure, store, and compute data; and communicate information.**
- **Science drives technology because it provides principles for developing improved instrumentation and techniques and the means for addressing questions that demand more sophisticated instruments.**

LESSON 4

Lesson Plan

Part I: How Do We Know What We Know about the Planets?

1 Ask students: How do we know all that we know about the planets in our Solar System?

2 Record their responses on the chalkboard (or whiteboard or easel paper).

Part II: Connections to Saturn

1 Have the students form 10 groups. Have each group write answers to the following question on chart paper: What do you know to be true about Saturn?

2 Have the student groups post their charts and report out. Then ask the students: How do we know all that we know about Saturn? ("Knowing" could be the result of observing through sky-watching, telescopes, or space missions.) Record their answers on the chalkboard.

3 Display a transparency of *Sky Observation by Ancient Cultures* (Figure 1). Introduce the idea that Saturn was observed by ancient cultures as a wandering point of light in the night sky. Interpret the text in the figure, and ask the students to look at the drawings (the "sky pictures") and determine which point of light is wandering in the pictures provided.

Additional material: See Appendix 3 for an illustration and accompanying table depicting Saturn's position in the sky over the course of the Cassini mission. The illustration and table could be made into transparencies for display and discussion.

4 Tell students that they will receive information about different observers of Saturn — people or space missions. Give each of the 10 groups a copy of one *History of Discovery Card* (Figures 2–11). You will need to cut the pages along the dashed lines, or in half, as each page has two cards printed on it. Give each group a copy of the *Interview Guide* (Figure 12). Tell the students to prepare an interview role-play by answering the questions on the *Interview Guide*. The students should read their group's card and interpret the information, focusing on the people (or space mission), the technology, and the discoveries that resulted. The *Glossary* (*Appendix 2*) provides definitions of terms.

5 Ask the students to divide the work among group members to include the following roles: reader, interviewer, recorder, and actor who represents the scientist or space mission. To prepare for the role-play, the reader reads the card to the group. The group discusses how the actor will answer the interview questions and agrees on the responses. During the role-play, the interviewer asks the questions from the *Interview Guide*. The actor responds to the interview questions based on the group's discussion of the answers. The recorder writes the answers on the *Interview Guide*.

Suggest that actors respond dramatically to the questions. As an option, the students might use props and/or costumes that fit the information on their card.

6 Give each student a copy of the *History of Discovery Table — for Students* (Figure 13). Have each group role-play their interview for the class in chronological order of their *History of Discovery Card*. While each group role-plays their interview, have the students take notes on their *History of Discovery Table*.

7 When all discoveries have been role-played and recorded, ask the students what they have learned about technological advancements and discoveries about Saturn. Discuss the relationship between scientific discovery and technology and how knowledge about Saturn has

changed over time as a result of technological advancements. Guide students to see that many kinds of people in different cultures have made and continue to make contributions to science and technology. (See *Background for Lesson Discussion*.)

Part III: Assessment

1 Post a 1-meter strip of adding-machine tape or butcher paper on the chalkboard. Measure and record dates from 1610 to 2010 on the strip of paper, as shown below. Explain that the 25-cm increments represent 100-year periods. Alternately, you might use a 2-meter strip having 50-cm increments.

2 Give each group a strip of paper that is 1 meter (or 2 meters) long. Instruct the students to use the data on their *History of Discovery Table* to create a timeline of technology advancements and discoveries about Saturn. The students' timelines should have three types of information: 1) date, 2) technology, and 3) major Saturn discoveries. You might have the students use different colors for each type of information.

3 Have each student interpret the timeline and compose a letter to Galileo on notebook paper telling him how scientific understanding of Saturn has evolved (and might yet evolve) since the time of his observations. Ask students to address these questions: What news would be most exciting to share with Galileo? What advances have been made in technology? What additional discoveries were made due to these advances? What do we hope to learn by the year 2010, after the Cassini spacecraft has toured the Saturn system?

Assessment Criteria

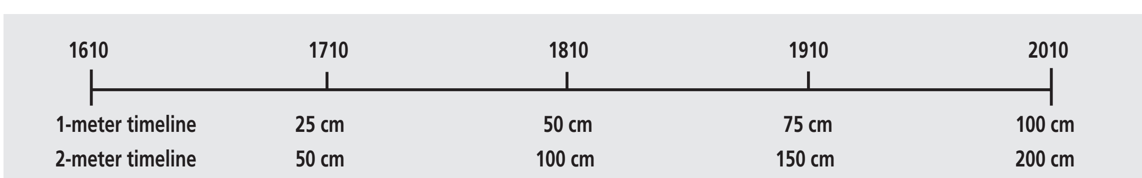
1. Figure 14 is a History of Discovery Table *for the teacher that includes the correct location on the timeline for each of the Saturn explorers (scientist or spacecraft), plus a listing of discoveries and technologies.*

2. Each student's timeline should have:
- *Years properly labeled and spaced.*
- *Names, discoveries, and technologies properly placed and labeled.*

3. Each student's letter to Galileo should contain an explanation about the relationship between improved technology and increased discoveries. The letter should also give one or more examples of specific discoveries and the technology used to make the discoveries.

Part IV: Questions for Reflection

- What are the different categories of technologies that have been used to explore Saturn?
- What different cultures have been represented by the scientists who have made discoveries about Saturn?



Questions

These questions and their answers can be used to provide background for teachers or to explore prior knowledge and facilitate discussions with students. The answers are found in Appendix 1*, starting on page 225.*

Moons

35. How many moons does Saturn have?
36. Who discovered all these moons?
37. How did the moons get their names?
38. Are Saturn's moons like Earth's Moon?
39. Why does Saturn have so many moons, but Earth has only one?
40. Are Saturn's moons in the rings? Do the moons collide with the ring particles?
41. What is the difference between a moon and a ring particle?
42. What's gravity like on Saturn's moons? Could we walk there?
43. Are there volcanoes on any of Saturn's moons?
44. How cold are Saturn's moons?
45. Do any of Saturn's moons have an atmosphere? Could we breathe it?
46. Is there water on Titan?
47. Is there life on Titan?
48. What is the weather like on Titan?
49. Cassini carries a probe that is going to Titan and not Saturn or any other moons. Why Titan?
50. Will there be a mission that takes humans to Titan in the near future?

The Cassini–Huygens Mission

56. Why are we sending a spacecraft and not people to Saturn?
57. What will the Cassini robot do?
58. What spacecraft have been to Saturn? How have we gathered information about Saturn up until now?
59. What will Cassini learn that we do not already know from Voyager and Hubble Space Telescope data?
60. Why care about the Cassini mission?
61. Why is NASA's mission to Saturn called Cassini?
62. How much does the Cassini mission cost? Who pays for it?
63. How long does it take to plan and carry out a mission like Cassini?

LESSON 4

Materials

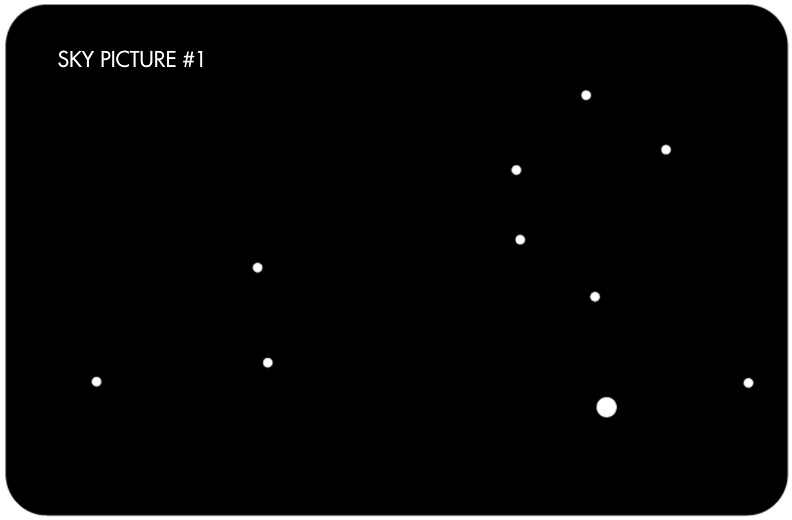
Figure 1	**Sky Observation by Ancient Cultures (2 pages)**
Figures 2–11	**History of Discovery Cards**
Figure 12	**Interview Guide**
Figure 13	**History of Discovery Table — for Students (2 pages)**
Figure 14	**History of Discovery Table — for Teacher**

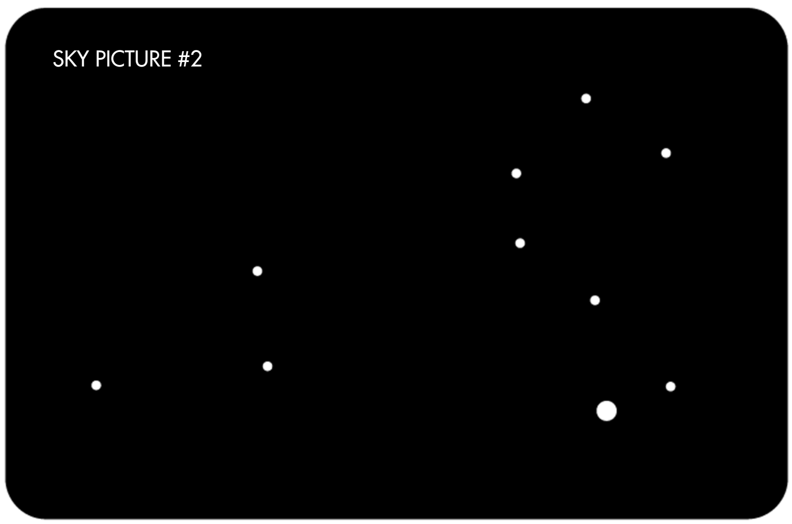
Sky Observation by Ancient Cultures

LESSON 4

Figure 1 (1 of 2)

These "sky pictures" show the constellation Leo — notice that a point of light moves through the constellation. The pictures are separated in time by approximately one month. The wandering light is the planet Saturn.





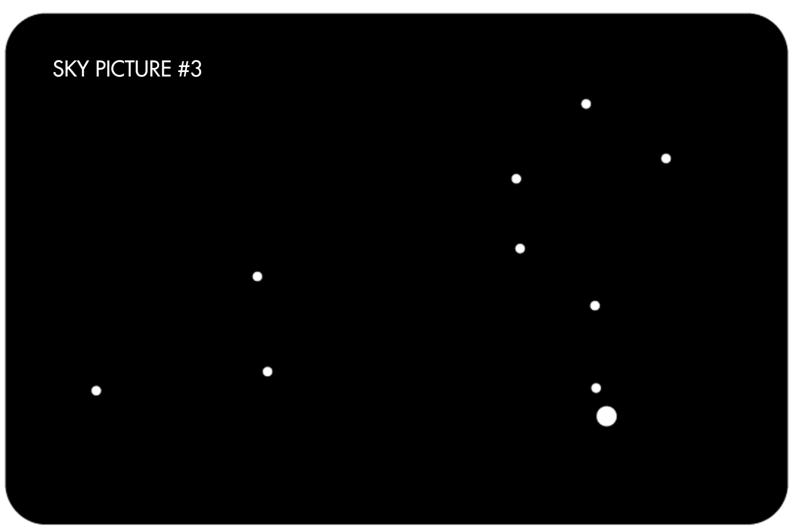
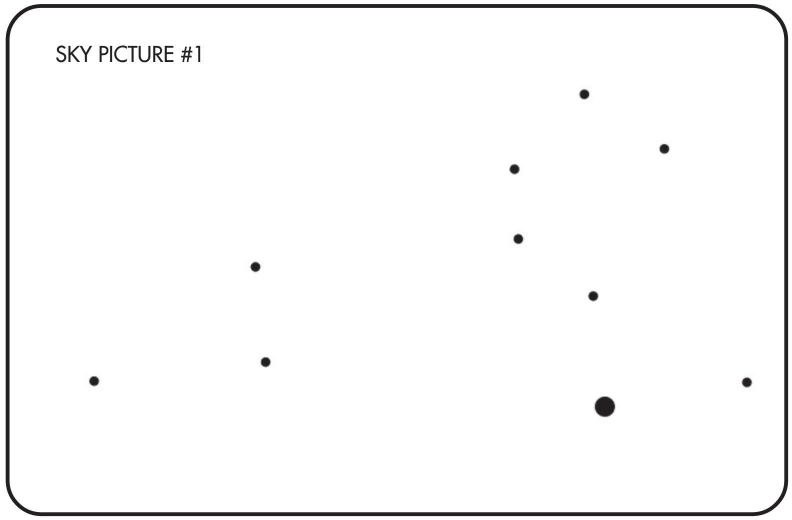
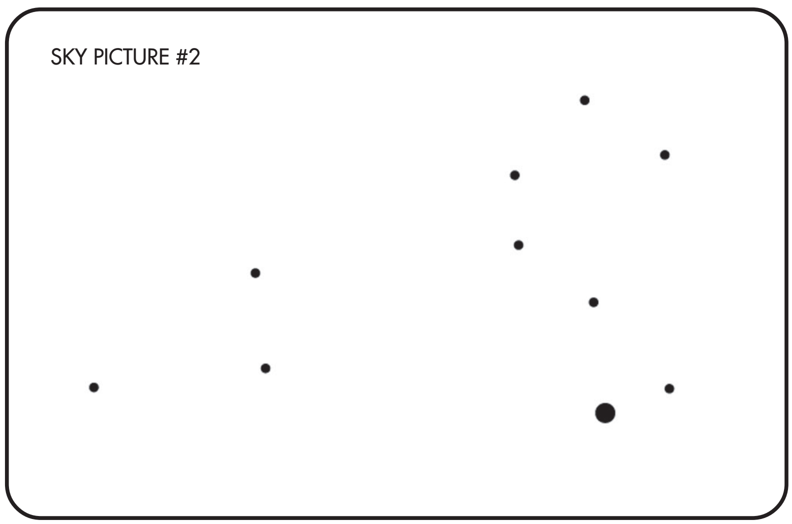
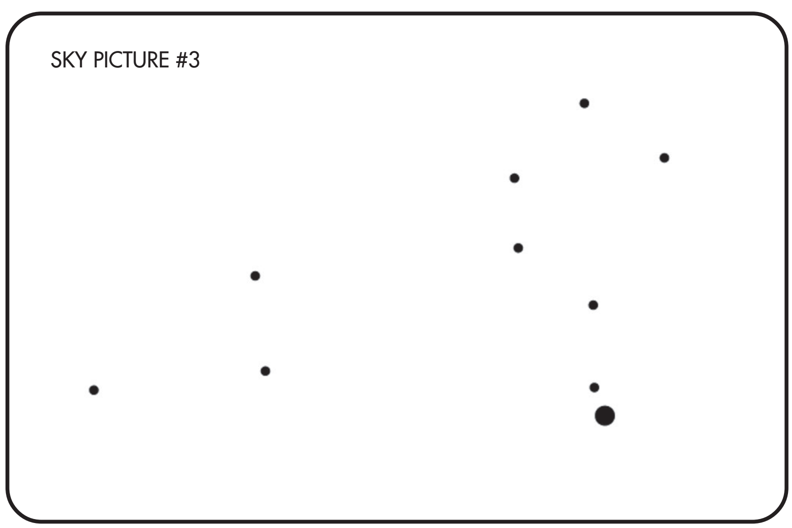


Figure 1 (2 of 2)

Astronomers frequently use "negative" images of star fields for detailed studies because black stars and other celestial objects on a white background are easier to see. At night, "negative" star charts are often easier to use with a flashlight.







LESSON

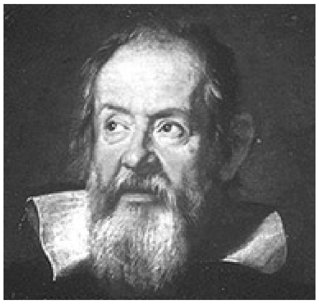
4

Figure 2

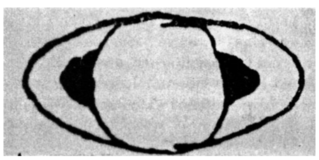
History of Discovery Card

Galileo Galilei 1610

Italian astronomer (1564–1642)



Istituto e Museo di Storia della Scienza



Le Opera di Galileo Galilei Edizione Nazionale

In 1610, Galileo Galilei observed Saturn through a refractor telescope, which used lenses a few inches across to magnify distant objects by 20 to 30 times. He observed Saturn to be “triple,” thinking that he was seeing two “lesser stars” (moons) or companions to the planet, or perhaps they were two bulges that were features of the main body. In the fall of 1612 he observed Saturn again and to his surprise he found the planet to be perfectly round! In 1616, he found that Saturn’s “companions” had reappeared and grown, and he made a drawing that today would be readily interpreted as Saturn and its ring system. Galileo died never knowing that he’d been the first to observe Saturn’s rings.

(Middle) Galileo’s 1610 drawing of Saturn. His telescope was unable to resolve the ring shape and he thought he was seeing three objects.

(Left) Galileo’s 1616 drawing of Saturn. He was able to discern the ring shape but thought it was attached to the planet.

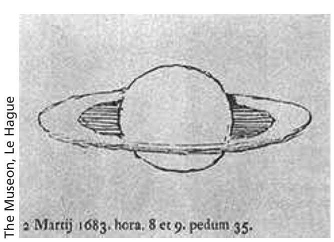
Figure 3

History of Discovery Card

Christiaan Huygens 1655

Dutch astronomer (1629–1695)

Huygensmuseum Hofwijck



The Museon, Le Hague

In March 1655, at age 26, Christiaan Huygens viewed Saturn through a more powerful telescope than Galileo’s. Huygens’ skill at crafting lenses allowed his instrument to magnify objects about 50 times. Huygens’ observations and his study of other astronomers’ observations led him to determine that Saturn had a flat ring encircling its equator, and unlike Galileo, he could see that the ring did not touch the planet. Huygens discovered Saturn’s largest moon, which would be named Titan 200 years later. He observed that the moon orbited Saturn every 16 days. Its orbit was well beyond the extent of the ring, but like the ring, it was in the plane of Saturn’s equator. He recognized that the disappearance of Saturn’s “companions,” which Galileo had observed in 1612, occurred whenever Saturn’s thin ring appeared edge-on to Earth observers. This event occurs about every 15 years because, like the Earth, Saturn’s north–south axis is tilted. This tilt causes our view of Saturn’s rings to change as the planet travels in its 30-year orbit around the Sun. The Huygens probe to Titan, built by the European Space Agency, is named after Christiaan Huygens.

(Bottom) Huygens’ drawing of Saturn, 1683.

LESSON 4

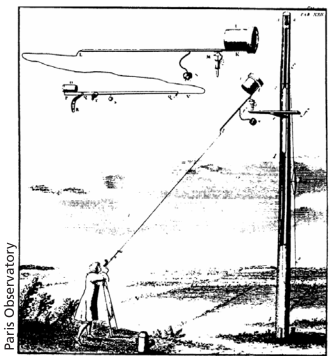
Figure 4

History of Discovery Card

Jean-Dominique Cassini 1675

Italian–French astronomer (1625–1712)

Paris Observatory



Paris Observatory

In the late 17th century, Jean-Dominique Cassini studied Saturn from the Paris Observatory using a series of refracting telescopes. Cassini's largest telescope was 136 feet long, dwarfing Galileo's 4-foot telescope and allowing him to see far greater detail. In 1675, Cassini discovered that Saturn's "solid" ring had a gap in it that divided it into two separate rings. Today this gap is called the Cassini Division. The ring outside the division is the A ring, while the brighter ring within is the B ring. No one yet knew what the rings were made of, how thick they were, or whether they were permanent features around Saturn. Cassini also discovered four moons of Saturn (the moons weren't named until later): Iapetus (1671), Rhea (1672), and Tethys and Dione (1684). Other moons would not be discovered until over a century later. Cassini is the astronomer for whom NASA's Cassini mission to Saturn is named.

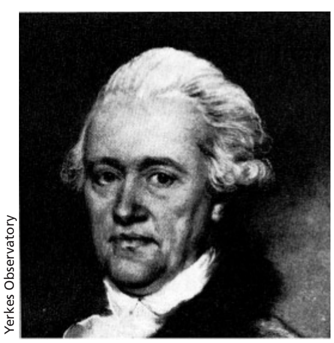
(Left) Many astronomers of Cassini's time used tubeless telescopes. A framework structure or a rope, as shown here, was used to align the eyepiece with the objective lens.

Figure 5

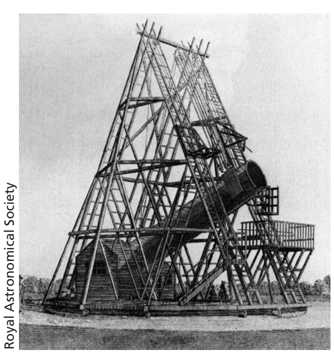
History of Discovery Card

William Herschel 1781

German–British astronomer (1738–1822)



Yerkes Observatory



Royal Astronomical Society

In 1781, William Herschel discovered the planet Uranus beyond the orbit of Saturn, ending Saturn's long reign as the most-distant planet. The discovery also effectively doubled the size of the Solar System because Uranus is twice as far away from the Sun as is Saturn. In 1789, Herschel discovered the sixth and seventh moons of Saturn, which would later be named Mimas and Enceladus. Herschel was among the first to use a reflecting telescope, which used mirrors instead of lenses to focus the light coming from distant objects. He constructed and used a telescope with a 48-inch mirror that weighed a ton and was housed in a tube 40 feet long. The telescope was located in his backyard in Bath, England. To reach the eyepiece, he climbed a scaffolding that rose 50 feet into the air! Herschel was often assisted by his sister Caroline, who was also an accomplished astronomer.

Royal Astronomical Society

(Above) Caroline Herschel.

(Left) Herschel's 40-foot-long reflector telescope in Bath, England.

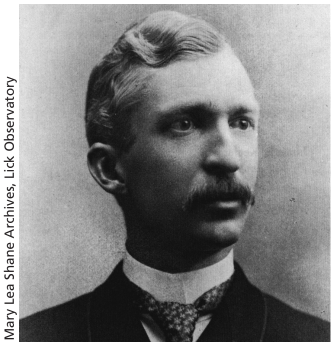
LESSON 4

Figure 6

History of Discovery Card

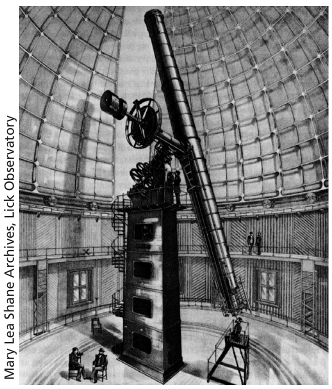
James Keeler 1895

American astronomer (1857–1900)



Mary Lea Shane Archives, Lick Observatory

In 1888, James Keeler observed Saturn with the telescope at the Lick Observatory in California. On the first night the observatory began operating, Keeler saw a narrow, dark gap close to the outer edge of Saturn's A ring. This gap is now called the Encke Gap (the astronomer Johann Encke received the credit, though he could not quite resolve the gap in detail when he observed it in 1837). In 1895, Keeler observed Saturn's rings using a telescope at the Allegheny Observatory in Pennsylvania. Connected to the telescope was a spectrograph, which analyzed the light reflected from the rings. The light he saw indicated that the innermost parts of the rings were moving around Saturn faster than the outermost parts. This offered experimental evidence that the rings were not a solid disk, but instead made up of individual particles moving like tiny moons around Saturn.



Mary Lea Shane Archives, Lick Observatory

(Left) An 1888 engraving of the 36-inch refractor used by Keeler at the Lick Observatory.

Figure 7

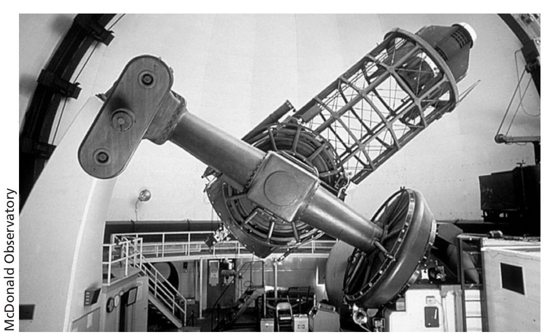
History of Discovery Card

Gerard Kuiper 1944

Dutch–American astronomer (1905–1973)

Yerkes Observatory

In 1944, Gerard Kuiper [KOY-per] discovered Titan's atmosphere using a spectrograph attached to a reflector telescope at McDonald Observatory in Texas. Unlike Keeler's spectrograph, Kuiper's spectrograph detected infrared light (that is, infrared radiation, often called heat) instead of visible light. Kuiper was particularly interested in finding out if any of the moons orbiting around other planets in the Solar System had atmospheres. He studied the infrared light reflected off the 10 largest moons, and in 1944 he reported that Titan, the largest moon of Saturn, was the only one having an atmosphere that could be easily detected. Astronomers observed the sky only in visible light until the 1930s, when the first radio-wavelength observations were made. Today, we view the Universe across the entire electromagnetic spectrum, in radio, microwave, infrared, visible, ultraviolet, x-ray, and gamma ray.



McDonald Observatory

(Left) This is the 82-inch reflector telescope at McDonald Observatory that Kuiper used for his observations.

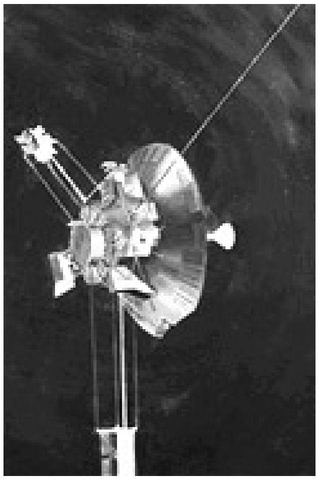
LESSON 4

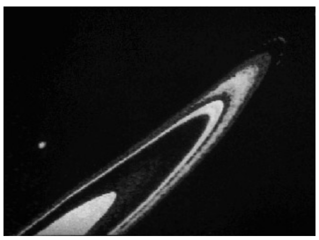
Figure 8

History of Discovery Card

Pioneer 11 1979

U.S. spacecraft





NASA's small robotic observer passed within 22,000 km of Saturn's cloudtops in September 1979, providing the first close-up images of the Saturn system. Pioneer 11 took pictures of Saturn's poles and clouds, detected heat generated deep from within Saturn, made the first measurements of Saturn's magnetic field, confirmed the E ring (suggested in 1967 by scientists studying Earth-based telescope images), discovered the F ring just outside the A ring, and made a possible detection of the G ring (a faint, narrow ring just beyond the F ring). Pioneer 11's view of Saturn was about 50,000 times closer than any Earth-based telescope could see. Pioneer 11 represented a new way for astronomers to explore the planets. Rather than scientists building their own telescopes and working individually to make new discoveries from observatories on Earth, a team of people — scientists, engineers, and different kinds of specialists working together — built a robot having various instruments and sent it into space to send back images and other kinds of data.

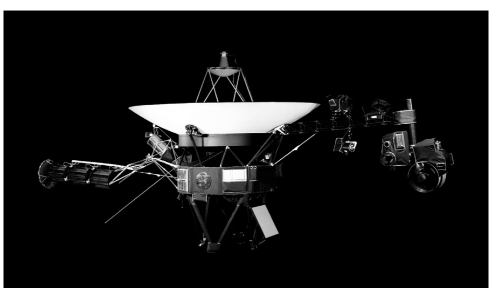
(Left) A portion of Saturn's rings observed by Pioneer 11.

Figure 9

History of Discovery Card

Voyager 1 & 2 1980–1981

U.S. spacecraft



Twin NASA spacecraft made extensive flyby studies of Saturn — in November 1980, Voyager 1 passed within 125,000 km of Saturn's cloudtops, and in August 1981, Voyager 2 passed within 101,000 km. The Voyager missions sent back tens of thousands of color images of the Saturn system. They measured high wind speeds along Saturn's equator, provided close-up pictures of several known moons, and discovered that Titan's atmosphere is very thick and made mostly of nitrogen. The Voyagers also discovered several small moons: Telesto, Calypso, Pan, Atlas, Prometheus, and Pandora. Voyager cameras showed us that Saturn's rings are actually made up of thousands of tiny "ringlets," and that strange spoke-like structures hover above the B ring. The spacecraft confirmed the existence of both the innermost D ring as well as the outer G ring that had been tentatively identified by Pioneer 11. By observing the way radio waves and visible light pass through the rings, scientists inferred from Voyager data that ring particles range in size from nearly invisible dust to icebergs the size of houses.

(Bottom) A Voyager close-up image of Saturn's rings.

LESSON 4

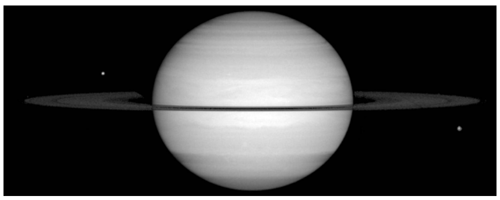
Figure 10

History of Discovery Card

Hubble Space Telescope 1995

U.S. orbiting observatory

IMAX, Smithsonian, Lockheed



NASA launched the Earth-orbiting Hubble Space Telescope (HST) in 1990 from Space Shuttle Discovery. HST's main mirror is 2.4 meters across, and the entire telescope is about the size of a school bus. HST observes in visible, ultraviolet, and infrared light. It is not significantly closer to the planets and stars than are telescopes on the ground, but its views of the Universe are undistorted by Earth's atmosphere. HST orbits the planet every 90 minutes from about 600 km (370 miles) above the surface. Astronauts can visit it every few years to upgrade the instruments. HST has provided views of cloud eruptions in Saturn's atmosphere, monitored the thickness and density of the faint, outermost E ring, and searched for new Saturn moons during times when the rings appear edge-on to Earth observers. HST has also made infrared images of Titan's surface that helped to show where the Cassini mission would land its Huygens probe.

(Top) Deploying the HST on April 25, 1990, from the Space Shuttle.

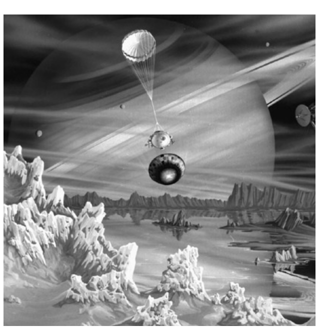
(Bottom) A nearly edge-on view of Saturn's rings taken by the Wide-Field and Planetary Camera aboard HST.

Figure 11

History of Discovery Card

Cassini–Huygens 2004–2008

U.S. spacecraft and European probe



Cassini–Huygens was launched in 1997 and will arrive at Saturn in 2004. During a 4-year tour of the Saturn system, the spacecraft will study the majestic planet, its extraordinary rings, and its moons. The Cassini orbiter carries six instruments to "see" in four kinds of "light" (visible, infrared, ultraviolet, and radio), as well as instruments for measuring dust particles, charged particles, and magnetic fields. The Huygens probe will parachute through Titan's atmosphere and land on the surface, taking more than 1,000 images of Titan's clouds and surface. No human has ever seen the sights that will be captured by the Huygens probe — will there be lakes, oceans, mountains, and craters? Compared with the instruments aboard the Voyagers or the Hubble Space Telescope, the Cassini orbiter instruments can observe in much finer detail. Cassini will have 4 full years to study the Saturn system instead of just a few days as did the Pioneer 11 and Voyager flyby missions. Cassini will fly within about 20,000 km of Saturn's cloudtops, and as close as 1,000 km to some of the moons.

(Top) Cassini–Huygens in the assembly bay at JPL.

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

LESSON 4

Figure 12 (1 of 2)

Interview Guide

Names of Interview Team Members:

Interview questions to be role-played:

1. What is your name and where do you come from? or What is the name of the space mission that you represent?

2. What year do you represent?

3. What was the most exciting thing about your work?

4. Describe the technology you used when you studied Saturn.

5. How many major discoveries did you make?

6. What was the most exciting discovery that you made about Saturn? Why was it the most exciting?

7. What do you hope future scientists will discover as they study Saturn?

8. What inventions will allow more discoveries to be made?

History of Discovery Table — for Students

Year	Scientist or Spacecraft	Discoveries	Technologies

**Figure 13
(2 of 2)**

Year	Scientist or Spacecraft	Discoveries	Technologies

LESSON 4

Figure 14

History of Discovery Table — for Teachers (1 of 2)

Year	Scientist or Spacecraft	Location from Start of Timeline 1-m Timeline	2-m Timeline	Discoveries	Technologies
1610	Galileo Galilei (b. Italy)	0 cm	0 cm	• Saw "bulges" on either side of Saturn that resembled ears or handles.	• Used a 20- to 30-power handheld refractor telescope.
1655	Christiaan Huygens (b. Netherlands)	11.3 cm	22.5 cm	• Suggested that Galileo's "bulges" were the two sides of a detached, flat ring encircling Saturn. • Discovered Titan, Saturn's largest moon.	• Used a more powerful telescope (50-power) than Galileo's.
1676	Jean-Dominique Cassini (b. Italy as Gian Domenico Cassini; moved to France)	16.5 cm	33.0 cm	• Saw a gap (Cassini Division) in the ring that Huygens saw, dividing the ring into the A and B rings. • Discovered the moons Iapetus, Rhea, Tethys, Dione.	• Used very long refracting telescopes at the Paris Observatory.
1789	William Herschel (b. Germany; moved to England)	44.8 cm	89.5 cm	• Discovered the moons Mimas and Enceladus.	• Used a 48-inch reflector telescope in England.
1895	James Keeler (b. United States)	68.8 cm	137.5 cm	• Saw a narrow gap in the outermost portion of the A ring (the feature was later named the Encke Gap). • Showed that rings are not solid disks.	• Used a 36-inch refractor at Lick Observatory, California (gap in A ring). • Used a 13-inch refractor with spectrograph at Allegheny Observatory (rings not solid).
1944	Gerard Kuiper (b. Netherlands; moved to U.S.)	71.3 cm	142.5 cm	• Discovered that Titan has an atmosphere.	• Used 82-inch reflector with an infrared spectrograph at McDonald Observatory.
1979	Pioneer 11 (U.S./NASA)	92.3 cm	184.5 cm	• First close-up images of Saturn; detected planet's magnetic field; found F ring; tentative find of G ring.	• Flyby space mission; camera and other instruments.

History of Discovery Table — for Teachers (2 of 2)

LESSON 4

Figure 14

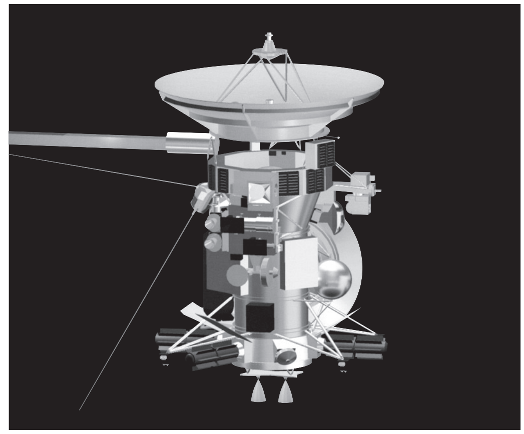
Year	Scientist or Spacecraft	Location from Start of Timeline 1-m Timeline	2-m Timeline	Discoveries	Technologies
1980–1981	Voyager 1 and 2 (U.S./NASA)	92.5–92.8 cm	185.0–185.5 cm	• Images of Saturn, moons, rings, and "ringlets." • Discovered moons Telesto and Calypso; moon Pan "clearing" Encke Gap; moon Atlas "guarding" edge of A ring; moons Prometheus and Pandora "shepherding" the braided F ring. • Imaged the E ring. • Found high winds on Saturn at the equator. • Found Titan's atmosphere to be very thick and mostly nitrogen. • Saw spoke-like structures on B ring. Confirmed D and G rings. Data showed sizes of ring particles.	• Two flyby missions; cameras and other instruments.
1995	Hubble Space Telescope (U.S./NASA)	96.3 cm	192.5 cm	• Provided view of cirrus-like clouds erupting in Saturn's atmosphere; imaged edge-on view of rings in 1995. • Imaged Titan's features to show Huygens probe landing site.	• Earth-orbiting telescope; operates above atmosphere.
2004–2008	Cassini–Huygens (U.S./NASA; European Space Agency probe)	98.5–99.5 cm	197.0–199.0 cm	• Discoveries: to be made. • Study Saturn, rings, moons. • Four-year tour. • Huygens probe to Titan.	• Highly sophisticated spacecraft; many instruments.

LESSON 5

3–4 hrs

The Cassini Robot

Students begin by examining their prior notions of robots and then consider the characteristics and capabilities of a robot like the Cassini–Huygens spacecraft that would be sent into space to explore another planet. Students compare robotic functions to human body functions. The lesson prepares students to design, build, diagram, and explain their own models of robots for space exploration in the Saturn system.



A computer-generated rendering of Cassini–Huygens.

MEETS NATIONAL SCIENCE EDUCATION STANDARDS:

Unifying Concepts and Processes
- *Form and function*

Science and Technology
- *Abilities of technological design*

PREREQUISITE SKILLS

Drawing and labeling diagrams

Assembling a spacecraft model

Some familiarity with the Saturn system (see Lesson 1)

BACKGROUND INFORMATION

Background for Lesson Discussion, page 122

Questions, page 127

Answers in *Appendix 1*, page 225

56–63: The Cassini–Huygens Mission

64–69: The Spacecraft

70–76: The Science Instruments

81–94: Launch and Navigation

95–101: Communications and Science Data

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher

Photocopier (for transparencies & copies)

Overhead projector

Chart paper (18" × 22")

Markers; clear adhesive tape

For each group of 3 to 4 students

Chart paper (18" × 22")

Markers

Scissors

Clear adhesive tape or glue

Various household objects: egg cartons, yogurt cartons, film canisters, wire, aluminum foil, construction paper

Materials to reproduce

Figures 1–6 are provided at the end of this lesson.

FIGURE	TRANSPARENCY	COPIES
1		1 per group
2	1	
3	1	1 per student
4		1 per group
5	1	
6 (for teacher only)		

Background for Lesson Discussion

LESSON 5

The definition of a robot

(See Procedures & Activities, Part I, Step 2)

When asked what a robot is, students often come up with images of fictional devices like C3PO, who walks and talks with a British accent in the *Star Wars* movies. Another robot candidate is the one in *Lost in Space*. Such Hollywood-generated robots are shaped more or less like humans and they communicate like humans. Students tend not to think of washing machines or spacecraft like Voyager or Cassini as robots — but these are classic examples of what is meant by "robot."

Definition of a robot: A programmable and/or remotely controlled machine, capable of performing or extending human tasks, often in environments that are too hazardous for humans or in situations that are too repetitious or tedious for humans.

Robots like Voyager, Pathfinder, and Cassini are extensions of human senses, not only in terms of operating in a remote, hostile environment like outer space, but also in terms of sensing in ways that humans cannot — e.g., detecting magnetic fields, or "seeing" in the infrared or ultraviolet portions of the electromagnetic spectrum (see the *Appendices*).

In this lesson, the natural tendency for students to liken robots with humans is channeled toward an analogy between the functions of spacecraft components and those of human body parts. This approach allows class discussion around the concept of form and function (Part II, Step 5).

According to the NRC National Science Education Standards, "form" and "function" are complementary aspects of objects, organisms, and systems in the natural and designed world. The form or shape of an object or system is frequently related to use, operation, or function. Function frequently relies on form. Students should be able to explain function by referring to form and explain form by referring to function.

For example, a spacecraft's antenna is shaped like a dish to help receive radio waves, or a probe may be shaped like a cone so that it will more easily travel through an atmosphere, or a spacecraft instrument may be hung on a boom to allow it to directly sample properties of the environment without interference from the spacecraft.

Lesson Plan

LESSON 5

Part I: What Is a Robotic Spacecraft?

1. Arrange students in groups of four or fewer. Ask them to record a group definition of a robot on a piece of chart paper. One person in the group should record the definition and another should report the definition to the whole class.

2. Have each group post and report their definition of a robot. Record the key words from the definitions on the blackboard. (See *Background for Lesson Discussion*.)

3. Inform students that a robot designed to explore space is called a spacecraft.

4. Ask students what capabilities or features they would recommend for a robot that would be sent into space to explore another planet. List their responses for later comparison. If needed, guide students by suggesting an analogy with human capabilities, such as movement, senses, communication, thinking, etc.

5. Give each group a copy of *Spacecraft Components* (Figure 1). Have students work in groups to discuss and predict the humanlike function of each of the parts.

6. Instruct students to cut out the different spacecraft components and then arrange and attach them to a sheet of paper in a logical configuration.

7. Instruct students to label each of the spacecraft components with its name as well as the predicted humanlike function. Have the students give their robot a name using one of the scientists from the time line in Lesson 4 or one of the moons in Lesson 2.

8. Have the students in each group attach their individual diagrams to a piece of chart paper and display it to the whole class.

9. Quickly review the various student designs. Ask students if they would like to share the rationale for their designs.

10. Ask students what they would like to know about spacecraft. List their questions on chart paper.

Part II: Making Connections to Cassini

1. Introduce the Cassini spacecraft by displaying and reading a transparency of *Cassini: "Gee Whiz" Facts* (Figure 2).

2. Give each student a copy of the *Cassini Component Functions Table — for Student Use* (Figure 3), and give each group a copy of the diagram entitled *Cassini: A Robot in Our Own Image — for Student Use* (Figure 4).

3 Display a transparency of the students' version of Figure 3, *Cassini Component Functions Table*. Tell the students that the function description in the table offers hints about how to determine a human analogy for each spacecraft component. Work with students to determine a human analogy for the first component or two listed.

4 Explain that the students will use their *Cassini Component Functions Table* to predict the function of each component. (See Figure 6 for the teacher's version of the *Cassini Component Functions Table*.) Members of each group should take turns drawing symbols on the *Cassini: A Robot in Our Own Image* diagram. Students should begin with the skeleton symbol shown on *Cassini: A Robot in Our Own Image — for Teacher Use* (Figure 5) and move clockwise around the spacecraft.

5 After student groups have completed the *Cassini: A Robot in Our Own Image* diagram with their symbols, display a transparency of the completed diagram, *Cassini: A Robot in Our Own Image — For Teacher Use*. Using the transparency, review the form and function of each major part of the Cassini robot.

6 Discuss the students' discoveries about the Cassini spacecraft in light of what they wanted to know about a robotic spacecraft. Guide students to reflect on the mission the Cassini spacecraft is designed to do, and on how the key components of Cassini's technological design will enable it to carry out that mission. Discuss whether or why each component is essential to the success of the mission.

Part III: Assessment

1 Arrange students in groups of four or fewer.

2 Instruct the groups to identify and record the robotic spacecraft components necessary to explore their favorite location in the Saturn system. Ask them to consider how and what the robot will explore. Will it land on a surface of a moon? Will it orbit a moon? Will it fly over the rings? Will it probe into Saturn's or Titan's atmosphere?

3 Student groups should design and build models of their spacecraft using an assortment of objects such as yogurt and egg cartons, wire, film canisters, construction paper, and aluminum foil. The model robot should have all the components to fulfill critical functions.

4 Student groups should diagram their models and each provide a table on chart paper that lists the critical spacecraft components and their functions.

5 Have student groups present their robotic spacecraft models to the class. Students should review and describe their process of technological design by identifying their missions, and how the spacecraft will fulfill those missions. Each group member should be responsible for explaining the form and function of at least one critical component.

LESSON 5

Assessment Criteria

1. The students' tables have identified needed spacecraft components and function descriptions. Bare essentials include:

- *Bus framework*
- *Rocket motors for propulsion*
- *Antennas for communication*
- *Computer for processing data*
- *A scientific instrument such as a camera or a dust analyzer*

2. The model of the spacecraft corresponds to the components identified on the chart.

3. The diagram is labeled and accurately represents the model.

4. The presentation communicates the mission objective and the form and function of each component of the model spacecraft in a way that makes it clear how the spacecraft will fulfill its mission.

Part IV: Questions for Reflection

- How is a spacecraft a robot?
- Does the robot that you designed have humanlike capabilities?
- What would you hope to discover with your robot?
- What questions would your robot help scientists answer?

LESSON 5

Questions

These questions and their answers can be used to provide background for teachers or to explore prior knowledge and facilitate discussions with students. The answers are found in Appendix 1, *starting on page 225.*

The Cassini–Huygens Mission

56. Why are we sending a spacecraft and not people to Saturn?
57. What will the Cassini robot do?
58. What spacecraft have been to Saturn? How have we gathered information about Saturn up until now?
59. What will Cassini learn that we do not already know from Voyager and Hubble Space Telescope data?
60. Why care about the Cassini mission?
61. Why is NASA's mission to Saturn called Cassini?
62. How much does the Cassini mission cost? Who pays for it?
63. How long does it take to plan and carry out a mission like Cassini?

The Spacecraft

64. How big is the Cassini spacecraft?
65. How much wire is used in the Cassini spacecraft?
66. Is the Cassini spacecraft really all covered with gold?
67. Will the spacecraft use solar panels to provide power to the instruments on Cassini?
68. How does an RTG work? If it involves plutonium, is it dangerous?
69. How well can Cassini aim its instruments?

The Science Instruments

70. What kind of instruments does Cassini have? What do they do?
71. How well can the Cassini cameras see?
72. How do you know what color a planet or moon really is?
73. What does the Huygens probe do?
74. What kind of instruments does the Huygens probe have?
75. What happens to the Huygens probe after it lands on Titan?
76. If the Huygens probe were to sink, would there be any way to send information back?

Launch and Navigation

81. When was Cassini launched?
82. Which launch vehicle did Cassini use?
83. How much rocket fuel does Cassini carry in order to complete its mission at Saturn?
84. When does Cassini arrive at Saturn?
85. How long does the Cassini mission last?
86. Why does it take so long to get to Saturn?
87. Couldn't we get to Saturn faster if we flew directly to Saturn instead of wrapping around other planets?
88. What is gravity assist?
89. How close does Cassini come to Earth during its flyby?
90. Can we see the Cassini spacecraft from Earth during its flyby of Earth?

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

92. How fast does Cassini go?

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

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

Communications and Science Data

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

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

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

98. What is the Deep Space Network?

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

100. How much science data will Cassini return?

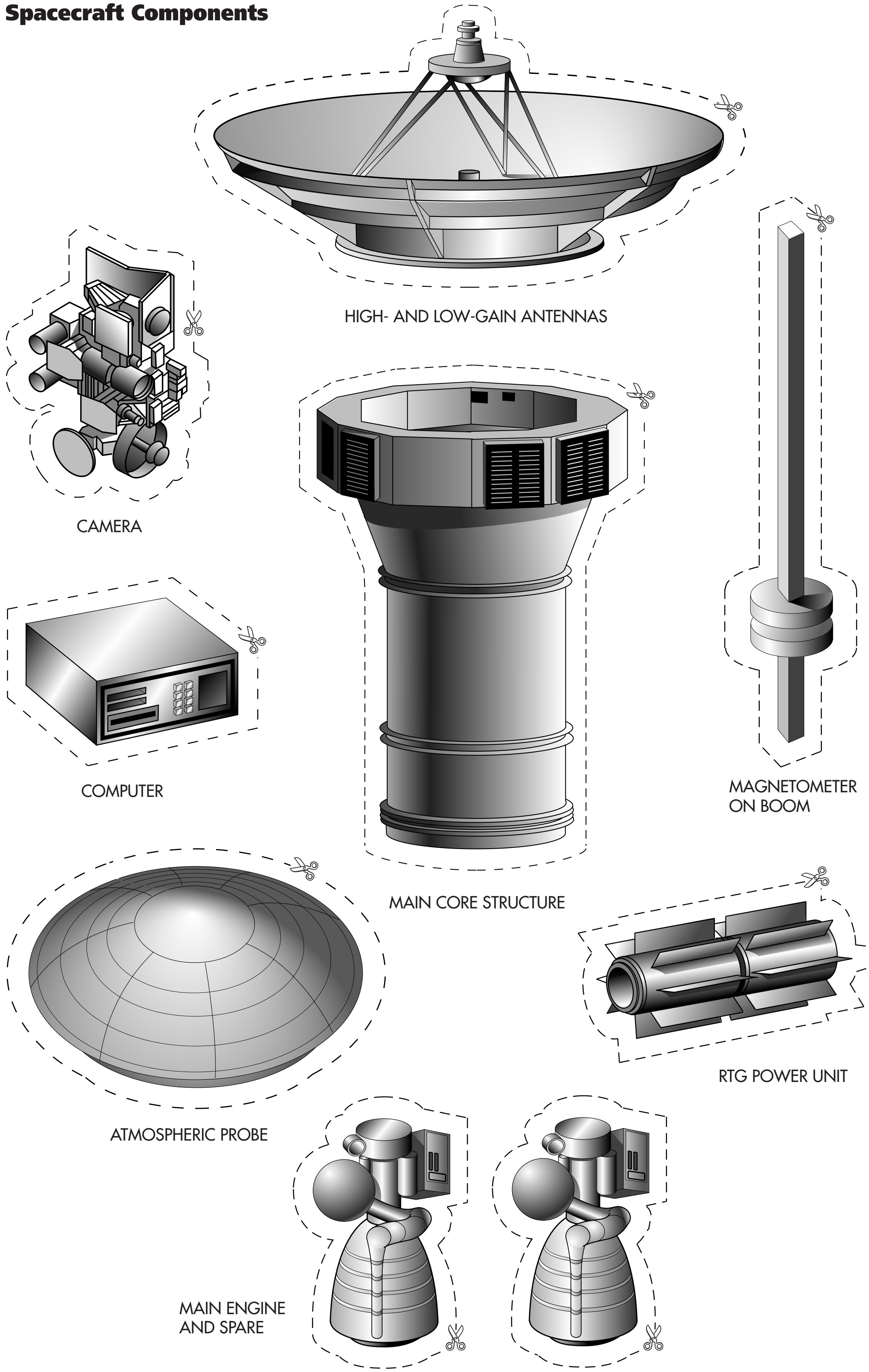
101. How many pictures will be sent back from Cassini–Huygens?

Materials

Figure 1	**Spacecraft Components**
Figure 2	**Cassini “Gee Whiz” Facts**
Figure 3	**Cassini Component Functions Table — for Student Use**
Figure 4	**Cassini: A Robot in Our Own Image — for Student Use**
Figure 5	**Cassini: A Robot in Our Own Image — for Teacher Use**
Figure 6	**Cassini Component Functions Table — for Teacher Use**

LESSON 5

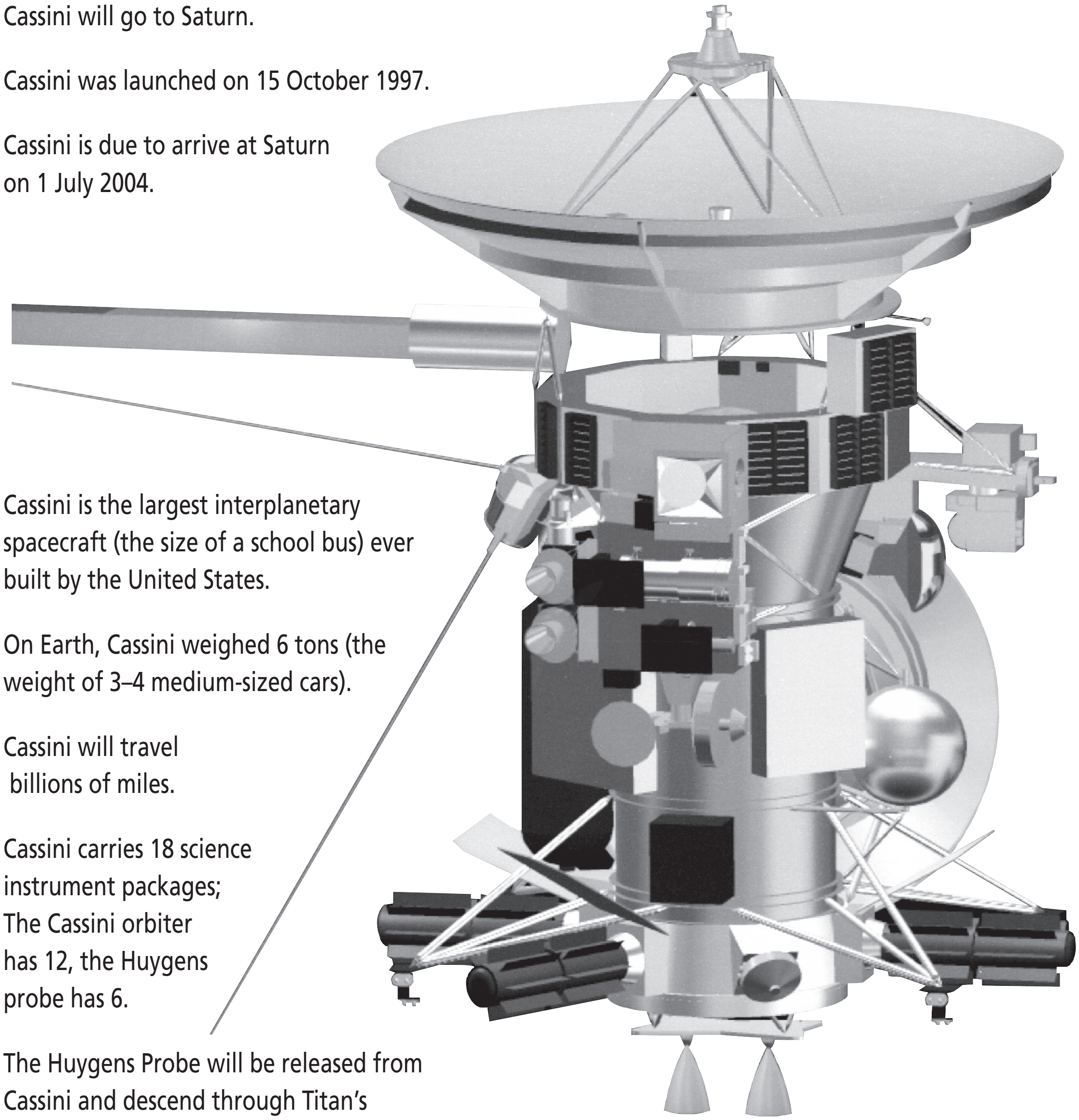
Spacecraft Components



LESSON 5

Figure 2

Cassini "Gee Whiz" Facts



- Cassini will go to Saturn.
- Cassini was launched on 15 October 1997.
- Cassini is due to arrive at Saturn on 1 July 2004.
- Cassini is the largest interplanetary spacecraft (the size of a school bus) ever built by the United States.
- On Earth, Cassini weighed 6 tons (the weight of 3–4 medium-sized cars).
- Cassini will travel billions of miles.
- Cassini carries 18 science instrument packages; The Cassini orbiter has 12, the Huygens probe has 6.
- The Huygens Probe will be released from Cassini and descend through Titan's atmosphere.
- Cassini uses 7.5 miles of wiring. It serves as the spacecraft's "nervous system."
- Much of Cassini is covered with a gold-colored material for protection from extremes of hot and cold, and impacts of small space debris. This serves as Cassini's "skin" or "clothing."
- Cassini will reach a speed of up to 32 kilometers/second relative to Saturn. How fast is that in miles per hour?

LESSON 5

Figure 3

Cassini Component Functions Table — for Student Use

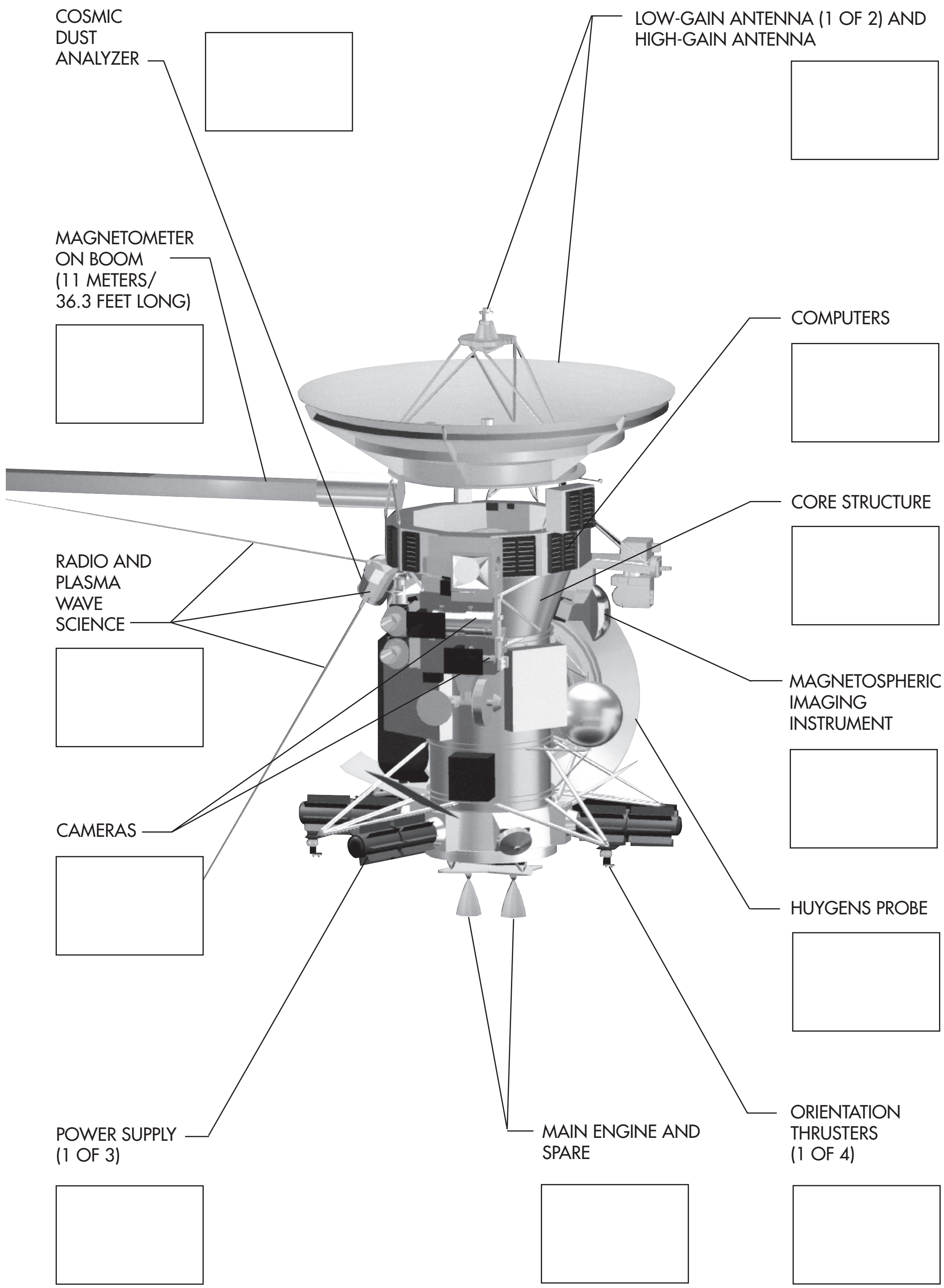
Use the descriptions in the column labeled "Function" to determine a possible human analogy for each Cassini component. Write your human part(s) or human need(s) in the blank column at the right.

Cassini Component	Function	Human Analogy
Spacecraft bus	The bus is the core structure (or framework) to which spacecraft components are attached. This is made out of aluminum, the same metal used in soft-drink cans.	
Orientation thrusters	These are small rocket thrusters (not the main engines) that are used for delicate maneuvers that rotate the spacecraft. This is useful for aiming instruments and pointing the antennae toward Earth.	
Main engines	Rocket motors provide thrust for moving the spacecraft in a particular direction or for braking maneuvers.	
RTGs	Radioisotope thermoelectric generators (RTGs) are the source of energy for Cassini's instruments and transmitters. RTGs convert nuclear energy to electrical energy. RTGs are not used for propulsion.	
Spacecraft cameras	Cameras and other science instruments "see" radio waves, infrared, visible, and ultraviolet light emitted or reflected by Saturn and its rings and moons.	
RPWS	The radio and plasma wave science instrument "listens" to different aspects of the environment around Cassini.	
Cosmic dust analyzer	The dust analyzer will sense dust particles that come into direct contact with the instrument.	
Magnetometer boom	This is an 11-meter-long "arm" extending from the spacecraft. There are instruments in the middle and on the end of it that are used to detect and measure magnetic fields.	
High/low gain antennas	Receivers and transmitters are used for communication between the spacecraft and Earth-based controllers. The antennae "hear" and "speak" for the spacecraft.	
Computers	Computers manage a variety of intelligent functions such as navigation and propulsion, storing information from scientific instruments, and sending information to Earth. There are over 40 different computers on Cassini.	
Huygens probe	This probe will be released from the "mother" spacecraft to descend through Titan's atmosphere to gather data on this mysterious moon of Saturn.	

LESSON 5

Figure 4

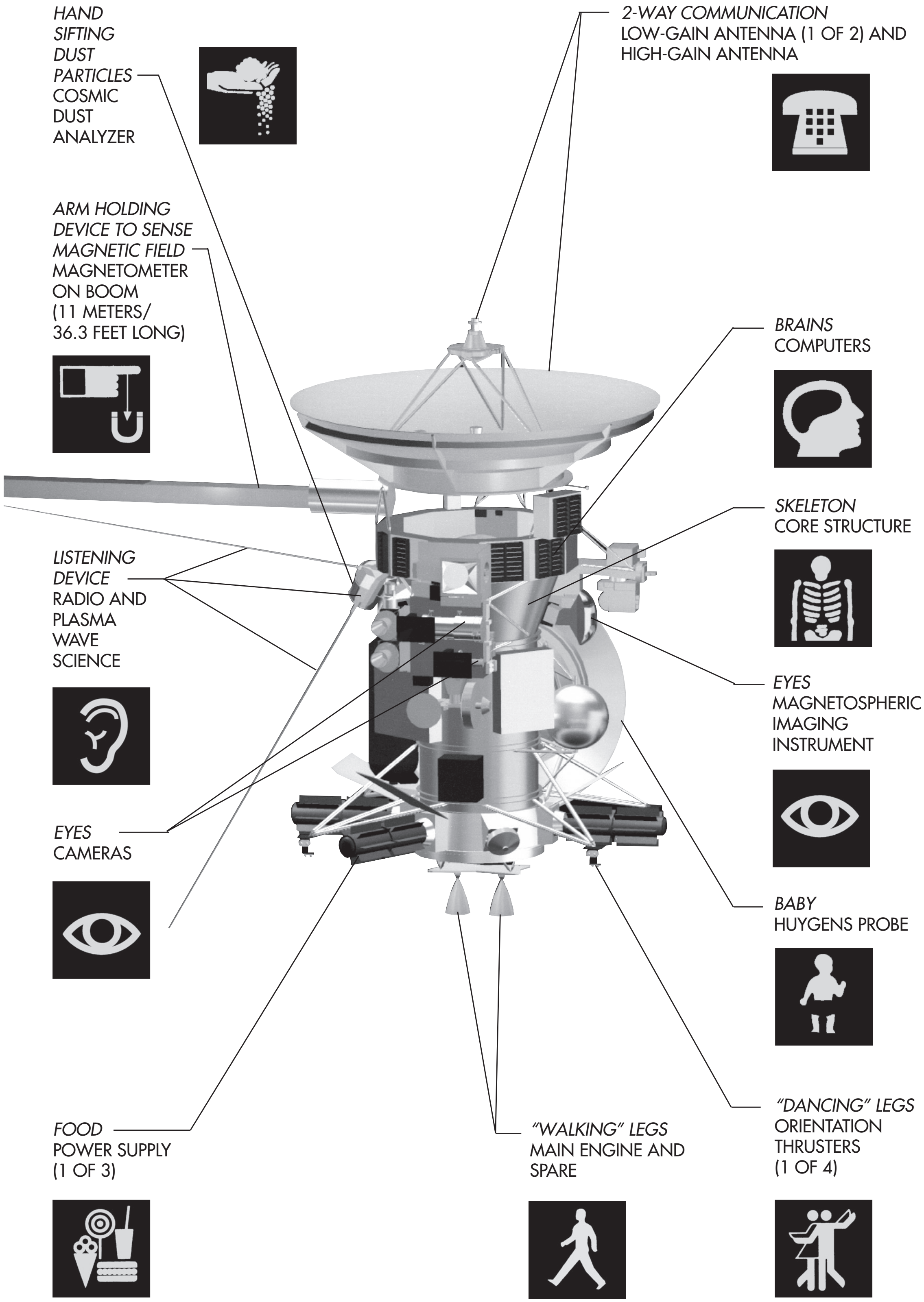
Cassini: A Robot In Our Own Image — for Student Use



Cassini: A Robot In Our Own Image — for Teacher Use

LESSON 5

Figure 5



LESSON 5

Figure 6

Cassini Component Functions Table — for Teacher Use

Use the descriptions in the column labeled "Function" to determine a possible human analogy for each Cassini component. Write your human part(s) or human need(s) in the blank column at the right.

Cassini Component	Function	Human Analogy
Spacecraft bus	The bus is the core structure (or framework) to which spacecraft components are attached. This is made out of aluminum, the same metal used in soft-drink cans.	Body/torso/skeleton
Orientation thrusters	These are small rocket thrusters (not the main engines) that are used for delicate maneuvers that rotate the spacecraft. This is useful for aiming instruments and pointing the antennae toward Earth.	Dancing feet or legs
Main engines	Rocket motors provide thrust for moving the spacecraft in a particular direction or for braking maneuvers.	Walking/running feet or legs
RTGs	Radioisotope thermoelectric generators (RTGs) are the source of energy for Cassini's instruments and transmitters. RTGs convert nuclear energy to electrical energy. RTGs are not used for propulsion.	Food and drink
Spacecraft cameras	Cameras and other science instruments "see" radio waves, infrared, visible, and ultraviolet light emitted or reflected by Saturn and its rings and moons.	Eyes
RPWS	The radio and plasma wave science instrument listens to different aspects of the environment around Cassini.	Ears
Cosmic dust analyzer	The dust analyzer will sense dust particles that come into direct contact with the instrument.	Hands/tongue/nose
Magnetometer boom	This is an 11-meter-long "arm" extending from the spacecraft. There are instruments in the middle and on the end of it that are used to detect and measure magnetic fields.	Extended arm
High/low gain antennas	Receivers and transmitters are used for communication between the spacecraft and Earth-based controllers. The antennae "hear" and "speak" for the spacecraft.	Ears listening and mouth talking on the phone
Computers	Computers manage a variety of intelligent functions such as navigation and propulsion, storing information from scientific instruments, and sending information to Earth. There are over 40 different computers on Cassini.	Brain
Huygens probe	This probe will be released from the "mother" spacecraft to descend through Titan's atmosphere to gather data on this mysterious moon of Saturn.	Baby

LESSON 6

1.5–2 hrs

People of the Cassini Team

Students use a diverse collection of profiles of people who work on the Cassini–Huygens mission to learn about science as a human endeavor and to reflect on their own career goals and personal impressions of the mission.

A model of the Cassini–Huygens spacecraft at JPL and a few of the thousands of Cassini team members.

MEETS NATIONAL SCIENCE EDUCATION STANDARDS:

History and Nature of Science
- *Science as a human endeavor*

Science in Personal and Social Perspectives
- *Science and technology in society*

PREREQUISITE SKILLS

Reading in the content area of science
Working in small groups
Interpreting narrative information
Taking careful notes
Writing essays

BACKGROUND INFORMATION

Background for Lesson Discussion, page 144
Questions, page 147
Answers in *Appendix 1*, page 225
56–63: The Cassini–Huygens Mission
77–80: The People of the Cassini Team

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher

Photocopier (for transparencies & copies)
Overhead projector
Chart paper (18" × 22")
Color markers; clear adhesive tape
3-ring binder (notebook)
3-hole punch

For each group of 3 to 4 students

Pencils
Red and blue markers (optional)
Chart paper (optional)
Atlas or world map (optional)

Materials to reproduce

Figures 1–19 are provided at the end of this lesson.

FIGURE	TRANSPARENCY	COPIES
1	1	1 per group
2	1	1 per group
3–18		1 of each (3-hole punched)
19		1 per student (3-hole punched)

Background for Lesson Discussion

In Part II (*Making Connections to Cassini*), Step 6, discussion questions might include:

- *What was missing from the* Jobs Chart *that was created at the beginning of the lesson compared to the* Jobs Chart *after hearing the reports on the* Cassini Team Member Profiles*?*

Here you may expect students to fill in other qualifications besides the easy ones of education, degrees, and technical skills. These might include oral and written communication skills, teamwork skills, creativity, ability to solve problems, openness to new ideas, willingness to persist in the face of adversity, and so on.

- *What do you notice about the work that is required for a space mission?*

It is important to recognize the vast number and diversity of talents, interests, and careers necessary to support and carry out a space mission.

- *What have you learned about the people who are involved in a space mission?*

Not only are the people well-educated and qualified to do their jobs, but they are also basic human beings with families, hobbies, likes, dislikes, and a variety of life experiences that motivated them to choose their career paths.

According to the National Science Education Standards, students should be aware that:

"Women and men of various social and ethnic backgrounds — and with diverse interests, talents, qualities and motivations — engage in activities of science. ...Some scientists work in teams and some work alone, but all communicate extensively with others."

"Science requires different abilities, depending on such factors as the field of study and type of inquiry. Science is very much a human endeavor, and the work of science relies on basic human qualities, such as reasoning, insight, energy, skill, and creativity — as well as on scientific habits of mind, such as intellectual honesty, tolerance of ambiguity, skepticism, and openness to new ideas."

Lesson Plan

Part I: Who Makes a Space Mission Possible?

1. Tell the students that they are future candidates for positions at a Space Center. The mission of the Space Center is to design, build, and fly an international robotic spacecraft to explore an outer planet of the Solar System. They are meeting to learn about the different positions available at the Space Center. They will be asked to determine which of the positions is the most appealing to their interests and matches best with their abilities. They will also be asked to select a mentor from among people who are already involved in supporting a spacecraft mission.

2. Tape a piece of chart paper on the wall or chalkboard, label it *Jobs Chart*, and divide it into two columns, one marked "Job" and the other marked "Qualifications."

JOBS CHART

Job	Qualifications

3. Ask students: What jobs would need to be filled to accomplish the mission? List their responses in the "Job" column.

4. Ask students: What qualifications, work habits, skills, and special attributes are necessary for these positions? Record their responses in the right column of the *Jobs Chart*.

LESSON 6

Part II: Making Connections to Cassini

1 Display a transparency of the *Worldwide Participation Map* (Figure 1). Share with students that Cassini–Huygens is an international robotic spacecraft designed to explore Saturn. Cassini team members are from universities, laboratories, and businesses all over the world. Share with students that Cassini is a similar mission to the one they are planning.

Note: You can extend use of the map into a geography lesson. Put students in groups of 3–4. Give each group some chart paper and blue and red markers. Have student groups identify as many participating states (with red marker) and countries (with blue marker) as they can in 3 minutes. Allow students to use an atlas or world map. After 3 minutes, have students post their charts. Discuss with the students which countries and/or states were not identified.

2 Continue by telling students that the Space Center models its selection of team members after the Cassini–Huygens mission to Saturn (which is a collaboration of the National Aeronautics and Space Administration, the European Space Agency, and the Italian Space Agency). In order to learn more about the people and positions available, the candidates for the Space Center mission (that is, the students) will review and share profiles of Cassini team members.

3 Arrange students into groups of three. Give each group a copy of the *Profile Summary* (Figure 2) and one of the *Cassini Team Member Profiles* (select from Figures 3 through 18). The groups are to prepare an introduction of this Cassini team member for the whole class by studying the information on the profile and completing the *Profile Summary*. Technical terms used by the featured members of the Cassini team may be found in the *Glossary*.

4 After the student groups have had adequate time to read their profiles and to record information about the Cassini team member on their *Profile Summaries*, continue by telling students that you want to help them prepare for their interview at the Space Center by hearing a report about each Cassini team member. Each candidate (student) should listen to the reports for the purpose of identifying a possible mentor for the new mission.

5 As student groups share the information on their *Profile Summaries*, the teacher adds relevant information to the *Jobs Chart* using a different color marker. Each group then posts their *Profile Summary* on a bulletin board or on the chalkboard.

6 After all groups have presented, and the *Jobs Chart* is complete, ask students to compare the new list of jobs and qualifications to the list created at the beginning of the lesson. Guide students to discover that a broad diversity of people with a wide variety of interests, talents, qualities, and motivations is necessary to design, develop, and fly a mission of scientific exploration like Cassini–Huygens. The goal is to offer a sense of "science as a human endeavor." (See *Background for Lesson Discussion*.)

Part III: Assessment

1 Compile a classroom notebook with all the *Cassini Team Member Profiles* as a reference for students. Ask students to consider which kind of position interests them most, and which Cassini team member they would like to have as a mentor. Allow time for students to review the classroom notebook and the posted *Profile Summaries* prepared by each of the groups, and to ask questions of each other about the different Cassini team members.

LESSON 6

2 Have each student write an essay that addresses two questions: "Which Cassini team member would you select for a mentor and why?" and "How is the Cassini mission an example of science as a human endeavor?"

Note: If a student's interests and goals would not lead them to choose a mentor from the Cassini team, then the first question of the essay can be adjusted by asking them to describe an imaginary mentor that would meet their needs.

3 Have each student complete a *Student Profile* (Figure 19). Add the *Student Profiles* to the classroom notebook containing the *Cassini Team Profiles*. This becomes a resource that could be shared at parent/teacher conferences, placed in the school library, or displayed at a school open house. Copies of individual student profiles can be placed in student portfolios.

Assessment Criteria

1. The student selects or describes a mentor in a position that matches his or her interests and goals.

2. The student justifies the mentor selection and description from a personal perspective.

3. The student uses examples to explain how the Cassini–Huygens mission demonstrates science as a human endeavor.

4. The student completes a Student Profile *for the Cassini–Huygens mission that includes a personal perspective and possible contributions to a similar space mission.*

Part IV: Questions for Reflection

- What kind of people does it take to support a space mission like Cassini–Huygens? What different kinds of abilities do they need? How many people does it take? What countries are they from?

- What is important to you in choosing a mentor? What is interesting or surprising about the mentor you described in your essay? How is your mentor like or unlike you?

LESSON 6

Questions

These questions and their answers can be used to provide background for teachers or to explore prior knowledge and facilitate discussions with students. The answers are found in Appendix 1*, starting on page 225.*

The Cassini–Huygens Mission

56. Why are we sending a spacecraft and not people to Saturn?
57. What will the Cassini robot do?
58. What spacecraft have been to Saturn? How have we gathered information about Saturn up until now?
59. What will Cassini learn that we do not already know from Voyager and Hubble Space Telescope data?
60. Why care about the Cassini mission?
61. Why is NASA's mission to Saturn called Cassini?
62. How much does the Cassini mission cost? Who pays for it?
63. How long does it take to plan and carry out a mission like Cassini?

The People of the Cassini Team

77. How many people have worked on Cassini?
78. Who manages the Cassini Project?
79. What sorts of people work on a space project like Cassini?
80. How could I prepare for a career involving a space project?

LESSON 6

Materials

Figure 1	**Worldwide Participation Map**
Figure 2	**Profile Summary**
Figures 3–18	**Cassini Team Member Profiles**
Figure 19	**Student Profile (2 pages)**

LESSON

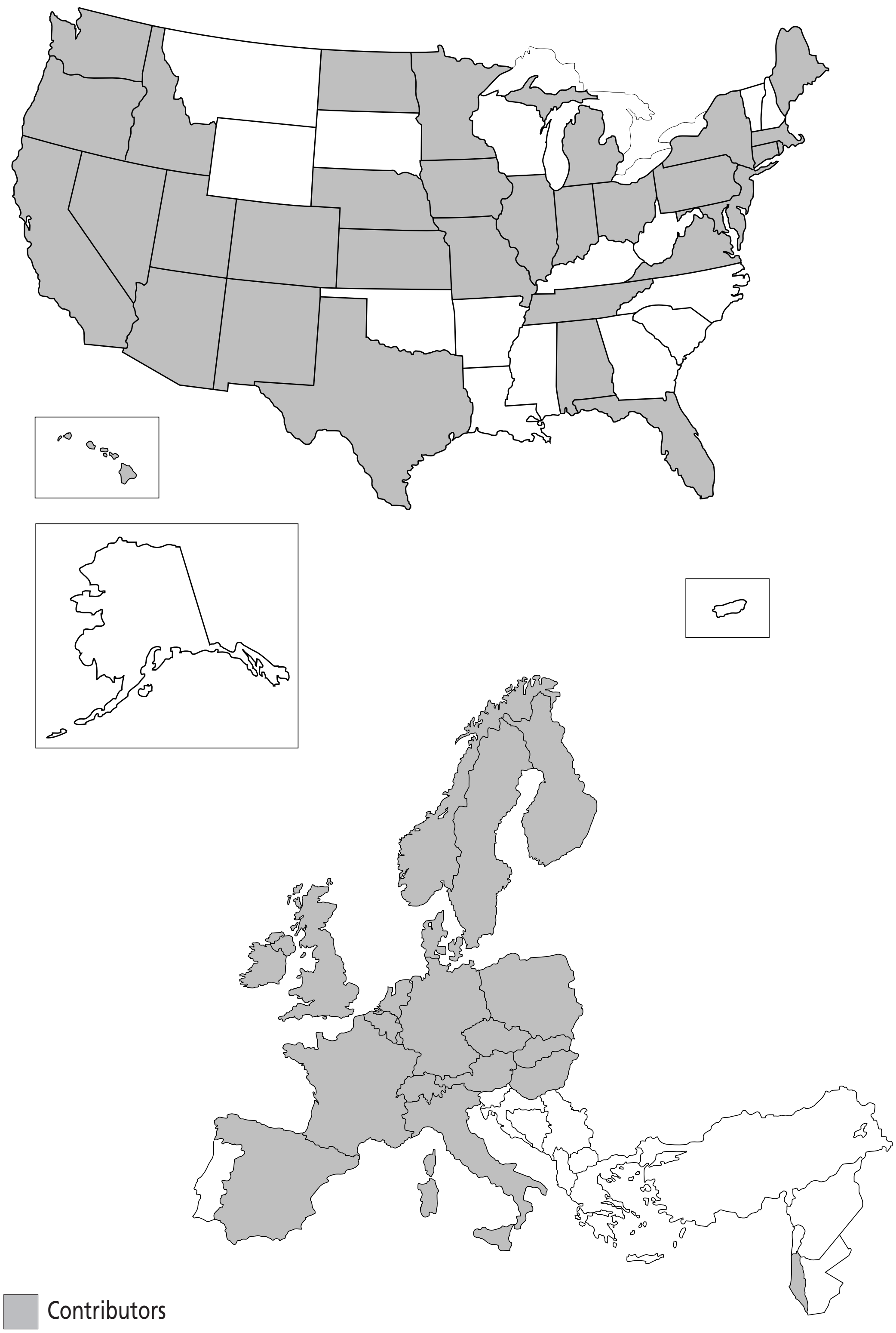
6

LESSON 6

Figure 1

Worldwide Participation Map

Shaded states and countries show participation in the Cassini–Huygens mission.



LESSON 6

Figure 2

Profile Summary

Cassini Team Member's Name ______________________

Job Title ______________________

Responsibilities	Qualifications
Commitment to Space Exploration	**Personal/Inspirational/Surprising Attributes**

Mark Adler *Mission Engineer*

Words of Wisdom

"Find something that you enjoy doing, that has some value to society, and that you have some talent for. Then excel at it — I mean really excel. Pick a path that means something to you, something that touches you, that calls you. If you don't know what that is, keep looking — it'll find you."

Personal

Birth date: 3 April 1959
Home: Pasadena, California
Children: Joshua (b. 1992)

Favorite hobbies:
- Bicycling
- Flying small planes
- Cooking (especially desserts)
- Model rocketry
- Acting and singing in theater

Education

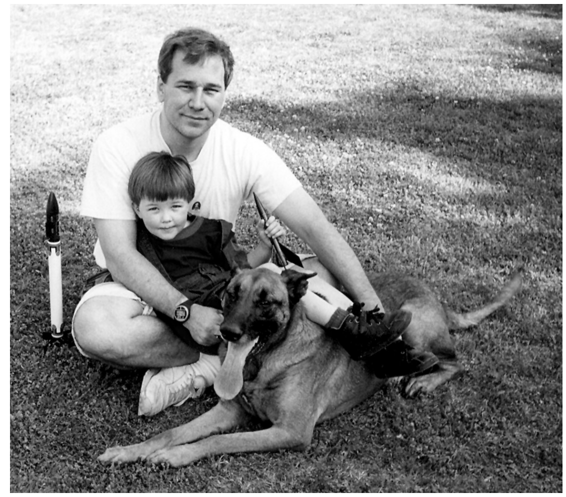
(All in North Miami Beach, Florida)
Elementary: Greynolds Park
Junior high: John F. Kennedy
High school: North Miami Beach

Highest college degree: PhD in Physics, California Institute of Technology

Favorite subject: Mathematics

Least favorite subject: Foreign Language

Subject I wish I had studied more: "Every subject, including more study of foreign languages."



"Devilishly Handsome, Brilliant, Humble (just kidding), Curious, Quick, Funny"

Professional

What I do for the Cassini mission: I was the Mission Engineer. I had to creatively marry the spacecraft's limitations and constraints (the robot part) with the ground system's work force and tool limitations (the people part) in order to best meet the ambitious goals of the scientists (the curiosity part).

In my work, I must know how to:
- Pay attention to important detail
- Find creative solutions to complex problems
- Program a computer to do calculations
- Learn new things quickly
- Find compromises to benefit everyone

The coolest thing about my work is: Learning about lots of other people's jobs, and their part of the mission. Getting a very wide, and in places, deep understanding of the entire mission.

Mark Adler, continued

How I describe Saturn: Big, Cold, Beautiful

How I describe Cassini: Magnificent, Audacious, Expensive

Why care about Cassini? If Cassini does half the things we planned for it to do, it will be one of the great explorers of all time. Cassini is an extension of yourself reaching out to touch another world. You don't want to sleep through that! Here is my favorite quote about exploration, from T.S. Eliot:

We shall not cease from exploration,
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

Human Interest

My First Looks at the Sky
I noticed the moon and stars right from the start. I guessed that the stars were suns, but I thought that the moon was an impaired reflection of the Earth. Planets I had to read about before I noticed that some of the stars wandered. That was in about the third grade — it was then that I started doing a lot of science reading.

How I Came to Cassini
I've pretty much always wanted to be involved in the exploration of space, since watching the Apollo missions when I was a kid. Exactly how I would be involved wasn't clear. In fact it probably still isn't, but I'm happy—I'm making significant contributions to a great adventure.

My parents had little money for my education, so I did computer consulting on the side to pay for my bachelor's and master's degrees. I got a fellowship from an aerospace company that paid for my PhD. Typically a PhD degree is in the same subject as the master's and bachelor's, but all of mine were different. In addition to my PhD in Physics from Caltech, I earned an MS in Electrical Engineering and BA in Mathematics, both from the University of Florida. This diversity turns out to be a strength for my work and lets me do jobs in which I have to understand a wide range of subjects.

My Work Environment
I work in a "cubicle," kind of like a bathroom stall, but a little bigger and without the door. I've worked with probably a sixth of the people on the Cassini project at one point or another, which is a lot. This was because my job involved understanding nitty gritty details of many aspects of the spacecraft hardware, the operations of the spacecraft, the path the spacecraft will follow on the way to Saturn, and the science observations to be done.

Ten Years from Now?
I'd like to be preparing a human mission to Mars.

LESSON 6

Figure 4

Cassini Team Member Profile

Rozita Belenky *Flight Systems Engineer*

Words of Wisdom

"I think the most important aspect of human life, regardless of age, is continual learning. Missions such as Cassini allow for learning of the new, but most importantly, they inspire new minds to reach farther than before, allowing for even more learning. Regardless of what the budget situation looks like on Earth, money should be made available to further our knowledge and the exploration of the unknown."

Personal

Birth date: 20 January 1970
Home: North Hollywood, California
Children: not yet

Favorite Hobbies:
- Theater
- Opera

Education

I started my schooling in the former Soviet Union, but I went to junior and senior high schools in Los Angeles, California.

Highest degree: MS in Aerospace Engineering, University of Southern California

Favorite subject in school: Math

Least favorite subject in school: I can't think of one.

Subject I wish I had studied more: Non-engineering classes; to learn more diverse subjects.

"Dedicated, Resourceful, I laugh a lot"

Professional

What I do for the Cassini mission: I work in flight systems operations. In particular, I am involved in writing and testing computer procedures that control the attitude and orientation of the Cassini spacecraft. I develop sequences that will be sent to the spacecraft, and I analyze data Cassini sends back to Earth. My immediate team is 9 members strong, but I have to interface with many people from different areas on a daily basis.

In my work, I must know how to:
- Apply basic math skills
- Analyze data
- Use and program a computer
- Manage my time efficiently
- Work well with others
- Laugh a lot

The coolest thing about my work is: Being a part of the Cassini team. It's still unbelievable to me that this spacecraft will travel so far away from "home" and let us in on some secrets of the Universe.

How I describe Saturn: Mysterious, Complicated, Fascinating

How I describe Cassini: Exciting, International, Understaffed

Why care about Cassini? Everyone should care about such important projects. The desire to learn and better oneself is a human characteristic that can flourish only when there is something worthy, exciting, and intellectually stimulating to discover. Discovery arouses curiosity, and the more we learn, the more we realize there is still more to be learned. Space exploration (such as the Cassini mission) is key to intelligent human life forms of the future.

Human Interest

Friends and Relatives in the Soviet Union
My family and I immigrated to the United States from the Soviet Union when I was 10 years old. At that time, no one would imagine that I would end up where I am now. Some of them still can't imagine it! "Space" was something that most people just read about or watched on TV specials. To them, it seemed like an unrealistic goal to work on a "space" project. Of course, my family was incredibly supportive of my goals and very proud of my accomplishments. I first became interested in engineering when I entered junior high, and now here I am! Whenever a spacecraft story makes the news, I get many phone calls and questions from my friends and family members. I think that knowing someone like me who works at the Jet Propulsion Laboratory (JPL) makes people more aware of the space program and makes them pay a little more attention to the news.

Ten Years from Now?
I will hopefully still be involved with flight projects at JPL (that's most exciting to me).

LESSON 6

Figure 5

Cassini Team Member Profile

Bonnie J. Buratti *Investigation Scientist*

Words of Wisdom

"Whatever you do in life depends on your own efforts. Trust yourself and be yourself. Strive to achieve all you can, but remember that what kind of a person you are is what ultimately counts. Say little and do much, and learn from all men and women."

"Inquisitive, Energetic, Interested in everything"

Right: Bonnie (in dark glasses) with her three sons and mother on a sailboat in Pennsylvania.

Personal

Birth date: 24 March 1953
Home: Altadena, California
Children: Nathan (b. 1983), Reuben (b. 1986), and Aaron (b. 1988)

Favorite hobbies:
- Skiing and ice skating
- Hiking with family
- Growing organic foods
- Reading and studying languages
- Cooking, sewing, decorating

Education

Elementary: Coopersburg Elementary School, Pennsylvania
Junior high: Southern Lehigh Jr. High
High school: Southern Lehigh High School, Pennsylvania

Highest college degree: PhD in Astronomy and Space Sciences, Cornell University (Ithaca, NY)

Favorite subject: Science

Least favorite subject: Driver's Education

Subjects I wish I had studied more: More foreign languages like French and German.

Professional

What I do for the Cassini mission: I am the Investigation Scientist for one of the 12 instruments on Cassini — the Visible and Infrared Mapping Spectrometer. It will tell us more about what Saturn and its rings are made of.

In my work, I must know how to:
- Observe with large telescopes
- Apply mathematics and physical science
- Use computers and the Internet
- Write papers and proposals
- Work with teams of 3 to 20 people

The coolest thing about my work is: There is nothing routine about it. It involves the joy and wonder of discovery.

Bonnie J. Buratti, continued

How I describe Saturn: Mysterious, Beautiful, Big

How I describe Cassini: Exciting, Worthwhile, Challenging

Why care about Cassini? The Cassini mission represents the tradition of discovery that has made the human species great. It will answer questions about the origin of the Solar System and life on Earth (Titan, a satellite that will be closely studied by Cassini, is sort of an "Earth in deep freeze"). We hope the success of Cassini will inspire students to excel in their own studies so they can perform even greater feats. Finally, discoveries from the Cassini mission and other NASA missions have been useful right here on Earth — in medicine, computers, robotics, and materials.

Human Interest

How I Became Interested in Space
I was hooked in third grade when I read a book called *A Child's Book of the Stars*. I was home sick that day. I was particularly fascinated by a picture that showed a steaming rain forest on Venus. (Now we know that's wrong; Venus is way too hot for life to exist there!)

What My Work Environment Is Like
I'm usually in my office, hooked into my computer. I use it to do calculations, run models, and analyze data from telescopes and previous space missions (especially Voyager). I communicate with other scientists by e-mail, and I do a great deal of writing, mainly papers and proposals. For my work on Cassini, I often work with teams of people, usually 3 to 20 other scientists and engineers. We have meetings or work in laboratories where the instrument is in an environment similar to that in space. I sometimes take data at telescopes on mountain tops, such as the large one on Palomar Mountain. My job involves a lot of travel, often to Europe where I meet with our Cassini European colleagues. I attend scientific conferences all over the world.

Can a Scientist Raise a Family?
I am very proud of the fact that I have raised a family while continuing in a successful career as a scientist. In 1983, I was the first graduate student in the Astronomy Department at Cornell to have a baby, and many faculty members found it hard to accept that I was the same scientist after the birth. I defended my PhD thesis when my first son was only 4 months old. In 1985, I think I was the first pregnant astronomer to observe at Palomar Mountain.

Ten Years from Now?
I will be analyzing data from Cassini!

Karen M. Chan (Karenator) *Secretary*

Words of Wisdom

"Go to school, study hard, extend yourself beyond what's easy for you. Don't be afraid to fail; make yourself try again. Listen to your parents. Love and spend time with your family; they will be the biggest supporters in your life. Take time to play and make friends because friends will add to the adult you become. Learn the difference between right and wrong, and always do right."

Personal

Birth date: 27 April 1963
Home: Monrovia, California
Nephews: Christopher (b.1990) and Andrew (b. 1994)

Favorite hobbies:
- Dodgers baseball
- Softball
- Jazzercise
- Crafts
- Reading

Education

(All in Los Angeles, California)
Elementary: Arlington Heights
Junior high: Louis Pasteur
High school: Los Angeles

Highest college degree: BA in English from California State University Northridge (1984), emphasis in poetry

Favorite subject: Art, acting, and creative writing

Least favorite subject: Math

Subject I wish I had studied more: More physical sciences and geosciences that would help me understand more about planetary exploration.

"Flirty, Cute-but-Intelligent, Bossy"

Professional

What I do for the Cassini mission: I am a secretary in the Cassini Program Office at the Jet Propulsion Laboratory (JPL). I support some of the senior engineering managers who run the program. I handle a lot of the day-to-day operations like scheduling, ordering supplies, and fixing jammed copiers and printers. I also spend time training others how to use different types of computer software or how to handle the "red tape" of complex administrative procedures. Having majored in English, I can make sure other people understand better what my managers (engineers) are trying to say! Sometimes when people ask me what I do in my job, I tell them "Waitress, maid, and mother" because often that's what it feels like.

In my work, I must know how to:
- Use computers and office-related software
- Use electronic mail, fax, and phone systems
- Diagnose and correct computer problems
- Smile, even when things are rough
- Communicate with a diversity of people
- Learn new things all the time
- Think ahead and anticipate people's needs

Karen M. Chan, continued

The coolest thing about my work is: Working directly in the Cassini Program Office, I get to be where all the action is, and that's very exciting. I've actually learned quite a bit about Saturn and Cassini.

How I describe Saturn: Big, Beautiful, Wondrous

How I describe Cassini: Amazing, Beautiful, Expensive

Why care about Cassini? Every endeavor which is begun today will affect how you may be able to live your life in the future. How can we know if humans can live in space if we don't know what's out there? Space exploration is important for learning how planets developed and what might be done to extend life into the Solar System. Cassini will return lots of great data and beautiful pictures, and we'll learn so much more about the Saturn system and Titan.

Human Interest

My First Looks at the Sky
I first learned about stars and planets in school, but didn't really pay that much attention until a botany class camping trip. My science teacher got us kids together and pointed out a bunch of planets and constellations and told us some stories about what we were seeing. After that, it was "Wow...stars!"

My Work Environment
I work in the Cassini Program Office alongside several other secretaries. My "office" is an open-landscaped cubicle which I share with another secretary and a student-intern. There's no way to hide in here! At my desk I have both a Macintosh and PC computer, and I do use both of them at the same time. I have a motto: "Whatever Happens, Smile." I use this a lot whenever I'm dealing with people who are more difficult to deal with. In my job I also get to meet and deal with a lot of people from many areas of life, and I really enjoy that a lot. Sometimes you get me talking with folks and I can't stop!

How I Came to Work on Cassini
When I was little, I remember wanting to be a ballerina, nurse, fireman, or race car driver. When I got older, I added the possibilities of becoming President of the United States, an actress, or a newspaper reporter. When I graduated from college, I wanted to write children's books.

My first job was in a student work-study program at Cal State Northridge. I worked in the Geology department office, and this was my first taste working with computers and office organization. After graduating, I worked for an insurance company for a while. I left that job to spend a summer in Taiwan, and upon returning a friend suggested that I check into JPL because her father worked there (and, she said "there are tons of cute guys!). As it turned out, her father hired me because his secretary quit unexpectedly, and I've been working for him ever since.

Ten Years from Now?
I'd like to move to higher levels of work in administration and office management. I've also thought about training to be a computer consultant and maybe starting my own business. Maybe somehow I'll still be helping Cassini scientists do their work.

LESSON 6

Figure 7

Cassini Team Member Profile

Carrie P. Duits *Teacher and Education Specialist*

Words of Wisdom

"We should strive to be responsible citizens, caring for others, offering a helping hand, and sharing our talents. When we give gifts of kindness and friendly smiles to others, they are encouraged to do the same. The greatest gift we can give ourselves is to learn. There is no end to what we can learn, and learning is the path that leads to our dreams."

Right: Carrie is the "Mom" in the middle.

"Caring, Creative, Organized"

Personal

Birth date: 21 April 1957
Home: Thornton, Colorado
Children: Jake (b. 1982), Nicole (b. 1983), Zach (b. 1987), and Barb (b. 1988)

Favorite hobbies:
- Camping and boating
- Watching my kids play soccer
- Writing and learning

Education

Elementary: Northeastern Elementary
Junior high: Hastings Jr. High
High school: Hastings High

Highest college degree: Masters of Education Instruction, Colorado State University
PhD in progress, University of Denver

Favorite subject: Chemistry

Least favorite subject: Physical Education (However, my husband Tom is a P.E. teacher, so I make an enthusiastic fan!)

Subject I wish I had studied more: Math

Professional

What I do for the Cassini mission: I work with a scientist at the Space Science Institute in Boulder, Colorado, and a team of teachers to write lesson plans that will help students learn about Saturn and the Cassini mission. The scientist I work with communicates with many scientists and engineers at JPL where Cassini was assembled. I also teach teachers about Saturn and the Cassini mission so they are inspired to teach their students about the mission and associated science concepts.

In my work, I must know how to:
- Connect Cassini to students' needs in science
- Write effective lesson plans
- Make learning focused, challenging, and fun
- Work with teachers and scientists
- Clearly explain my ideas and listen carefully to other people's ideas

The coolest thing about my work is: Watching students question, explore, and test their ideas. I can always tell when they finally understand something they have worked hard to learn.

Carrie P. Duits, continued

How I describe Saturn: Huge, Magnificent, Alluring

How I describe Cassini: Fast, International, Remarkable

Why care about Cassini? Cassini is proof of the incredible learning that takes place in schools all over the world. The people who have made Cassini possible have valued their education. Their work inspires others to reach for the stars. As an international effort, Cassini is a robot that brings many people together. Cassini will help us discover what we want to learn next!

Human Interest

How I First Became Interested in Space
Every year of my life, my family and I have spent our summers at a cottage in northern Michigan. When I was a little girl, I always thought we were at the top of the world. The stars seemed to multiply in the clear, dark night sky. The full Moon stretched a ribbon of moving light across the lake. The wonders of the aurora borealis sparked my summertime thoughts. Because of these childhood memories, I used to think about space as a way to teach poetry and story telling. But when I attended a workshop for teachers called Marsville, I discovered a new way to teach about space. Marsville's ideas for teaching the science of Mars were creative, exciting, and fun. My students were challenged to think creatively and critically as they designed systems for human survival on Mars. I grew to love the planet and the enthusiasm that it sparked within my students. As a result, ideas for teaching about space started to snowball in my mind. I've been hooked on space ever since. Its my mission to inspire other teachers to teach space education.

How I Came to Cassini
I serve on a committee in Colorado whose goal is to find ways that will encourage teachers to teach space education to all students in the state of Colorado. Randy Sachter is a teacher at Nederland Elementary School who serves on the state committee with me. She gave my name to Dr. Cheri Morrow, a scientist at the Space Science Institute in Boulder, Colorado. The Jet Propulsion Laboratory (JPL) had granted Cheri the opportunity to work with educators and JPL scientists to develop materials for teachers that would help students all across the United States learn about the exciting Cassini mission. Since I love inspiring teachers to teach about space I jumped at the chance to work with a dynamite team (including Cheri, Randy, Melody Randall, and others).

My Work Environment
When we discuss Cassini lesson plans, I work with teachers, a scientist, and a graphic artist (Steve Mercer) at the Space Science Institute in Boulder, Colorado. We work in a conference room that has walls of glass. We are inspired when we look at the mountains to the west, the vast sky to the south, and the rocket that hangs from the ceiling in the lobby. When I draft Cassini lesson plans, I work very late at night when my kids are all in bed and the house is quiet! My dog, Buddy, sits by my green rocking chair watching me work on my laptop computer and waiting for me to turn off the lights.

Sharon Elaine Grant *Mission Planner*

Words of Wisdom

"In my opinion, the most important thing to remember is to be happy with yourself. I try to accomplish this by following these simple guidelines: Enjoy what you do, be observant, never stop learning, don't waste time, maintain a positive attitude, and give of yourself in any way you can without expecting anything more in return than the warm satisfaction of knowing you've made someone's day a little brighter."

"Outspoken, Enthusiastic, Persevering"

Personal

Birth date: 6 July 1973
Home: Tujunga, California
Children: None (a dog: Wolfgang)

Favorite hobbies:
- Singing and playing the guitar
- Theater
- Swimming and scuba diving
- Camping and skiing
- Reading
- Playing with my dog
- Skydiving

Education

(all in San Antonio, Texas)
Elementary: Coker, Thousand Oaks, and Harmony Hills
Junior high: Eisenhower Middle
High school: Churchill High

Highest college degree: BS in Aerospace Engineering, University of Texas at Austin

Favorite subjects: Math, English

Least favorite subject: History

Subject I wish I had studied more: Spanish

Professional

What I do for the Cassini mission: As a Mission Planner, I assist in coordinating various spacecraft activities. There are many things to keep track of on the spacecraft. Is there enough power? Is there space on the recorder to store the information? Is there time to send the information back to Earth? If an activity takes propellant, is there enough to spare? Will the spacecraft be pointed in the right direction? Are any rules of the mission being violated? I ask all of these questions and many more, in order to help schedule mission activities.

In my work, I must know how to:
- Apply math and science principles
- Handle the unexpected
- Program a computer
- Be eager to know and learn
- Communicate effectively
- Be responsible for deadlines
- Keep a positive attitude

The coolest thing about my work is: Knowing that I am an integral part in such an important, ground-breaking task.

Sharon Elaine Grant, continued

How I describe Saturn: Intriguing, Beautiful, Enigmatic

How I describe Cassini: Resourceful, Intricate, Powerful

Why care about Cassini? I believe the Cassini mission will be a positive influence on humanity through all of the knowledge gained and because it will spark desire for knowledge and accomplishment in many potential leaders of tomorrow. Space missions, Cassini especially, serve as excellent means for international cooperation.

Human Interest

My First Look at the Stars
As a kid, I went to a summer camp in the Texas hill country. It was so clear, and there were no lights for miles, so I could see more stars with my naked eye than I've ever been able to see anywhere else.

How I Came to Cassini
My career preference was not always in the spaceflight industry. I wanted to sing, and I wanted to teach others to sing. At one point I also wanted to be a social worker. Finally, I chose to be an aerospace engineer. Before working at the Jet Propulsion Laboratory, I had many different types of jobs. I've been a camp counselor, a teaching assistant, a waitress, and I've worked in an experimental lab to test sonar signals. Each of these jobs has taught me skills that I still use in work and in life today. I really love my job at JPL as a Mission Planner. Sure, everything doesn't always happen exactly the way I plan, and sometimes work can become demanding, but as long as I keep a good attitude about my job, I have fun and I look forward to accomplishing more every day.

My Work Environment
I work in an office. My shelves are filled with references including college textbooks, technical magazines, computer manuals, Cassini project documents, etc. I must wear a badge with my picture on it (ick!) around my neck at all times. I work with many different people every day. Most work at JPL, but some work at other locations around the country and even around the world.

My Most Challenging Experience at Work
In my second year at the University of Texas (at age 19), I started working at JPL as a "Cooperative Engineering Education" employee. I was using physics principles from college to analyze the Cassini spacecraft's ability to keep from tumbling when it flies by Titan, Saturn's largest moon. I sometimes wondered how I was given the opportunity to work on such a task with the education I had. This experience gave me more confidence in my abilities as a student and as a professional engineer.

Ten Years from Now?
I hope to have earned a Master's Degree, and I hope to be working on innovative space mission ideas and technologies.

LESSON 6

Figure 9

Cassini Team Member Profile

Michael Quinley Hooks (Mike) *Archivist and Historian*

Words of Wisdom

"I would like to think that I have succeeded in my life because I care about others and they care about me. I believe that it is important to treat people, regardless of age or cultural differences, with respect, honor, and caring. If you do this, they will treat you in the same way. Work hard, dream your dreams, and make them happen. Set goals and achieve them, never give up, and never say die. And, do not blame others all the time for the problems facing all of us. Strive to make the world a better place for everyone."

Personal

Birth date: 2 October 1947
Home: Los Angeles, California
Children: None (a dog: B.J.)

Favorite hobbies:
- Traveling
- Collecting baseball cards
- Collecting model cars
- Swimming in my own pool
- Visiting the beach or mountains

Education

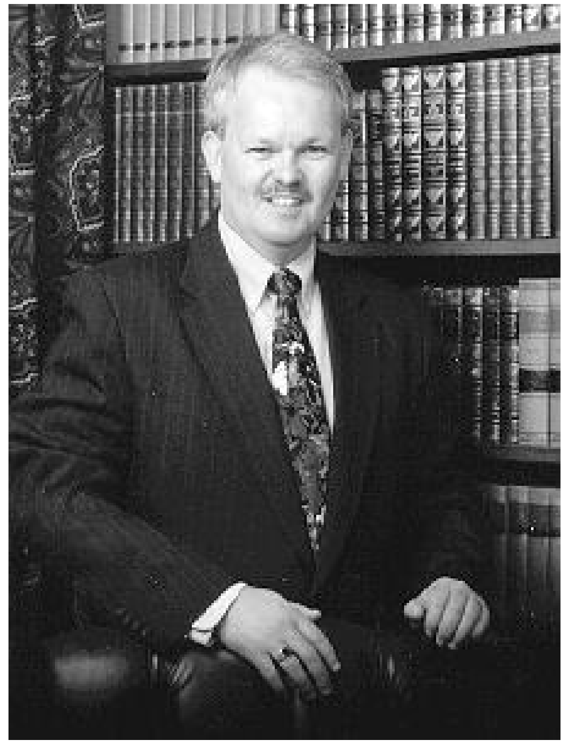
(All in Henderson, Texas)
Elementary: Central Elementary School
Junior high: Henderson Jr. High
High school: Henderson High

Highest college degree: PhD in History, with a minor in Urban Geography, Texas Tech University

Favorite subjects: History, Government/Civics

Least favorite subject: Geometry; I just could not get it.

Subjects I wish I had studied more: Geology and Geography



"Optimistic, Organized, Hardworking"

Professional

What I do for the Cassini mission: I am the Chief Archivist for the Jet Propulsion Laboratory. This means that I am responsible for identifying, collecting, preserving, and making available the historical records pertaining to the Laboratory and its various projects, tasks, and activities. This includes the historical records of the Cassini mission. The records can come in various forms, such as paper, photographs, compact disks, tapes, videos, and oral history interviews with people involved in the mission.

In my work, I must know how to:
- Be familiar with the history of JPL
- Work with people
- Use a computer
- Research and discuss historical records
- Persevere when it seems overwhelming

Michael Quinley Hooks, continued

The coolest thing about my work is: Being at JPL itself. Working with interesting people. Knowing that I am preserving information about space missions that will be of value to researchers in the future who wish to know more about the "whys" and "hows" of things at the Laboratory.

How I describe Saturn: Beautiful, Fascinating, Mysterious

How I describe Cassini: Ambitious, Well-planned, Beneficial to the American people

Why care about Cassini? We should care about the Cassini mission because it represents that continuing need of the American people to explore, to expand their interests, and to learn more about the unknown. We should care about the mission because it represents the end of an era of great missions, an era of much success in expanding our knowledge of the Universe and beyond. So many people have put so much time and energy into the mission, and will continue to do so after Cassini is launched, so I want to see it succeed. I also want Cassini to succeed for the benefit of the American people, who continue to support the space program and understand its value to the nation and the world.

Human Interest

How I First Became Interested in Space
I am not sure when I first noticed the sky, but I remember helping my older brother and his friends launch small rockets in the field near our house, and wondering what it would be like to be launched into space. This was in the late 1950s and early 1960s, at the time NASA was formed and working on the Apollo program to send astronauts to the Moon. Later, when I moved to West Texas, where the land is flat and the sky is so clear at night, I would look at the stars and wonder what it would be like to actually see them up close.

How I Came to Cassini
When I was younger, I guess I really wanted to be a baseball player when I grew up. Baseball was so much more popular when I was a kid than was football or basketball. Unfortunately, I was not a good athlete, so I had to channel my baseball interest into collecting baseball cards. As I grew older, I became very much interested in history and decided that I wanted to teach history at the college level and to write books on historical events and people. This interest in history then turned toward collecting the historical information that others would use to write their books and teach their classes. Before coming to JPL, I was the Archivist for the Texas General Land Office in Austin, Texas, for 5 years. Before that I was the Associate Archivist at Texas Tech University for a little over 7 years.

Overcoming Adversity in My Career
I owe much of my success to my parents and to my mentors. Although neither my father nor my mother has a college degree, they instilled in my brother and I the value of education, hard work, and commitment. My brother also has his PhD (in Economics), and he teaches at the University of Alabama. So, the influence of my parents is a large part of my professional success. In addition to my parents, the influence of people whom I see as mentors in my profession has been important. They have helped me in achieving success with their training, guidance, knowledge, and support.

LESSON 6

Figure 10

Cassini Team Member Profile

Christopher A. Kelly (Banish) *Security and Fire Dispatcher*

Words of Wisdom

"Never quit wondering, and never, ever quit asking. Ask until you get an answer."

Personal

Birth date: 24 September 1963
Home: Fontana, California
Children: Michael (b. 1989)

Favorite hobbies:
- Computer games
- Surfing the Internet
- Jogging
- Racquetball
- Weightlifting

Education

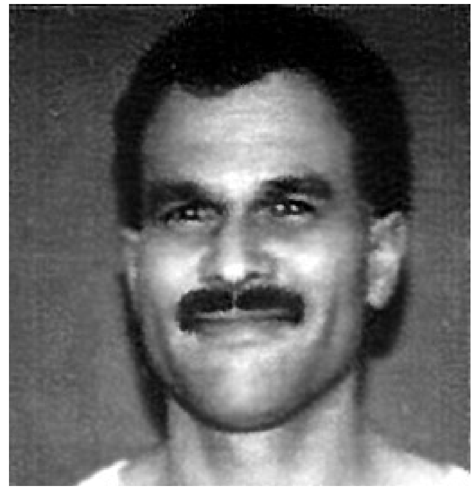
Elementary and junior high: (Grades 1–8): St. Rita's Catholic School, Sierra Madre, California
High school: St. Vincent's Seminary, Montebello, California

Highest college degree: Associate of Arts degree at Pasadena City College (pending)

Favorite subject: History. I find it fascinating to study the events and people that have affected and continue to affect our everyday lives; everyone from world leaders to the people who carry out their decisions.

Least favorite subject: Speech. I don't like speaking in front of crowds.

Subject I wish I had studied more: Speech. I think more of this class might have helped me overcome my dislike of speaking in front of crowds.



"Curious, Understanding, Sensitive"

Professional

What I do for the Cassini mission: I work in the Emergency Operations Center dispatch. I maintain a secure environment/work area for the people who work on the Cassini spacecraft. From the dispatch center, we can view and monitor many of the areas of the Jet Propulsion Laboratory using closed-circuit TV. In addition, we have an alarm computer, which gives us reports from different areas of the Lab. If someone were to enter the Cassini area without proper authorization, I would receive an alarm, and dispatch or send officers to that area.

In my work, I must know how to:
- Use many types of computers
- Communicate effectively with others
- Be resourceful
- Pay close attention

The coolest thing about my work is: Seeing some of the things that have been and continue to be built here at JPL. The Galileo spacecraft is a good example. I've seen it, and I've talked with the people who designed and built it. Now I read about it in the newspapers and see it on TV. The Cassini mission will be the same way. This is history, and I have a front-row seat!

How I describe Saturn: Wondrous, Breathtaking, Inspiring

How I describe Cassini: Capable, Ambitious, Noble

Why care about Cassini? This spacecraft is far and away one of the most well-designed ever assembled. It has been designed and built by some of the finest minds and people in the world. Thousands of people have spent years creating it. This spacecraft will answer questions people have had about Saturn for a long time. This is a noble venture! I think lots of things we know about we tend to take for granted, such as the Moon. What we know about the Moon today was the result of thousands of people, and 20 years worth of work. And there are still questions that need to be answered. People should never quit wondering and asking.

Human Interest

How I First Noticed the Stars

Funny story here. I come from a large family, and my mom would occasionally sit outside on the porch and just look at the stars. This was her quiet time. So, I'd sit out there with her, and look. I asked her what they were, and she told me that they were "angels washing dishes." Never forget that one! Well, I learned later that she was not totally truthful with me, but I'd still sit out there with her. She would show me the different constellations — the Big Dipper and so on.

How I Came to Work at JPL

I started out wanting to be a priest. I attended the major Seminary in Perryville, Missouri, and discovered there that it was not meant to be. I returned to the Southern California area to attend school, and obtained part-time work with JPL. I applied for a full-time position and was accepted. The Lab is a great place to work. It is quite satisfying to see some of my own ideas regarding my job taken and made part of the job. The best "perk" that comes with my job is the "front-row seat" I have in watching the history-making events of deep space exploration.

My Most Challenging Experience at Work

Without a doubt, one of the most trying times during my employment with JPL was the day of the Northridge earthquake. It happened at about 4:30 in the morning, which is my regular work shift. It went from a quiet shift to total chaos. I must have answered about 1,000 phone calls, dispatched people to countless areas requiring a check, contacted many of the people responsible for the Laboratory, reporting to them the condition of the Lab. It was a very difficult time, and I believe I handled it well.

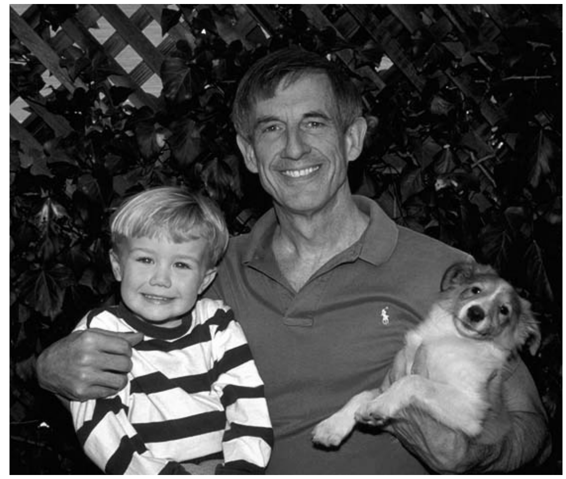
Figure 11

Cassini Team Member Profile

Charles E. Kohlhase (Charley) *Science and Mission Design Manager*

Words of Wisdom

"Rise early and seize each day, learn much and use this knowledge well, spend time with those you love, never abuse your pets, use logic to fight the irrational (for it is everywhere), defend the environment and its wildlife as a knight would protect King Arthur, meld mind and heart for greatest creativity, follow your dreams, and become all that you can be."



"Alive, Honest, Bright, Multidimensional"

Personal

Birth date: 15 August 1935
Home: Pasadena, California
Children: Wendy (b. 1961), Alison (b. 1960)

Favorite hobbies:
- Taking photographs
- Hiking and exploring the wilderness
- Playing golf
- Reading
- Developing computer adventure games
- Creating images using Photoshop and 3-D modeling programs

Education

(Both in Chattanooga, Tennessee)
Elementary and junior high:
Missionary Ridge
High school: The McCallie School

Highest college degree: Master of Engineering, UCLA

Favorite subject: Calculus

Least favorite subject: History

Subjects I wish I had studied more: Computer Graphics, Multimedia, Art, and Architecture.

Professional

What I do for the Cassini mission: Rather than being an architect who builds a large house, I am like an architect who designs a complex mission to another world. I have half a dozen talented people leading the work in different areas, and each of them has many engineers and scientists helping them. It is our job to decide how to go from Earth to Saturn, what demands to place on the robotic spacecraft to accomplish the scientific mission, and how to best orchestrate the total adventure.

In my work, I must know how to:
- Manage people
- Anticipate problems
- Apply math, physics, and astronomy
- Simplify a complex problem without overlooking anything important
- Have self-confidence
- Have strong intuition and a sense of humor

The coolest thing about my work is: Pulling the mission together like a large jigsaw puzzle, and not having a single piece out of place.

Charley Kohlhase, continued

How I describe Saturn: Vast, Beautiful, Remote

How I describe Cassini: Complex, International, Exciting

Why care about Cassini? I care about Cassini because it shows that there are ways to accomplish any task, no matter how difficult it might seem. It proves that nothing is beyond a person or a team of people who have the knowledge and the imagination. It shows that education counts for a lot. Time invested in exploring and learning is always returned many times over as life passes.

Human Interest

How I First Became Interested in Space

I first turned on to space (age 10–12) in reading stories by Isaac Asimov and other science-fiction writers. Amazingly, at a 40th high school reunion, an old friend said he used to remember me (when I was 12 or 13) lying in the grass at night looking up at the stars. He was not surprised to learn of my space career.

How I Came to Cassini

When I was 12, I wanted to be either a jet fighter pilot, a matador, or an architect. I would have chosen architecture, but my father could not afford to send me to the 5-year program, so I went for a 4-year physics degree, as it was the only area in which my father could not intimidate me. He said that it was the greatest mistake of my life, but I did it anyway. I do not know how I resisted his will. He even stopped paying my tuition and board, so I got a student-teaching job, as well as running a large dormitory, to make ends meet. Before starting work at JPL, I had done such jobs as working in a large candy company, "goosing" golf greens to remove the crabgrass, and even serving as the electrical officer of a nuclear weapons team aboard an aircraft carrier (not because I like nuclear weapons, but because I wanted an assignment related to physics on a ship large enough that I would not get seasick very much).

My Work Environment

I work at the Jet Propulsion Laboratory in an office with a nice view of the mountains and some nearby trees. Once, many years ago, I saw seven California condors circling overhead.

My Most Challenging Experience at Work

I had been at JPL for 10 years when I had to okay the science platform pointing angles for a brief flyby of Mars. The values output by the computer did not seem quite right, and I adjusted them by a mental calculation. The hour that followed was the longest in my life, waiting to see whether we had pictures of the Martian surface . . . or of deep space!

Ten Years from Now?

I expect to be working to save our natural environment, hiking to the last of the beautiful regions on Earth, writing a fictional adventure novel set around the turn of the next century, and trying to create some really first-class digital fine art.

LESSON 6

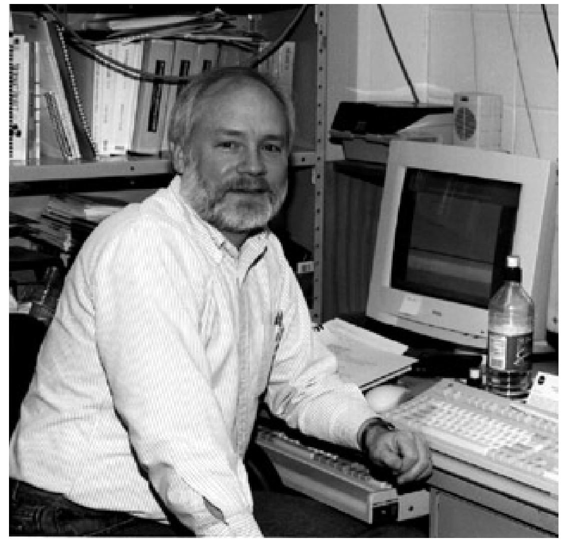
Figure 12

Cassini Team Member Profile

William S. Kurth (Bill) *Scientist and Principal Investigator*

Words of Wisdom

"Plan to do what you *like* to do with your life. While choosing a career based on how much money you can make sounds important, all that money is of little value if you aren't enjoying what you have to do to earn it. Prepare yourself for any career by staying in school as long as you can and by taking all of your classes seriously. It is less important *what* you major in in college than that you actually complete a course of study and learn to learn. Use part-time jobs on campus to explore different areas you might be interested in; these will give you an insight into what that type of work is *really* like."



"Busy, Curious, Adventuresome"

Personal

Birth date: 7 February 1951
Home: Coralville, Iowa
Children: Steven (b. 1975), Brandi (b. 1978), Marisa (b.1981), Jeremy (b. 1993)

Favorite hobbies:
- Photography
- Astronomy
- Radio-controlled airplanes

Education

Elementary: Oakwood Elementary, Charleston, West Virginia
Junior high: Taft Jr. High School*
High school: Jefferson High School*
*Both in Cedar Rapids, Iowa

Highest college degree: PhD in Physics, University of Iowa

Favorite subject: Astronomy

Least favorite subject: Math methods

Subjects I wish I had studied more: Math

Professional

What I do for the Cassini mission: I am the Deputy Principal Investigator for one of the science instrument packages on the Cassini orbiter called Radio and Plasma Wave Science (RPWS). RPWS will receive and measure the radio signals coming from Saturn, and will also measure properties of magnetic waves and electrons. As a scientist in Physics and Astronomy at the University of Iowa, I work in a group of about 45 people. I analyze scientific data, write papers and research proposals, interact with colleagues all over the world, and think about what space-based hardware can and cannot do.

In my work, I must know how to:
- Apply the physics of plasmas
- Use and program computers
- Write well
- Interact successfully with others
- Analyze science data from spacecraft
- Apply my understanding of electronics

The coolest thing about my work is: I often get to be the very first human being to see specific types of observations returned from planetary spacecraft. On Voyager, everything we observed with the plasma-wave instrument was a new discovery since an instrument of that kind had never flown to Jupiter and beyond.

How I describe Saturn: Wonderful, Alien, Beautiful

How I describe Cassini: Ambitious, Required, Exciting

Why care about Cassini ? The Cassini mission will define virtually all that we know about the Saturn system. All of this new knowledge will tell us more about the way our solar system works and the way the planets formed. It will tell us whether it is likely or not that other planetary systems formed and that we should not consider ourselves alone in the Universe. It should give us a better understanding about how we came to be. If Cassini arrives at Saturn in good working order, we are guaranteed to be astounded and surprised by what we find!

Human Interest

How I Became Interested in Science
When I was in high school, I noticed and photographed the aurora from my home in Iowa. I went to the public library to find out how the aurora are formed, but found very little. When I was an undergraduate student at the University of Iowa, I discovered that the space physicists there spent their entire careers studying the basic physics underlying the aurora. To be able to have a job pursuing my childhood curiosities has made me unbelievably fortunate.

My Most Exciting Experience at Work
As Voyager approached Uranus in early 1986, I plotted up some recent data from our plasma instrument and immediately noticed indications of the first radio emissions from Uranus. This provided the first evidence that the planet would have an extensive magnetosphere. Several days later, another instrument team agreed that we had seen Uranus, and we were all totally immersed in exploring yet another new world!

My Most Challenging Experience at Work
When the Galileo high-gain antenna failed to deploy, all of us were afraid that the mission would be a failure because the spacecraft would not be able to send back as much data. Instead, hundreds of people worked long hours, day in and day out, for nearly three years to find ways of making do with what we had. Instead of being able to send back 100,000 bits of information per second, Galileo could only send back about 10 bits per second. With some ingenious improvements they were able to increase this to about 100 bits of information per second. The rest of the job was up to the scientists to figure out how to make each bit count for more information. The results for our plasma instrument were remarkably good! With some clever programming, we were able to get the same quality of data using 5 bits of information per second instead of the 240 bits per second we had originally planned.

Ten Years from Now?
I hope that 10 years from now I will be analyzing Cassini data from Saturn and discovering why Saturn's moon Dione apparently controls the intensity of radio emissions generated in Saturn's magnetic field. I also hope to be continuing to monitor data from the two Voyager spacecraft, which will then be 100 times further from the Sun than is Earth.

LESSON 6

Figure 13

Cassini Team Member Profile

Stephen Charles Lane (Steve) *Mechanical Designer*

Words of Wisdom

"Keep a child's eye. Wonder at this marvelous Universe and take an active part in its exploration. Embrace the world, travel forth and explore with every God-given sense and talent, and with every good tool you can wield. Learn, and learn how to learn, and then experience every interesting and noble thing. Teach when your life's experiences have become worthy of a child's eye."

"Loyal, Curious, Persistent"

Personal

Birth date: 7 September 1956
Home: Broomfield, Colorado
Children: Zachary (b. 1992), Madeline (b. 1997)

Favorite hobbies:
- Fishing
- Fixing things
- Photography
- Skywatching

Education

(All in Dallas, Texas)
Elementary: Holy Cross
Junior high: St. James
High school: Bishop Dunne

Highest college degree: BS in Architecture and Environmental Design, University of Texas at Arlington

Favorite subject: Science — I LOVE to explore.

Least favorite subject: I liked everything; I liked school.

Subject I wish I had studied more: More science!

Professional

What I do for the Cassini mission: I work at a laboratory in Colorado where we designed and built Cassini's Ultraviolet Imaging Spectrograph (UVIS). UVIS can make images of the ultraviolet light reflected off Saturn's rings and the atmospheres of Saturn and Titan. From this, we can learn more about their structure and composition. I laid out the initial mechanical design for the spectrograph. I also designed and implemented tests of how well (mechanically) the UVIS instrument would survive and perform during the stressful Cassini mission. I am just one member of a large team of engineers, scientists, machinists, and many others.

In my work, I must know how to:
- Do detailed technical drawings
- Apply engineering and math basics
- Listen carefully and communicate with scientists and machinists
- Use my imagination to solve problems

Stephen Charles Lane, continued

The coolest thing about my work is: Being involved in the whole process of creating a new tool to be flown on a spacecraft to make new discoveries.

How I describe Saturn: Distant, Mysterious, Wondrous

How I describe Cassini: Ambitious, Hopeful, Difficult

Why care about Cassini? Cassini is a mission of discovery. Discovery educates, inspires, and uplifts. It separates us from the "dog-eat-dog" drudgery of survival. It's our nature to wonder, discover, and find out about the Universe. In every form (art, literature, science), the exploration of the Universe has always been the noblest of endeavors.

Human Interest

How I First Noticed the Stars
Noticing the stars was one my earliest memories. My family has a lake in East Texas (Pinedale). It's about 100 miles from the big-city lights of Dallas and 20 miles from the town of Tyler, Texas. I was probably 2 or 3 years old, but I "always" knew I'd see the whole Milky Way at the lake. We went several times each summer and I also saw bullfrogs, foxes, deer, snakes, turtles, wild turkeys, donkeys, cattle, and of course, fish (catfish, brim, bass). These days I take my own children there every year. My wife loves it too — pine trees, rolling hills, fresh air, and starry skies!

How I Came to Work on Cassini
When I was younger I wanted to be an astronaut, a space explorer, the first person on Mars! I started college in Aerospace Engineering, but switched to Environmental Design and Architecture. I've had some boring, everyday jobs in engineering and architecture. Thirteen years ago, I turned down two jobs in architecture to take a riskier job in aerospace. I've never regretted it! The job I have now has been challenging and mysterious every day. When it comes to designing an instrument like the UVIS for Cassini, my knowledge of the architectural design process sometimes serves me more than my engineering expertise. Often the solution is not so much about the numbers but more about the seeing all the possibilities (and then you crunch numbers).

Overcoming Adversity in My Career
No one achieves success without overcoming some adversity. At the time, we see our adversity (a problem, a person, a handicap) as the enemy. But when we persevere and succeed, we can see that the "enemy" was the teacher, and that we are stronger for the contest. The sixth and seventh operations on my right hand were successful, and I finally won my battle with repetitive stress injuries.

Ten Years from Now?
I expect to be doing much the same, only better, more fascinating and more fun!

LESSON 6

Figure 14

Cassini Team Member Profile

Patricia duFossé Lock *Systems Engineer*

Right: "Paddy" Lock visiting the Star Trek exhibit at the National Air and Space Museum in Washington, D.C., during the fall of 1992.

"Busy, Funny, Adventurous"

Words of Wisdom

"There is nothing you cannot do. Don't let people tell you that you can't do something you dream of doing. Go for it; if one way doesn't work, try another. And you *can* have a career and a family. It's hard, but it's worth it, and we can help each other."

Personal

Birth date: 11 January 1961
Home: La Crescenta, California
Children: Graeme (b. 1992) and Connor (b. 1993)

Favorite hobbies:

- Reading, especially science fiction, history, and mythology
- Camping
- Cooking experiments
- Riding trains with my sons

Education

Elementary: Cranford, New Jersey and Beverly, Massachusetts
Junior high: Loyalsock, Pennsylvania
High school: Loyalsock, Pennsylvania, and Sunnyvale, California

Highest college degree: BS in Aerospace Engineering and Minor in Classics, San Diego State University, California

Favorite subject: English

Least favorite subject: Social Studies; "It amuses me that a subject I hated most in school is really the history I now love."

Subject I wish I had studied more: Foreign language

Professional

What I do for the Cassini mission: I engineer the system for distributing computers and all the proper software to Cassini scientists all over the world. I also assist scientists in the operation of 4 of Cassini's 12 instruments.

In my work, I must know how to:

- Think broadly
- Anticipate problems
- Use computers and the Internet
- Learn new things
- Negotiate with others

The coolest thing about my work is: Cassini is going to Saturn and will send back images we've only dreamed of. And I have a high-speed connection to the Internet on my desk to look at them!

Patricia duFossé Lock, continued

How I describe Saturn: Fascinating, Mysterious, Lovely

How I describe Cassini: Ambitious, Challenging, Hopeful

Why care about Cassini? The Cassini mission will be a benefit to all of us. The huge amount of new information we get back from it will help us develop a better understanding of the Solar System, Earth, and ourselves too! There may be solutions to problems we have here on Earth that will be discovered as a result of new information sent back by Cassini. Also, Cassini keeps our sense of wonder alive. If we don't stretch our limits and explore, if we don't learn new things, how can we grow?

Human Interest

My First Look at the Sky
I remember watching the Moon out my window at night. I always wanted to go there. My father had a puppet he would pretend was a visitor from the Moon. We didn't figure it out until we were 12 or older! After I saw the Moon landing (I was 8 at the time), I knew I would always be in some way associated with space.

How I Came to Cassini
Since I began high school, I knew I wanted to do something technical. For a while I had wanted to be a physical therapist, but a couple weeks volunteering at my local hospital changed my mind. I always knew I would go to college and have a career. My grades and test scores were much higher in English than math, but still OK in both when I began to think about engineering. It was an early idea, but it fit with my childhood dream of going to the Moon, so I discussed it with my advisor. Well, this advisor told me that I couldn't go to engineering school because I was a girl! Obviously this advisor didn't know me very well, because right then I made up my mind to do it. I've never regretted that decision.

During college I worked two internships. One of them was working on the Apache Helicopter. That was loads of fun! After college, I was hired by Martin Marietta (now Lockheed Martin) in Denver, where I was an engineer. Five years later my husband was offered a job at the Jet Propulsion Laboratory and we decided he should take it. I set up an interview, then never stopped calling JPL until someone hired me! The job they hired me for was on Galileo (NASA's mission to Jupiter). I changed jobs three more times, all on Galileo, before moving to Cassini in 1994.

My Most Challenging Experience at Work
When the high-gain antenna on Galileo failed to deploy, and only a limited amount of science data could be sent back, I was very involved in rethinking how all the science observations would be done with the new setup. All the processes our team had worked out before launch were thrown out and we started over. It was quite a big job, requiring much perseverance.

LESSON 6

Figure 15

Cassini Team Member Profile

Ellis Devere Miner, Jr. *Science Manager*

Words of Wisdom

"Many people struggle to be recognized as great, as better than the rest, often by climbing over other people. Most only succeed in making enemies. The best and most successful, in my opinion, are those who unselfishly serve others in any way they can. There is no limit to what people can accomplish if they don't care who gets the credit."

Personal

Birth date: 16 April 1937
Home: Lake View Terrace, California
Children: (with wife Beverly) Steve (b. 1962), Marjorie (b. 1963), David (b. 1967), Jeffrey (b. 1970), Christin (b. 1972), Becky (b. 1976), Laura (b. 1980)

Favorite hobbies:

- Tennis, hiking, and mountain biking
- Studying family history
- Singing bass in a church choir
- Talking about astronomy and space science
- Tutoring students in math and science

Education

Elementary: Andrew Jackson Elementary in San Francisco and McKinley Elementary in Redwood City, California
Junior high: Logan Jr. High*
High school: Logan High*
*Both in Northern Utah

Highest college degree: PhD in Astrophysics, Brigham Young University

Favorite subjects: Physics and Algebra

Least favorite subject: Economics

Subjects I wish I had studied more: Geology and Meteorology

"Happy, Excited about space, Quick to understand new things"

Professional

What I do for the Cassini mission: I am the Science Manager for Cassini. I fund the U.S. scientists who are members of our Cassini science investigation teams. I also help set scientific priorities for the Cassini mission, direct some of the detailed planning for collection of science data, and serve as a science "expert" and spokesperson to broadcast media personnel and to other interested individuals and groups. I interact directly with about fifty people on the Cassini Project staff and with a similar number of scientists in the United States and Europe.

In my work, I must know how to:

- Apply basics of science
- Listen well
- Get along with others
- Use computers and e-mail
- Speak in public
- Express complex ideas in easy terms

The coolest thing about my work is: Getting to be close to and a part of such an exciting adventure as the Cassini mission, and to be one of the first to see the data (pictures and other information) coming back from the spacecraft.

How I describe Saturn: Beautiful, Intricate, Mystifying.

How I describe the Cassini mission: Well-designed, Unprecedented, Thrilling

Why care about Cassini? Spacecraft missions to the planets are a rare but very important way to learn about our neighborhood of the Universe. Keeping track of Cassini is a little like being there when the Declaration of Independence was signed, when Galileo first pointed a telescope at the skies, when William Herschel discovered the first new planet not known to the ancients, or when astronauts first stepped on the Moon!

Human Interest

How I First Noticed the Sky

My interest in astronomy and the Solar System began in Redwood City, California, when I was still in grade school. I used to love to lie on my back at night and contemplate the stars and Moon. However, it wasn't until I was a physics graduate student that I decided to major in astrophysics and that I had my first glimpses of the heavens through a telescope.

How I Came to Cassini

I was a fan of Bing Crosby when I was very young, and thought it would be great to grow up to be a professional singer and actor. Unfortunately, my talents didn't quite match my ambition. Then I thought about being an astronaut, but I was an inch too tall. I also thought about being a religion teacher, but I have settled for teaching religion as a volunteer each morning during the school year (now in my 12th year). I sort of stumbled into my job at Jet Propulsion Laboratory when I needed employment for the 4 months between the time I got my PhD and when I had to report for active duty in the Army. The Army then assigned me to work at JPL for my 2 years of active duty, and I've been here ever since.

A Major Challenge in My Career

One of the more challenging problems was how to use the limited time and limited computer memory of the two Voyager spacecraft to accomplish the maximum amount of science, while at the same time avoiding heated arguments between scientists about whose data was most important. We managed to be able to satisfy almost every scientist who worked on Voyager. Sometime a few years before I joined the Voyager Project as Assistant Project Scientist, I was asked to serve for 5 years as a Bishop in my church (The Church of Jesus Christ of Latter-Day Saints). I learned valuable counseling skills and how to recognize and appreciate the efforts of individuals. These attributes have been very helpful to my success in the space program.

Ten Years from Now?

Ten years from now the Cassini spacecraft will still be collecting data in orbit around the planet Saturn. I plan to stick around until the Cassini mission is complete and then retire. I will be 71 by then, and perhaps my wife and I will serve an 18-month mission for our church somewhere in the world.

LESSON 6

Figure 16

Cassini Team Member Profile

Fernando Peralta *Mission Design and Navigation*

Words of Wisdom

"Education is a must and should be pursued as a never ending endeavor. Education brings great personal pride, satisfaction, A great sense of accomplishment, and it opens one's horizons to unlimited and unimagined possibilities. I stand for honesty, integrity, and commitment to excellence."

Personal

Birth date: 8 January 1957
Home: La Cañada, California
Children: Catalina (b. 1979) and David (b. 1983)

Favorite hobbies:
- Photography
- Filmmaking
- Jogging
- Reading on diverse topics
- Contributing to my community

Education

Elementary and junior high: San Bartolome La Merced in Bogota, Colombia, South America
High school: Bogota, Colombia

Highest college degree: MS in Aerospace Engineering, University of Texas at Austin

Favorite subject: Humanities (history, literature)

Least favorite subject: English Composition

Subject I wish I had studied more: I wish I would have taken more and paid more attention to English since I came to realize how much I needed it when I started writing publications and memos to my colleagues at work.

"Positive, Enthusiastic, Participative"

Professional

What I do for the Cassini mission: I have participated in the design and analysis of the interplanetary trajectory of the Cassini mission. Presently, I'm more involved in the navigation aspect of the mission. I run computer simulations of the trajectory to be flown to Saturn. With a group of about 10 people, I ran tests and training exercises associated with the launch phase of the mission.

In my work, I must know how to:
- Use orbital mechanics
- Apply mathematics and physics
- Program computers
- Learn new things
- Get along with others

The coolest thing about my work is: The Jet Propulsion Laboratory stands for excellence in space exploration throughout the world and being part of it is really cool. It's the coolest when you can make use of all the different interests and skills you possess, allowing you to keep growing at a professional and personal level.

How I describe Saturn: Fascinating, Mysterious, Magnificent

How I describe Cassini: Revealing, Engaging, Unique

Why care about Cassini? As with any JPL mission, Cassini will return new knowledge (both expected and unexpected) for the benefit of humankind, and if we're lucky, it will keep bringing information back to Earth beyond the predicted life-span of the mission. Cassini's development has also brought technical innovations thus creating possibilities for spin-off technologies which in turn can generate new jobs. Also, Cassini will undoubtedly create an immense sense of pride and accomplishment, not only at the local level but also throughout the world.

Human Interest

How I Feel about My Job

My job is very challenging and rewarding. I believe that if a person likes what he/she does then that person gives more than what the written job assignments ask for, thus making use of all possible skills one can offer. In my case, I provide not only my technical skills and knowledge to JPL, but I also see myself as a public servant. Therefore, I promote science and space exploration at different outreach events. I give public talks and tours at JPL (even on Sundays). I volunteer at fair expos and I serve as liaison between JPL and different organizations, such as schools. To me, even one person is worth approaching, especially if the person comes from a relatively poor or risk-filled living environment.

How I Came to Cassini

I loved flying since I can remember and thought of being a commercial pilot, but I was also very intrigued as to why the airplane was able to fly. Later, I was fascinated not only with air ventures but also with space. Once I decided that I wanted to do interplanetary mission design, I had two questions: 1) What were the best schools to provide me with the knowledge to do mission design? and 2) Was there a market in mission design at JPL? I didn't want to spend such an amount of resources and find out that at the end of the road there was no market for my skills. I got the name of a person to contact at JPL to see if I could work there once I had completed my Master's degree. I selected Bill O'Neil (at the time, Galileo project manager), which was the name with the highest rank listed in on a conference paper I found. I would confess that making that phone call was very intimidating to me. Bill very nicely referred me to Roger Diehl (at the time, Mission Design Manager for the Cassini program) who invited me over to JPL and very kindly offered me advice in regard to my questions. I have come to realize that there are always people willing to assist you and guide you if you ask for it.

Ten Years from Now?

I plan to go back to school and obtain an MBA once I finish the certificate I'm pursuing in filmmaking. Most importantly, I envision myself working on another exciting planetary mission.

David Allen Seal (Shaggy) *Mission Engineer and Computer Artist*

Words of Wisdom

"Work hard, play hard, and spend part of your life doing something that improves the human race and not just maintains it. Don't be bothered by anything that won't matter in 6 months."

Personal

Birth date: 27 August 1968
Home: La Crescenta, California
Children: None

Favorite hobbies:
- Volleyball
- Playing in the ocean
- Playing the guitar
- Going to baseball games
- Playing race cars and Star Wars with my brother

Education

(All in Beverly, Massachusetts)
Elementary: Hardie and Cove schools
Junior high: Briscoe Middle School
High school: St. John's Prep, a Catholic Boy's School

Highest college degree: MS in Aerospace Engineering, Massachusetts Institute of Technology

Favorite subject: Creative Writing

Least favorite subject: A class called "multivariable control" that was all hairy math with no interesting examples.

Subject I wish I had studied more: Economics; I'm awful with money, and don't have the first clue how to buy a house...compound interest and all that.

"Rich, Famous, and Popular, of course!"

Professional

What I do for the Cassini mission: I'm only working odd jobs for Cassini now, but my role was the lead mission engineer. Essentially, my tasks fell into four categories: find out what the scientists want to do at Saturn; find out what the engineers can design; do trade-off studies to get science needs and engineering designs to match; and communicate the results of those studies effectively. I worked on everything from figuring out what Earth antenna to use to communicate, to developing a strategy to use the recorders to save as much data as possible. I also make computer artwork and animations for Cassini that can be found on the Cassini website.

In my work, I must know how to:
- Apply engineering and math principles
- Use and program a computer
- Work well with people
- Write clearly
- Use my imagination

David Seal, continued

The coolest thing about my work is: I get to make artwork for Cassini and other projects, and they pay me to do it.

How I describe Saturn: Elegant, Majestic, and really really Big

How I describe Cassini: Ambitious, Illuminating and Expensive — but worth it!

Why care about Cassini? First, space is cool. Some day we'll be flying around the Solar System without any problem, and learning about it now is necessary if we are going to do that. Second, the space program is a great source of new technology. There are a lot of new inventions that come out of developing a spacecraft like Cassini. I really hope it discovers something totally incredible!

Human Interest

How I Became Interested in Space
I was interested in space ever since I saw *Star Wars* and my Dad and I started looking through his telescopes. He's a really good amateur astronomer. I didn't live with him, but got to visit him during the summers (he was usually in a foreign country) so it was always a treat to get out the telescope and check out objects in the sky.

The Nature of My Work Environment
I work in one of the famous Dilbert-like "cubicles." But at least I have a window with a tree. I alternate between "tooling" on my own to working with teams of 4–8 people to get things done. I really recommend that people make high school and college a social experience as well as an academic experience. I've seen plenty of people with good technical skills who weren't really accomplishing anything because they didn't know how do communicate with people. In my work environment, technical and people skills are equally important!

A Fun Challenge at Work
One of the more fun challenges was fitting people's signatures on a CD-ROM that will travel to Saturn with the spacecraft. After signatures are scanned in, I had to think of a way to fit as many as possible on a CD-ROM without making them impossible to read.

How I Came to Do Space Art
In 1993, I had been playing with some software that was used to make computer images during the Voyager flybys of Jupiter and Saturn. I was the only person who seemed interested in keeping the software working. Strangely, I had first heard of the Jet Propulsion Laboratory when I was 8 years old and saw images created by this software on TV. It was an amazing twist of fate that I would wind up being the person in charge of it. Anyway, I offered to use the software to do a color picture of a comet called Shoemaker–Levy 9 crashing into Jupiter. The image wound up in *Time* and *Sky & Telescope* and lots of other magazines, and also on TV, in videos, and in books. I couldn't believe how much press the image got, and decided that not only was it fun (the main reason I still do it), but it's something people get excited about. So I've continued to do space art when I can. It really is part of my job here, too, spreading the word about space to the public (which pays for NASA). Lots of my Saturn work can be found on the Cassini website.

LESSON 6

Figure 18

Cassini Team Member Profile

Marcus Angelo Watkins (Marc) *Spacecraft Engineer*

Words of Wisdom

"Life is about learning, whether it is how to tie your shoe or how to fly an airplane. You learn from listening, observing, and questioning. *Take chances!!* Try almost anything as long as it will not hurt you! You are a unique individual and there is only one of you! Develop yourself into whatever you want. We live in America, where you have the best chance at becoming whatever you want to become. Most of the world does not have the opportunities that you have. Do not squander them. Embrace them!"

Personal

Birth date: 11 November 1960
Home: Santa Monica, California
Children: I am helping to raise my cousin Michael (b. 1987)

Favorite hobbies:
- Flag football
- Tennis
- Basketball
- Skiing
- Music (all kinds)

Education

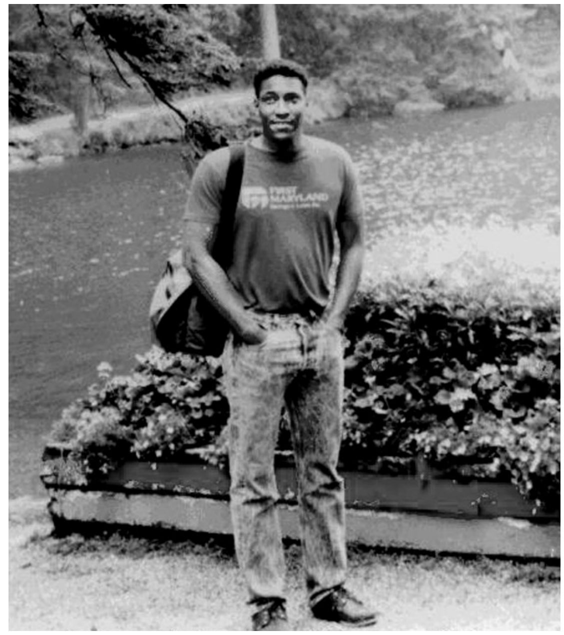
(All in Lanham, Maryland)
Elementary: Lincoln and Seabrook
Junior high: Thomas Johnson
High school: Duvall

Highest college degree: MS in Engineering, George Washington University in Washington, D.C.

Favorite subject: Mathematics

Least favorite subject: English

Subjects I wish I had studied more: Spanish, Art, and Music



"Easygoing, Personable, Playful "

Professional

What I do for the Cassini mission: I worked with the spacecraft manager and program manager on the antenna system and also the power and propulsion systems. Antennas are used to communicate with the spacecraft from the ground stations and to receive scientific data from the spacecraft. Power runs the radios, computers, and instruments. Propulsion moves the spacecraft from Earth into space and then on to Saturn.

In my work, I must know how to:
- Communicate with different people
- Apply technical skills in engineering, science, and math
- Be willing to try new things
- Have fun doing hard things

Marcus Angelo Watkins, continued

The coolest thing about my work is: Working on a spacecraft that travels billions of miles to investigate the Saturn system; working on one of the last of the huge spacecraft to be built; traveling to Germany and Italy to work with the Italians and Germans.

How I describe Saturn: Cold, Stunning, and Mysterious

How I describe Cassini: Complex, Scientific, Awesome!

Why care about Cassini? We should care about Cassini because knowledge is power, and learning anything new helps you and your civilization to grow and develop. If Cassini is successful, we will learn a lot more about Saturn, its rings, and its largest moon, Titan. Titan is the only moon in the Solar System that has a substantive atmosphere, and it is larger than the planet Mercury!

Human Interest

My First Looks at the Sky
When I was in school, I heard about the Apollo missions landing on the Moon. I thought it was pretty cool that people were actually on the Moon when I looked up at it. I have always liked looking up at the stars and constellations. When I was younger I thought it would be nice to live on the Moon. Maybe I will still get my chance!

My Work Environment
When I worked on Cassini, there were about 20 people who worked within the project office and were responsible for managing the project. There were also several hundred other people working on Cassini's design. Eventually, thousands of people would help build and launch Cassini. My job was hard because we were doing things that had never been done before, which makes it even more rewarding when it all works!! Most of the people who work for NASA do so because it's fun!

What I Wanted to Be When I Grew Up
First I wanted to be a policeman, then a fireman, and finally I decided to become a doctor. But then while in college, I changed my mind about becoming a doctor, and instead became an engineer. Neither of my parents had gone to college, but both were well-educated. They believed one should learn about many different things. I was the first one in my family to attend and graduate from college. My mom would help type my papers and my dad helped with some of my college expenses. I was a B to C student in high school and could get by without studying too much. But this made it very difficult for me when I went to college because I had poor study skills. I had to learn to study in order to get good grades. In my career I have changed jobs at least every 4 to 5 years. Yes, it's a little scary to try new things, but it pays off, and each time it gets a little bit easier.

Ten Years from Now?
Ten years is a long time! Hmmm, well, I hope that in ten years I will be working on the Space Station... or maybe working on the next Moon landing, or getting ready for the first mission that sends people to Mars!! I hope I will be working with some of you who become scientists, engineers, technicians, programmers, and teachers, helping to explain the mysteries of the universe and solving problems of the future!

LESSON 6

Figure 19

Student Profile (1 of 2)

Your name: ______________________

____

Your e-mail address: ______________________

____

Write three words that describe you:

____

____

____

Your Words of Wisdom

A Picture of You *(Draw a picture or attach a photo, then write a brief description of your picture.)*

Personal Information

Age (in Earth years): ______________________

Your address: ______________________

____

____

Brothers/sisters: ______________________

____

Your favorite hobbies: ______________________

____

____

____

____

____

____

Education

Your current grade level: ______________________

Your favorite subject: ______________________

____

____

Least favorite subject: ______________________

____

What subjects do you want to study more?

____

____

____

____

____

____

LESSON 6

Career Plans

What do you want to be or do?

What will you need to study and know in order to do this job?

What would be the coolest thing about this job?

Saturn and You

What three words would you use to describe Saturn?

What three words would you use to describe the Cassini mission?

If you had a chance to work on a project like the Cassini mission, what would you want to do?

If you could write a 50- to 100-word message on a plaque and send it into space on a spacecraft, what would the message say?

When the Cassini spacecraft arrives at Saturn in the year 2004, what do you think you will be doing?

APPENDIX 1

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?

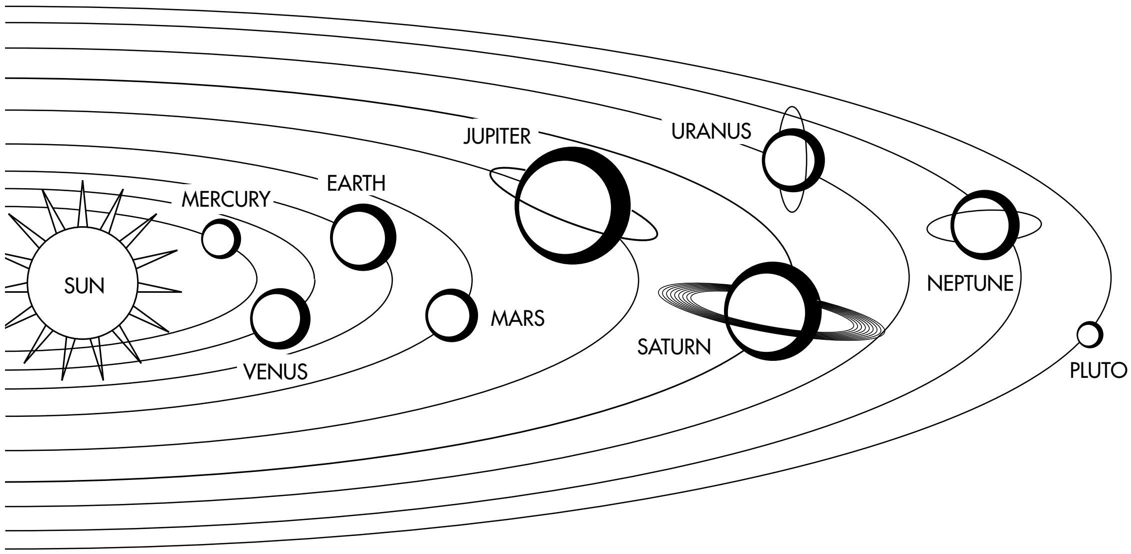
Nearly all ancient human cultures created names for, and stories about the Sun, the Moon, the planets and the stars. Like so many things in history, the naming of the planets happened by accident. For example, the ancient Babylonians recognized five specks of light moving across the night skies and believed 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.

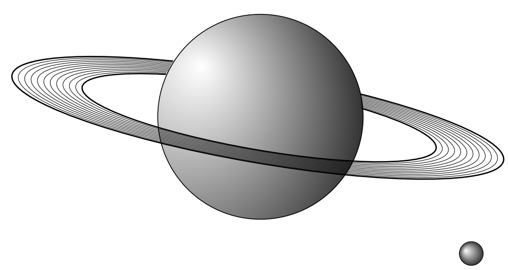
4. How old is Saturn?

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.



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 g/cm^3, which is less than that of water (1.0 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 (CH_4) and ammonia (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 m/sec^2 for Saturn, compared to 9.8 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?

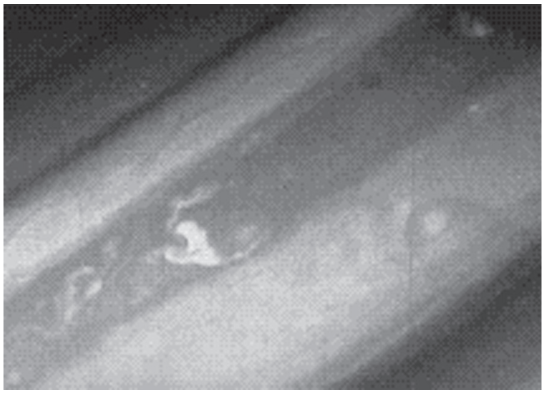
Astronomers have measured the temperature near the cloudtops of Saturn to be about –143 °C (–225 °F). This temperature increases with depth because the gases are compressed to dramatically greater pressures at depth. Computer models predict that Saturn's core is as hot as 10,000 °C (18,000 °F).

Saturn is about 10 times as far from the Sun as Earth is, so Saturn receives only about 1/100th (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 km/hr (1,100 mi/hr). By contrast, Earth's jetstream flows eastward at about 400 km/hr (250 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.

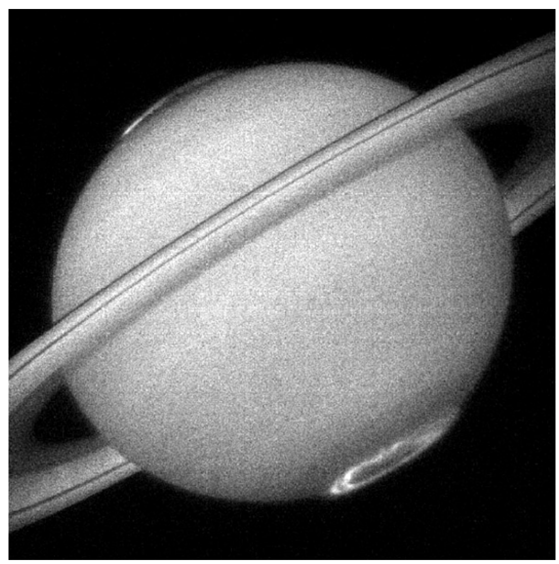
The colors of Saturn's cloud layers are due to the same basic cloud chemistry as on Jupiter. Near the top of the atmosphere, ammonia becomes cold enough to crystallize into ice particle clouds, like very high cirrus clouds in Earth's skies. But Saturn is colder than Jupiter, so the colorful ammonia cloud 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?

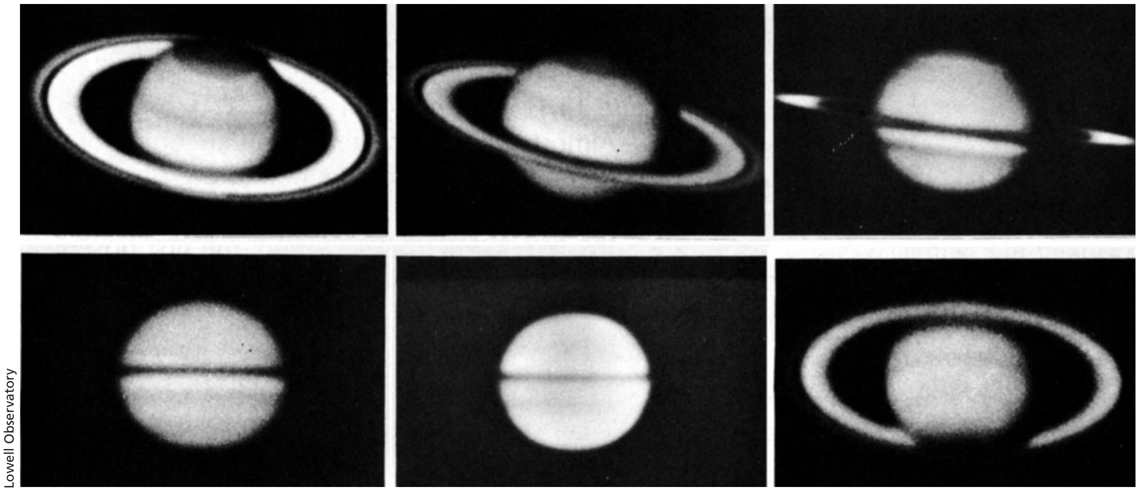
Yes. Deep inside Saturn, probably in the deepest layers of liquid hydrogen and helium, something is causing Saturn to act like a giant magnet. The same sort of thing happens in the hot liquid iron core of Earth. On Earth, this magnetism causes compass needles to align with Earth's magnetic poles. The 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.

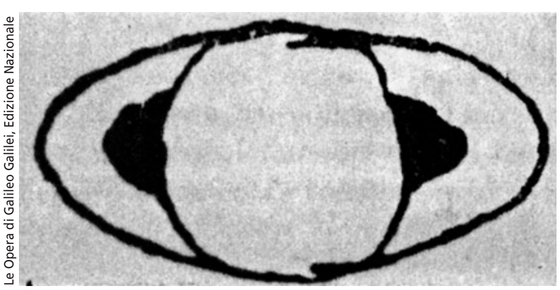
On Earth, a season only lasts about 3 months. But since Saturn takes almost 30 Earth years to go around the Sun, a Saturn season lasts more than 7 years — about the same amount of time it will take the Cassini–Huygens spacecraft to get to Saturn!

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

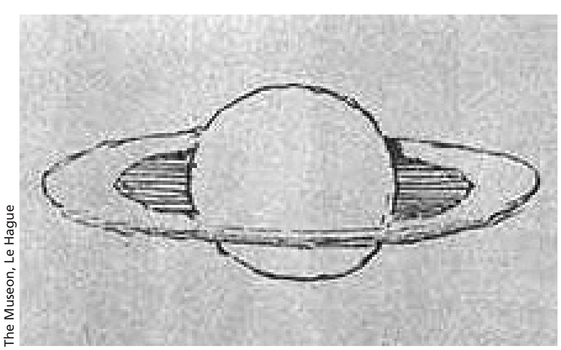
22. How did we first find out about Saturn's rings?

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 "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.



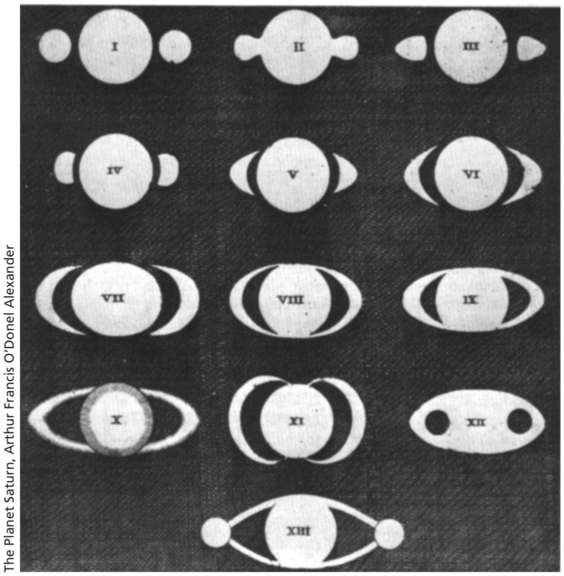
Le Opera di Galileo Galilei, Edizione Nazionale

A 1616 drawing by Galileo.



The Museon, Le Hague

Huygens' drawing of Saturn, 1683.



The Planet Saturn, Arthur Francis O'Donel Alexander

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

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.

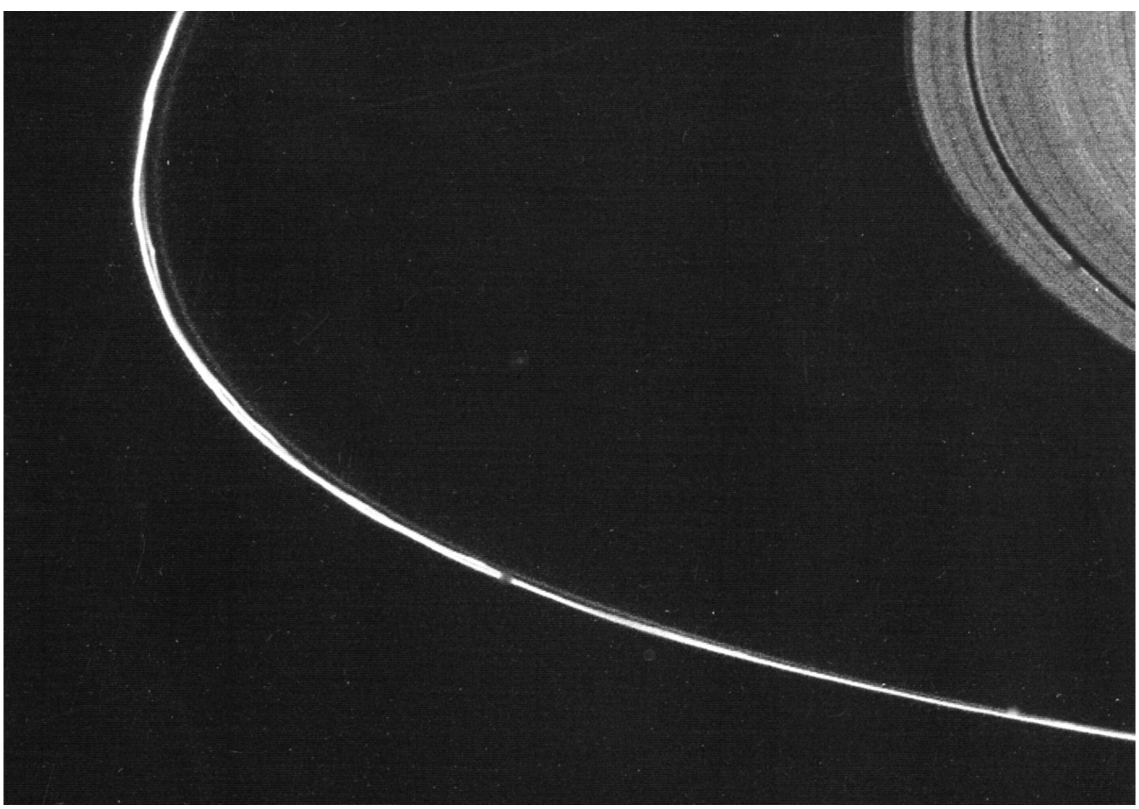
24. How many rings are there?

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: **D***aring* **C***assini* **B***egins* **A** **F***ar* **G***reater* **E***xploration.*

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)

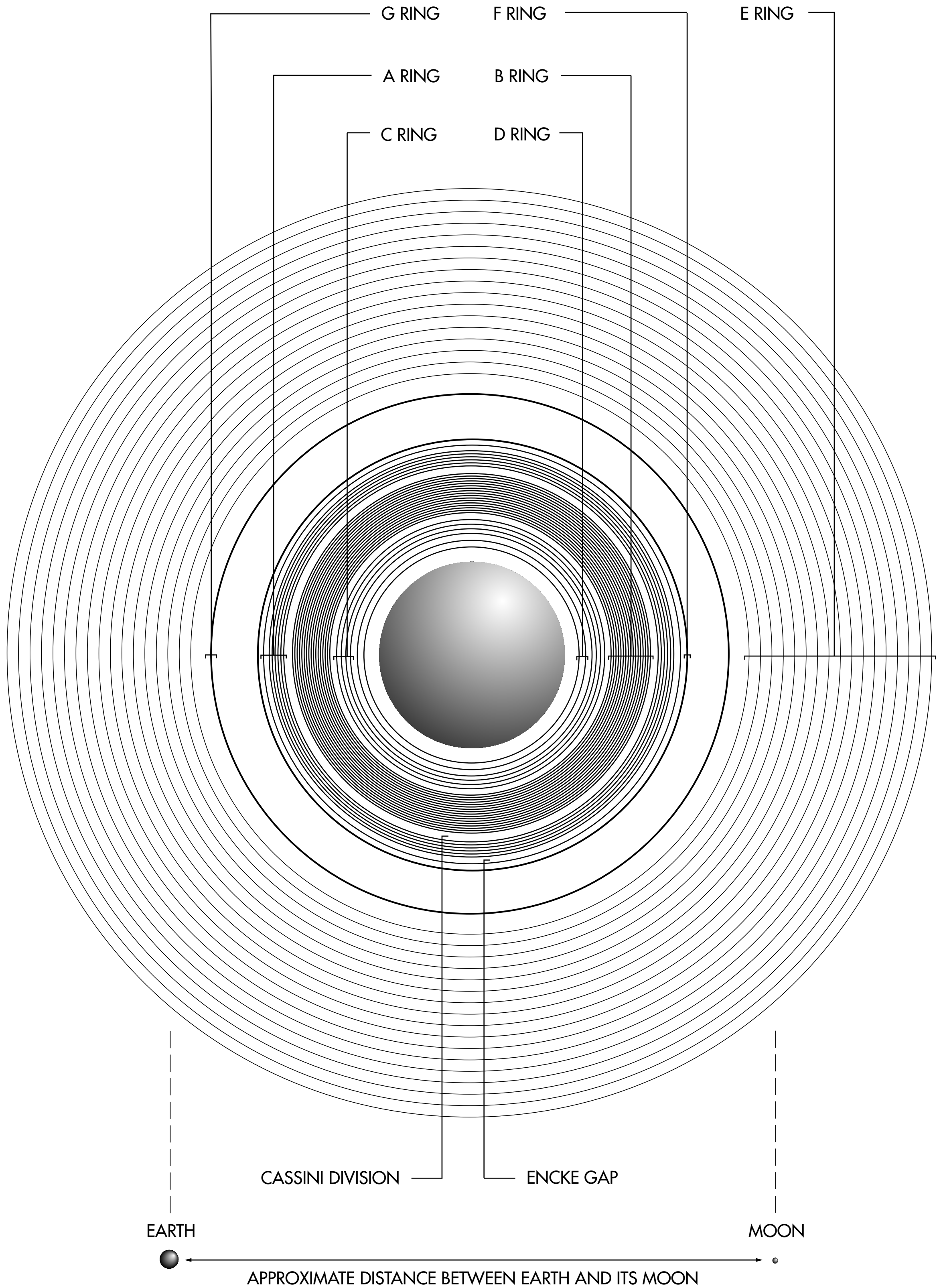


A Voyager image showing the clumped and braided F ring.

APPENDIX

1

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?

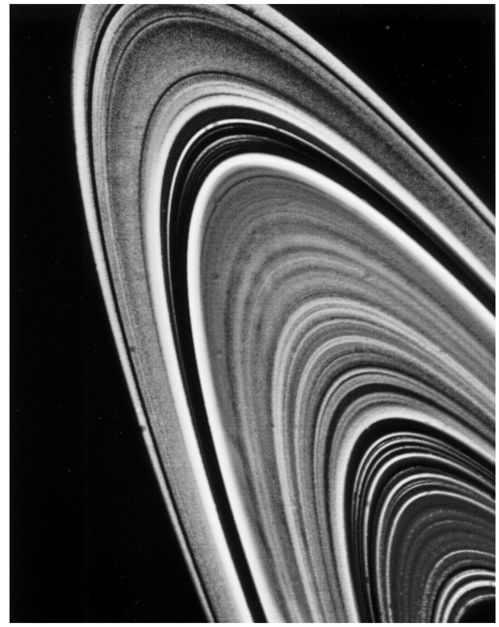
Yes, but not like a solid would move. The bits and boulders of Saturn's rings each orbit like tiny moons. They move around Saturn in the same direction as Saturn rotates and the same direction as all the known moons (except the outermost moon, Phoebe, which orbits in the opposite direction). The ring 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 (2.8×10^{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 4×10^{19} kg, or about 1,800 times less massive than Earth's Moon.

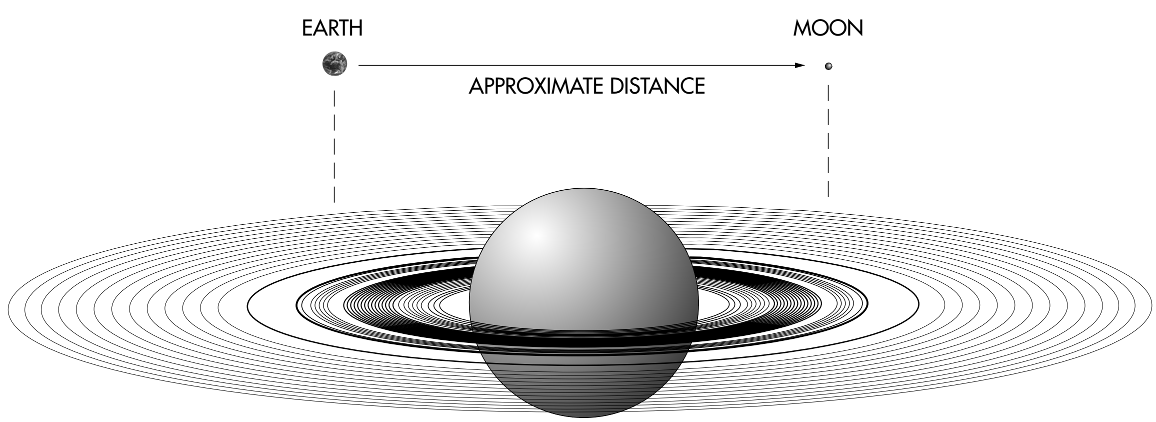
The majority of the mass of the rings is in particles from a few centimeters to a few meters in size — neither very large nor very small. This is because there are very few really big particles in the rings, and the mass of the dust is very small, so the biggest and smallest particles do not contribute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

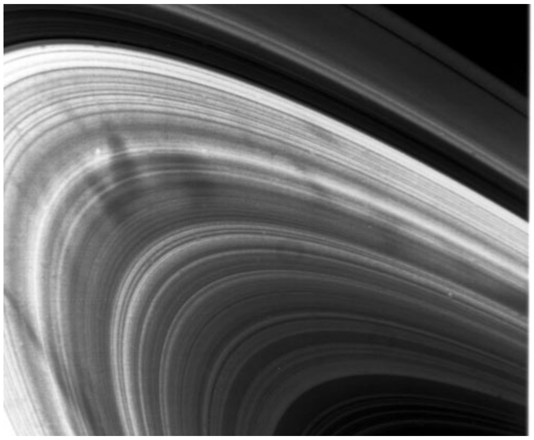
There is far less mass in Saturn's rings than is found in the asteroid belt between the orbits of Mars and Jupiter. Furthermore, the asteroids are made of rock and iron, substances which are many times denser than the water ice out of which Saturn's rings are made.

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.

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

APPENDIX 1

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 *maria* on Earth-facing side (probably lava flows following huge, ancient cratering events).

* 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 than 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.

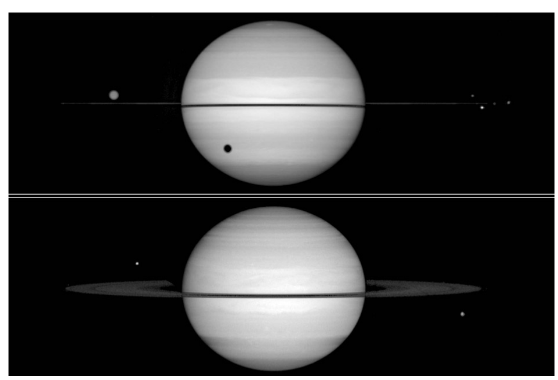
Later in the 1600s, the Italian–French astronomer Jean-Dominique Cassini discovered four more moons of Saturn: Iapetus (1671), Rhea (1672), and Tethys and Dione (1684). Not surprisingly, these moons were Saturn's next largest, with diameters ranging from 1,400 km (870 mi) for Tethys to 1,500 km (960 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.

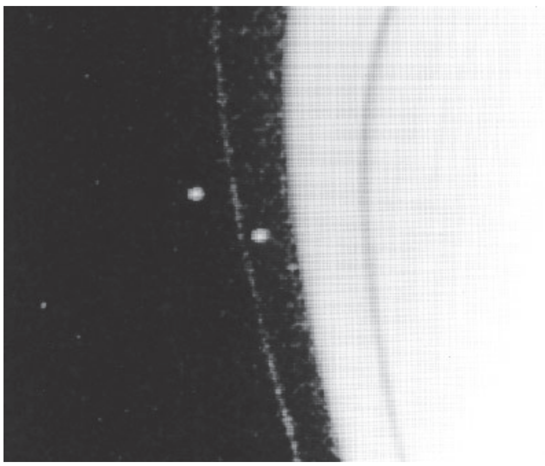
The rest of Saturn's currently known moons were discovered by observers on Earth during the 1966 and 1980 ring-plane crossings, when Saturn's thin rings were seen edge-on from Earth. With the rings temporarily not visible from Earth, faint objects near the planet are easier to see. During the 1966 ring-plane 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 disappointed 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 unlike 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 °C to –220 °C (–230 °F to –365 °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.

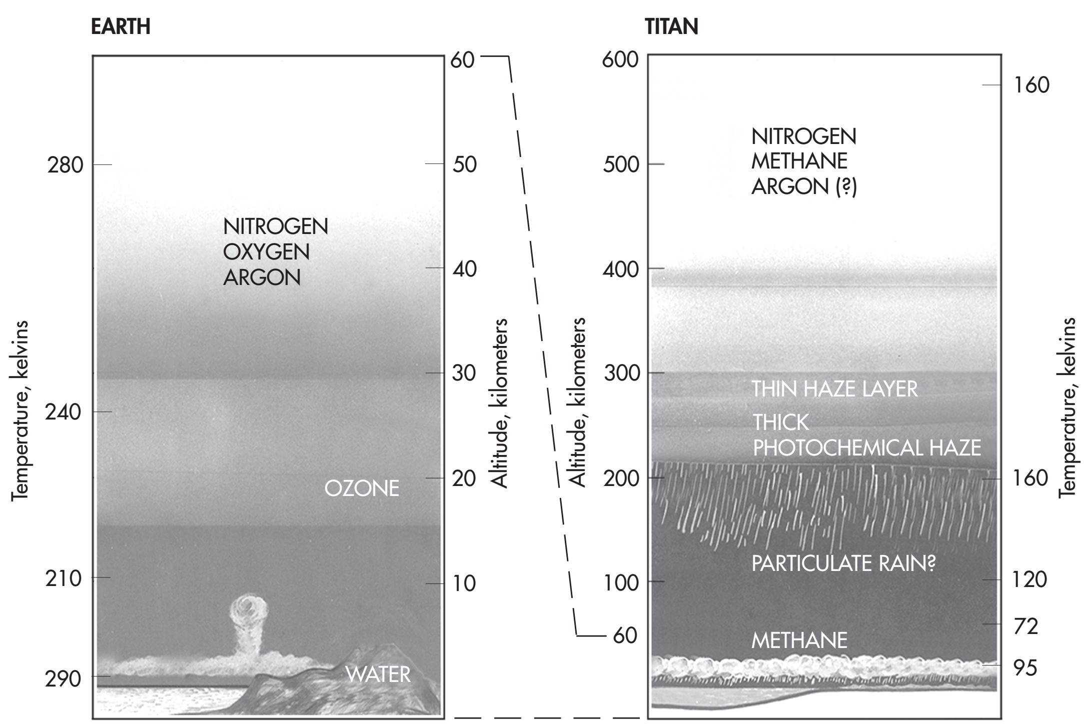
Some of Saturn's other moons may have extremely thin atmospheres, but these have not yet been detected.

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?

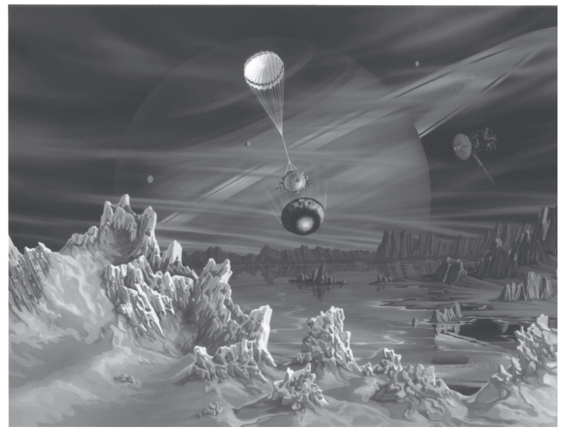
We know it is very cold on Titan, and that the atmospheric pressure at the surface is 1.5 times that of Earth, but we are not at all certain about the motions (winds and storms) in Titan's atmosphere. Titan turns very slowly, so a day on Titan is almost 16 Earth days long. There are 192 hours of dim 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 °C (–292 °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 °C (–297 °F), where it freezes, and –89 °C (–128 °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.

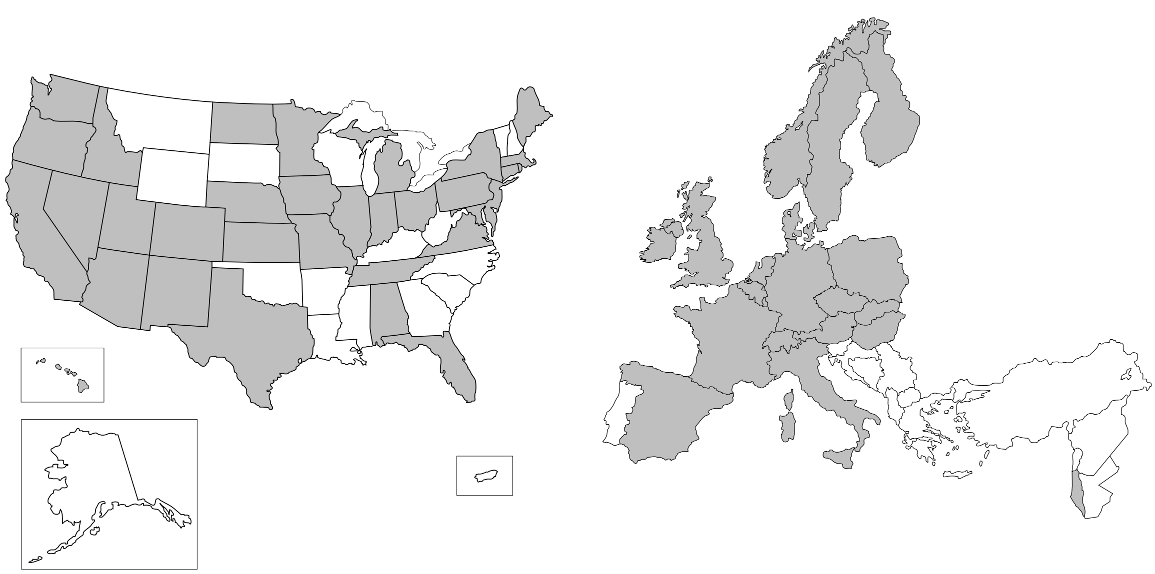
62. How much does the Cassini mission cost? Who pays for it?

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 Checkout; 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 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!

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

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° (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]

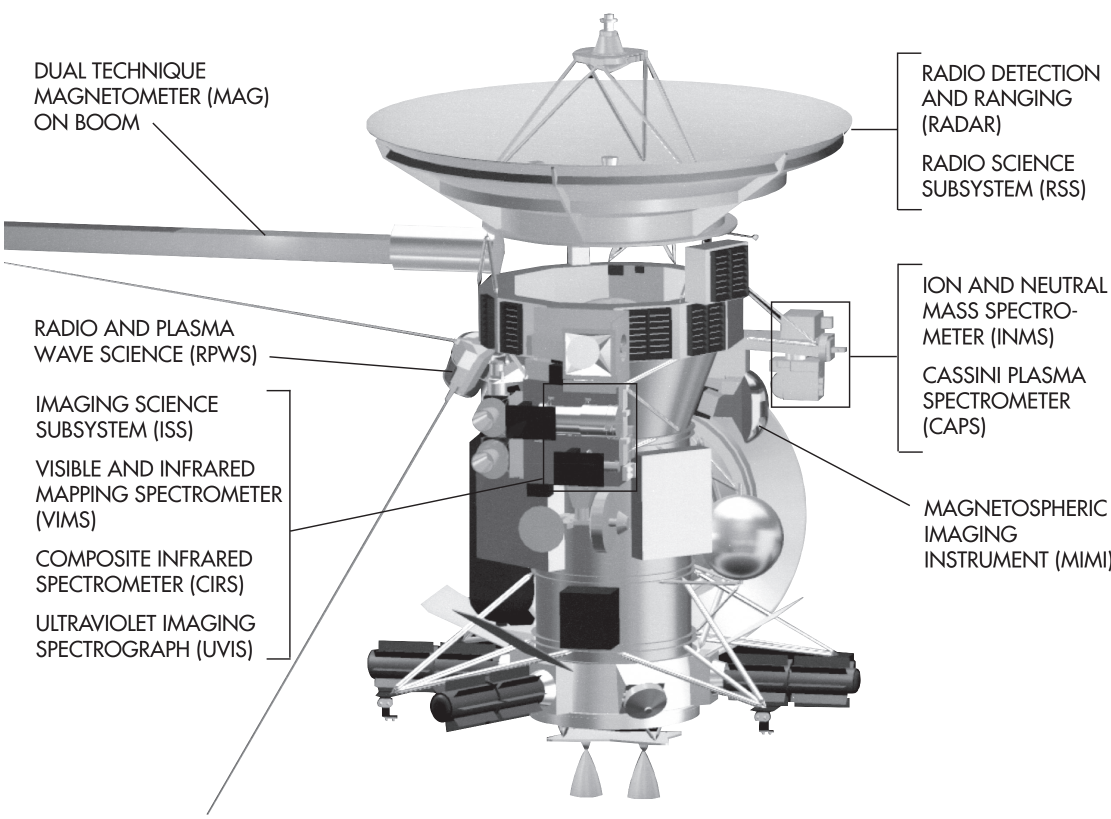
6. Composite Infrared Spectrometer (CIRS)
Measures the infrared light coming from an object (such as an atmosphere or moon surface) to learn more about its temperature and what it's made of. [Remote sensing / sight]

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?

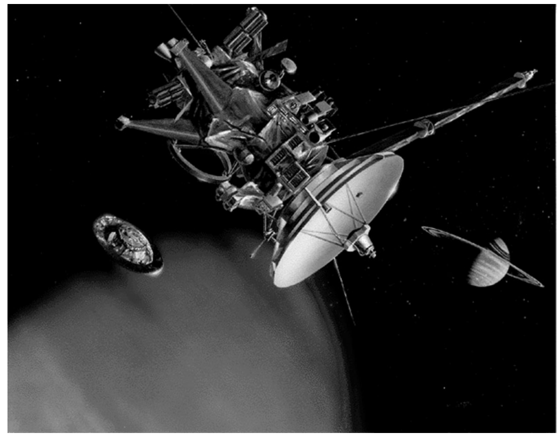
Cassini's highest-resolution camera is able to see a penny, 1.5 cm (0.5 in) across, from a distance of nearly 4 km (2.5 mi).

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:

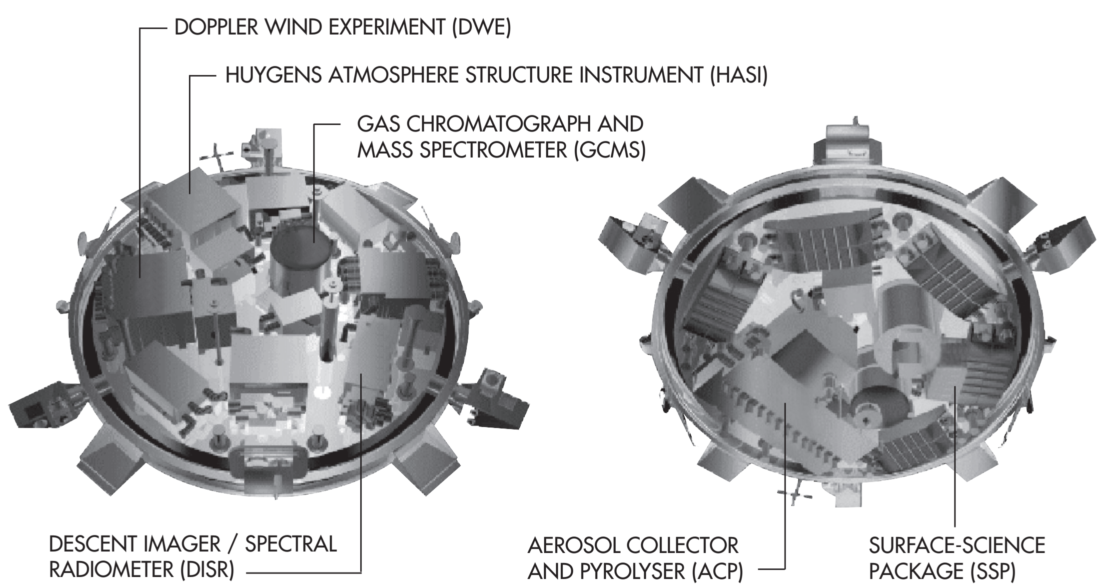
1. Gas Chromatograph and Mass Spectrometer (GCMS)
Analyzes the amounts of various gases in Titan's atmosphere. It will look for organic molecules that may indicate interesting chemistry happening in Titan's atmosphere, as well as simpler molecules that will help scientists understand how Titan formed. [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?

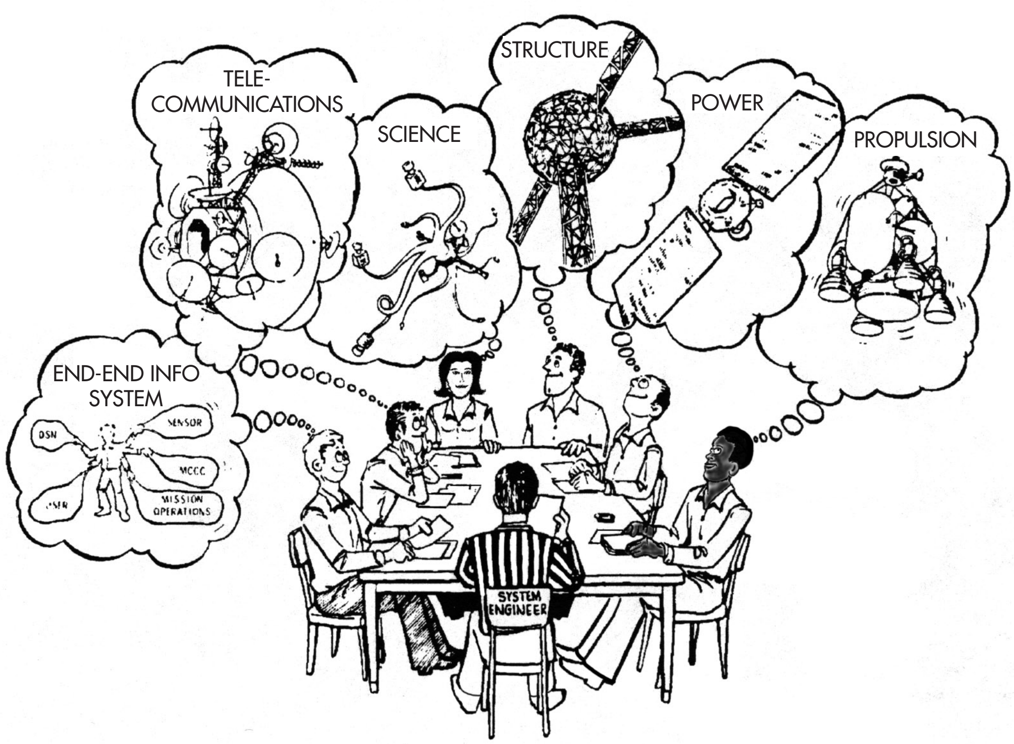
The Jet Propulsion Laboratory (JPL), a division of the California Institute of Technology, manages the Cassini Project. JPL is under contract with NASA to design and fly robotic space missions. JPL is especially famous for its work in planetary science, including the Voyager missions to the outer planets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

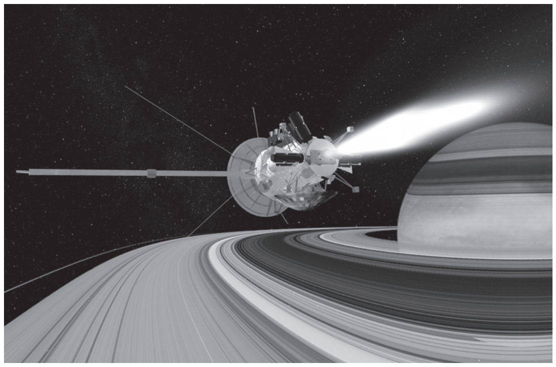
The Titan IV vehicle launching Cassini.

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.



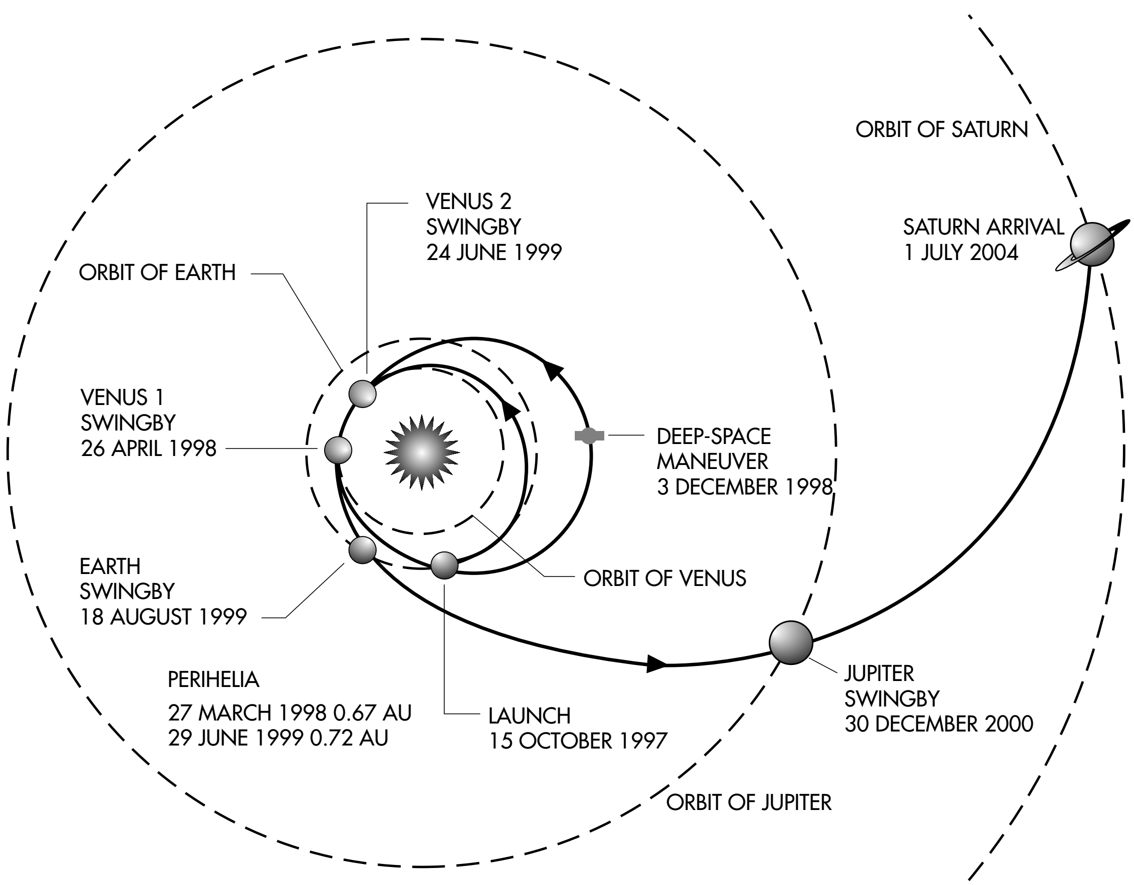
Artist's concept of Saturn orbit insertion.

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!

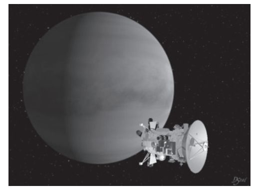
The increase in speed provided by the gravity assists from Venus, Earth, and Jupiter would otherwise require an additional 3.6 million kilograms of fuel. During Cassini's 4-year tour of Saturn, the 40 gravity assists from Titan will provide the equivalent of another 49 million kilograms of fuel. This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

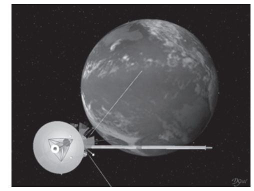
88. What is gravity assist?

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 "swinging") 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?

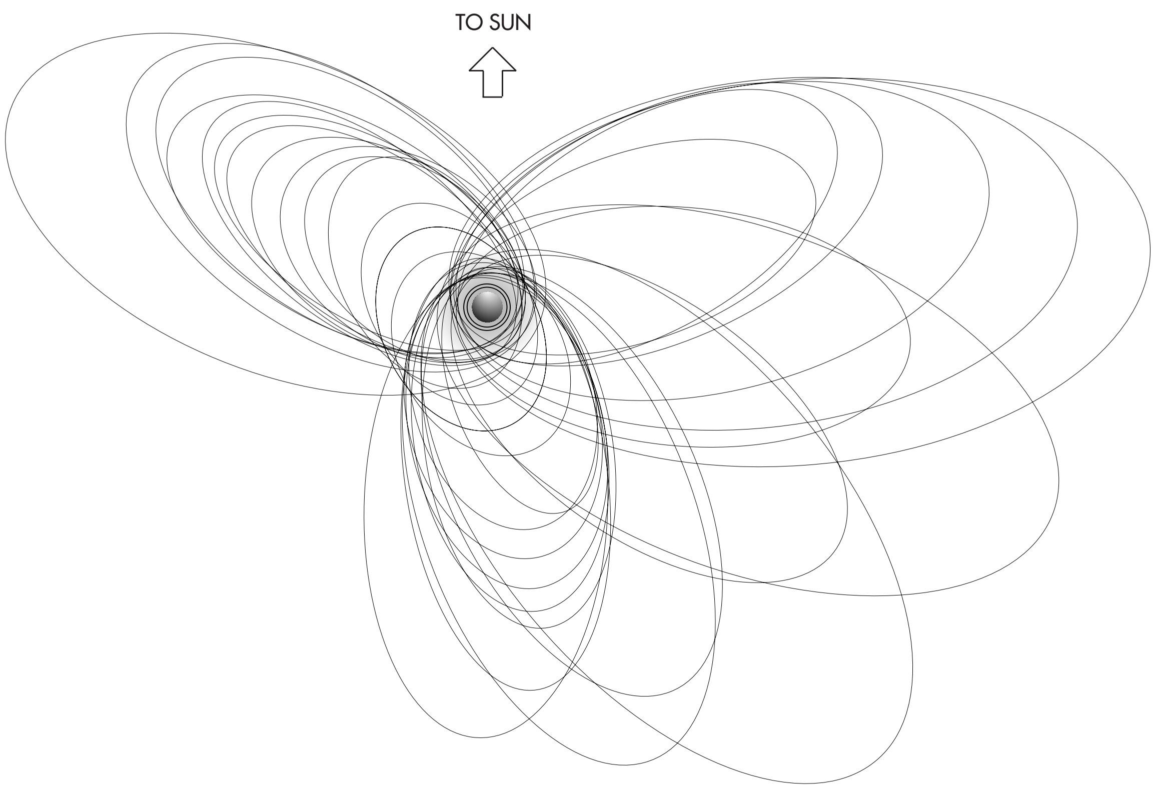
During the Cassini mission, the spacecraft reaches relative speeds of 13 km/sec (or about 29,000 mi/hr) flying by Venus (equivalent to flying from Los Angeles to Boston in under 5 minutes!), and 19 km/sec (43,000 mi/hr) flying by Earth. While cruising to Saturn, Cassini's speed is as high as 32 km/sec (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?

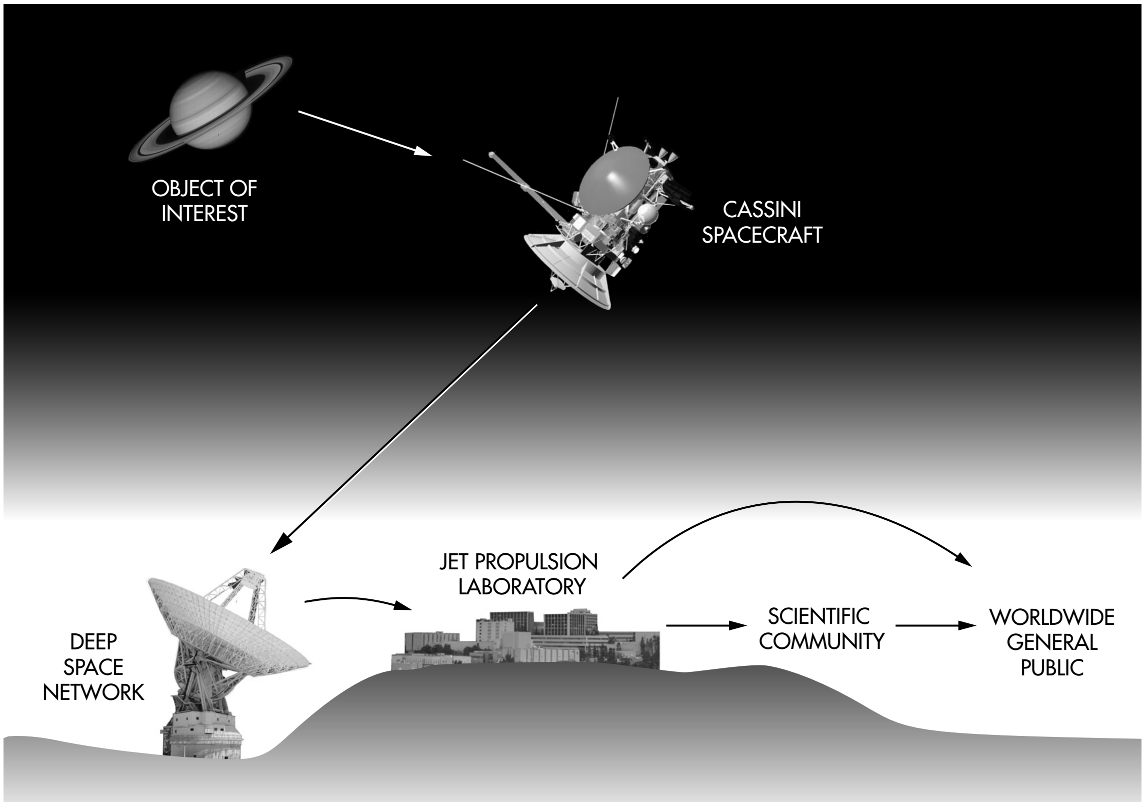
Upon reaching Saturn, Cassini swings close to the planet, to an altitude only one-sixth the diameter of Saturn itself — about 20,000 km (12,000 mi). This begins the first of more than 70 orbits during its 4-year mission, and it's the closest that Cassini ever gets to the planet.

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.

APPENDIX

2

Glossary

a

Asteroid — one of the many small celestial bodies revolving around the Sun, most of the orbits being between those of Mars and Jupiter. Also known as minor planet or planetoid.

Asteroid belt — the collection of asteroids orbiting the Sun between Mars and Jupiter, where most asteroids are found.

Atmosphere — the gaseous envelope surrounding a planet or celestial body. Saturn's largest moon, Titan, is the only moon in the Solar System known to have a substantial atmosphere.

When used as a unit of measure, one atmosphere is equal to the air pressure measured at mean sea level on Earth.

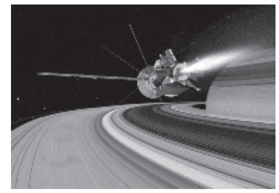
Attitude-control propellant — the propellant used by attitude-control thrusters on a spacecraft to maintain or change the spacecraft's orientation. For Cassini, this propellant is the chemical hydrazine (H_2NNH_2).

Aurora — beautiful, shimmering curtains of light in the night sky, generally visible at high latitudes when the sky is dark. Auroras (or aurorae) are caused when energetic electrons from Earth's magnetosphere collide with gases in Earth's upper atmosphere, making the gases glow like a neon sign.

b

Binary numbers — a system of numbers that has 2 as its base instead of 10. The zeroes and ones of a base-2 system are used by computers to numerically code data from spacecraft.

Bit — the most basic unit of information used in computing, in which one of two possible values (i.e., 1 or 0) designates one unit (binary digit) of information. There are 8 bits in a byte.



Byte — a sequence of bits that are combined and operated upon as a unit in a computer. For example, it takes one byte of information to express a letter like "A" or a number like "8" in a computer. The novel *Moby Dick* has about one million characters (letters or numbers), and thus to store it in a computer would require a million bytes (about a megabyte) of memory.

c

CD-ROM — Compact Disc Read-Only Memory. A CD-ROM is a disc 12 cm (4.5 in.) in diameter, used for the permanent storage of about 600 megabytes of data.

Charged particles — particles (usually atoms) that have lost one or more electrons and now have a positive electrical charge. Electrons are negatively charged particles.

Closest approach — the point at which a spacecraft is the closest to a moon or planet.

Comet — a "dirty snowball" in orbit about the Sun. Comets are a few kilometers in size and are composed mainly of ice and dust. As a comet comes close to the Sun, some of its material is vaporized to form a gaseous head and extended tail. Comet orbits range from almost circular to very narrow ellipses, and have inclinations to the orbital plane of the planets from 0° to 90°.

d

Deep Space Network — the collection of radio antennas and ground-support equipment located in California, Spain, and Australia that allows NASA to communicate with spacecraft.

Density — the mass of a given substance per unit volume, generally measured in grams per cubic centimeter (g/cm^3). The density of water is 1 g/cm^3. The average density of Saturn is only 0.7 g/cm^3. This means that Saturn would float if we could place it in a large enough tub of water!

Diameter — the line segment that passes through the center of a circle or sphere, and whose end points lie on the circle or surface of the sphere. The radius is half the diameter. The diameter of Saturn is about 120,000 km, which is 9.5 times greater than Earth's diameter.

Direct sensing — the gathering and recording of information involving direct contact with the object or area being investigated. Cassini's Cosmic Dust Analyzer is an example of a direct-sensing instrument.

Doppler shift (effect) — apparent shifts in the wavelengths/frequencies of sound or light as the distance along the line of sight between the emitter and the receiver changes. If the emitter and receiver are moving closer together, the shift is toward higher frequency/shorter wavelength (blue shift). If the emitter and receiver are moving farther apart, the shift is toward lower frequency/longer wavelength (red shift).

Dust particles — very small, solid particles (so small you can barely see the largest of them with your eyes).

e

Electromagnetic radiation — coupled electric and magnetic travelling waves of various lengths (wavelengths): radio waves, microwaves, infrared, visible, ultraviolet, x-rays, and gamma rays. All forms of electromagnetic radiation travel at the speed of light. Cassini's instruments are able to detect radio, infrared, visible, and ultraviolet radiation.

Electromagnetic spectrum — the complete span of all wavelengths of electromagnetic radiation, from the lowest energy (longer wavelength) radio waves to the highest energy (shortest wavelength) gamma rays. Light visible to human eyes comprises only a very narrow range of the electromagnetic spectrum. See *Appendix 4* for an illustration.

Electron — a low-mass component of an atom carrying a negative electrical charge.

Energy — the capacity for doing work. A deep space mission like Cassini offers a marvelous context for considering many different forms of energy and how one is transformed into another. For example, gravity assist transforms gravitational energy to kinetic energy, and RTGs transform the heat from radioactivity to electrical energy that powers the spacecraft's instruments and transceivers.

Equinox — a point in a planet's orbit around the Sun at which the planet is tilted neither toward nor away from the Sun. For Earth, this occurs in the fall (autumnal equinox is 21 September) and in the spring (vernal equinox is 21 March). On these dates, Earthlings experience equal time for day and night at all latitudes except 90°. When Saturn is in its equinox position, Earthlings may observe ring-plane crossings with the rings viewed edge-on.

Expendable launch vehicle — a rocket that can be used only once to place a payload into orbit. Its stages usually fall into the ocean. The Titan IV that launched Cassini–Huygens is an expendable launch vehicle.

f

Field of view — the area in space or on a planet or moon that can be "seen" at any one time by a science instrument that makes images or collects particles from a limited range of directions.

Flyby — a close approach of a spacecraft to a target planet in which the spacecraft does not impact the planet or go into orbit around it. Also known as a swingby when the spacecraft receives a gravity assist. Cassini–Huygens' trajectory to Saturn involves flybys of Venus, Earth, and Jupiter.

Frequency — the number of waves that pass a point in 1 second. Frequency is usually expressed in units of hertz (waves or cycles per second). Higher frequency electromagnetic waves carry more energy than lower frequency waves.

Fuel — the chemical that combines with an oxidizer to burn and produce thrust in an engine.

g

Gamma rays — the highest-energy electromagnetic radiation, with wavelengths shorter than 10^{-12} m.

Gravity — the attractive effect that any massive object has on all other massive objects. The greater the mass of the object, the stronger its gravitational pull. The closer the centers of two massive objects, the stronger the gravitational attraction between them. Surface gravity is the gravitational attraction experienced by objects at the surface of a planet or other celestial body. The surface gravity of Earth is 9.8 m/sec^2.

Gravity assist — 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 "swinging") by it. When the Voyager spacecraft flew by Jupiter, Voyager gained 16 km/sec of speed relative to the Sun at a cost of initially reducing Jupiter's orbital motion around the Sun by about 30 cm (1 ft) every trillion years!

h

Heliopause — the transition zone between the region of space influenced by our Sun's solar wind (the heliosphere) and the interstellar medium. The two Voyager spacecraft are looking for this region of space, which is very far beyond the orbit of Pluto, the outermost planet in our Solar System.

High-gain antenna — a large, dish-shaped radio antenna that can send and receive more information than a low-gain antenna. For Cassini, the high-gain antenna is the large white dish on the top of the spacecraft. The antenna must be pointed at Earth for communications to and from Earth.

Hydrocarbon — one of a very large group of chemical compounds composed only of hydrogen and carbon. The largest source of hydrocarbons on Earth is petroleum (crude oil). Hydrocarbons called ethane and methane may be present in lakes on Saturn's largest moon, Titan.

i

Infrared (IR) — electromagnetic radiation with wavelengths from about 0.75–0.8 micrometer (the long-wavelength limit of visible red light) to 1,000 micrometers (the shortest microwaves). One micrometer is 10^{-6} m.

Interstellar space — the vast space between the stars.

Ion — an atom or molecule that is electrically charged, having lost one or more electrons.

j

Jetstream — on Earth, a relatively narrow, fast-moving wind current usually observed at midlatitudes where jet airplanes fly. Saturn appears to have a broader equatorial jetstream with much faster wind speeds.

Jovian planets — the four giant gaseous planets (Jupiter, Saturn, Uranus, and Neptune) at a greater distance from the Sun than are the terrestrial planets (Mercury, Venus, Earth, and Mars).

k

Kepler's Laws — three laws, discovered by Johannes Kepler, that describe the motions of planets in their orbits around the Sun. Kepler's First Law states that the orbits of the planets are ellipses with the Sun at a common focus. Kepler's Second Law states that as a planet moves in its orbit, an imaginary line joining the planet and the Sun sweeps the same amount of area in equal intervals of time. Kepler's Third Law says that the square of the orbital period of a planet is proportional to the cube of its mean distance from the Sun. These laws may be more generally applied to any system in which gravity is the force acting to keep objects in orbit. Well after their discovery, these laws were found to be derivable from Newton's Laws of gravity and motion.

l

Lagrangian Points L4 and L5 — Points of gravitational stability where a particle can be trapped 60° ahead (L4) or 60° behind (L5) in the same orbit traveled by an object (e.g., a moon) around its primary (e.g., a planet).

Light — this term often refers to electromagnetic radiation that the human eye can perceive (visible light); however, terms such as ultraviolet light and infrared light are also frequently used. Also see "speed of light."

m

Magnetic field — one of the elementary fields in nature, found in the vicinity of a magnetic body (like a magnet or planet) or a current-carrying medium (like a wire). Magnetic fields are also present along with electric fields in electromagnetic radiation.

Magnetosphere — the region around a planet or moon in which the body's magnetic field is the controlling influence on the physical processes that take place. For Earth, the magnetosphere is usually considered to begin at an altitude of about 100 km (60 mi) and to extend outward to a distant boundary that marks the beginning of interplanetary space. Saturn has an extensive magnetosphere that will be explored by the Cassini spacecraft.

Mass — a measure of the total amount of material in a body. Mass can be measured either by how much effort it takes to move the body or by its gravitational influence on other bodies.

Meteoroid — any solid object moving in interplanetary space that is smaller than a planet or asteroid but larger than a molecule. If a meteoroid enters Earth's atmosphere, we call it a meteorite after it falls to the surface. The light that it produces as it passes through the atmosphere is called a meteor.

Methane — a colorless, tasteless, odorless gas with a chemical composition of carbon and hydrogen (CH_4). On Earth, methane is a chief component in natural gas; it can also be found emanating from swamps and marshlands. Gerard Kuiper first discovered the atmosphere of Saturn's moon Titan by detecting indications of methane in his observational data.

Micrometeoroid — a very small meteoroid with a diameter generally less than a millimeter. Although they are small, micrometeoroids can do serious damage to a spacecraft zooming through interplanetary space, and thus a spacecraft must have some shielding to protect it.

Microwaves — electromagnetic radiation with shortwave radio wavelengths of about 10^{-2} m.

Momentum — a measure of the state of motion of a body. The momentum of a body is the product of its mass and velocity (i.e., momentum = mass × velocity). Thus, bodies of the same mass moving at the same velocity have equal momentum.

Moon — a natural satellite of a planet. There are about 60 known moons in the Solar System. Earth has only one moon (which we call the Moon), but Saturn has at least 18 moons.

n

Nanometer — one billionth of a meter (10^{-9} m).

Nitrogen — a chemical element, normally in a gaseous state, symbolized by the letter N. Nitrogen in molecular form (N_2) makes up approximately 78% of Earth's atmosphere. Nitrogen is also abundant in Titan's atmosphere.

Nominal mission — the mission that will be accomplished if no problems occur. Cassini's nominal mission is due to end in 2008 after a 4-year tour of the Saturn system. If all goes well, the mission could be extended.

o

Objective lens or mirror — a telescope's primary light collector (large lens or mirror); sometimes called the primary lens or mirror.

Occultation — the passage of an object of large angular size in front of an object of smaller apparent size; e.g., the Moon in front of a distant star as viewed from Earth or Saturn's rings in front of a distant star as viewed by cameras on board the Voyager spacecraft. During occultation events, we can learn about the structure and dimensions of the object in the foreground.

Orbit — a path followed by a particle or body (e.g., the trajectory of a celestial body) under the influence of gravity. The properties of the orbital path are dependent on the gravitational force between two bodies — our Moon orbits Earth; Titan orbits Saturn; the Cassini spacecraft will be in orbit around Saturn.

Organic chemistry — the study of the composition, reactions, and properties of chemicals or compounds with a molecular structure involving chains or rings of carbon atoms.

p

Parking orbit — a temporary orbit placing a spacecraft in position before sending it on its desired trajectory. The Centaur upper stage placed Cassini–Huygens in a parking orbit.

Period — this term is used in three different contexts. 1) *Rotational period*: the time to make one complete rotation; e.g., the rotational period of Earth is 24 hours. 2) *Orbital period*: the time to complete one orbital revolution; e.g., the orbital period of Earth around the Sun is 1 year. 3) *Period of an electromagnetic wave*; i.e., the time to complete one cycle of the wave.

Plasma — an electrified gas; the fourth state of matter. Heat a solid, you get a liquid; heat a liquid, you get a gas. Heat a gas to the point where some of the atoms begin to lose electrons, and you get a gas of electrically charged particles (ions and electrons) called a plasma. Most of the matter in the Universe is believed to be in the plasma state. The Cassini spacecraft has instruments to measure the properties of the plasma in Saturn's magnetosphere.

Plasma wave — a disturbance of a plasma involving oscillation of its constituent particles and of an electromagnetic field. A plasma wave propagates from one point in the plasma to another without net motion of the plasma.

Power — a measure of energy expended or consumed as a function of time. A watt is a unit of power. A 100-watt light bulb uses more energy in an hour than a 60-watt light bulb. An 800-watt RTG is more powerful than a 500-watt RTG because it can deliver more energy per second to run Cassini's instruments.

Primary launch period — the first and most advantageous period of time during which to launch a spacecraft toward a particular destination. Cassini's primary launch period ran from 6 October to 15 November 1997.

Propellant — the fuel or oxidizer that, when combined with its counterpart, burns to produce a rocket thrust that propels a spacecraft to a desired destination.

r

Radio waves — electromagnetic radiation with the longest wavelengths, ranging from approximately 10^4 to 10^{-3} m. Radio receivers are designed to be sensitive to such waves. Radio waves can be used deliberately for communication and they can be generated naturally via interactions between charged particles and magnetic fields. Of course, Cassini is equipped to detect both!

Radioisotope thermoelectric generator (RTG) — a device for converting nuclear energy to electrical energy. The heat produced by the radioactivity of a radioisotope (like Pu-238) is used to produce a voltage in a thermocouple circuit. Cassini uses three RTGs to provide electricity for its science instruments, engineering equipment, and transmitters.

Reflector telescope — a telescope in which a mirror is used to gather light and form an image of a distant object. Also known as a reflecting telescope.

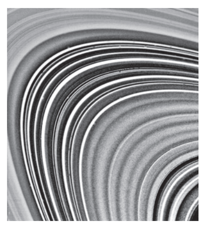
Refractor telescope — a telescope in which a lens is used to gather light and form an image of a distant object. Also known as a refracting telescope.

Remote sensing — the gathering and recording of information without direct contact with the object or area being investigated. Cassini's cameras are remote-sensing instruments, as are human eyes.

Resolution — the degree to which fine details in an image can be seen as distinctly separated or resolved. Cassini's highest-resolution cameras can distinguish objects that are about 350 millionths of a degree apart.

Ring (around a planet) — a "band" of icy, rocky, and/or dusty material encircling a planet. The various bits and boulders of the rings orbit around the planet as tiny moons. All the Jovian planets (Jupiter, Saturn, Uranus, Neptune) have rings, but Saturn's rings are by far the most elaborate in the Solar System.

Ring-plane crossing — this event occurs every 14 to 15 years, when Saturn is tilted neither toward nor away from the Sun so that Earth observers see the rings of Saturn edge-on. Because the rings are nearly invisible during this time, ring-plane crossings offer good opportunities to search for moons. Several of Saturn's 18 known moons were discovered during ring-plane crossings.



Ringlet — a narrow region in Saturn's planetary ring system where the density of ring particles is high. The Voyager spacecraft discovered that the rings visible from Earth are actually composed of tens of thousands of ringlets.

Robot — a mechanical device that can be programmed to perform a variety of tasks under automatic or remote control. The Cassini spacecraft is a robot.

Rotation — spinning on an axis. One full rotation of Earth takes 24 hours. One full rotation of Saturn takes 10 hours, 40 minutes.

S

Satellite (as in a ring particle or moon) — a relatively small, solid body moving in orbit around a planet. Moons and ring particles are satellites of Saturn.

Solar wind — the supersonic flow of hydrogen and helium plasma that flows continuously from the Sun outward through the Solar System, with velocities of 300 to 1,000 km/sec (180 to 600 mi/sec).

Solstice — the two days (actually, instants) during the year when Earth is located in its orbit so that the inclination of the rotation axis (about 23.5°) is maximally toward the Sun; the dates are around June 21 for the North Pole being inclined toward the Sun, and around December 21 for the South Pole.

Space physics — the study of the Sun, the solar wind, and their interactions with planetary magnetospheres and plasma environments. Space physicists investigate fundamental physical processes that have broad applicability across the entire plasma universe.

Spectrograph (or spectrometer) — a remote-sensing instrument used for dispersing and recording a particular range of wavelengths of the electromagnetic spectrum. Cassini will carry several of these instruments operating at different wavelengths.

Spectroscopy — the study of the way in which atoms absorb and emit electromagnetic radiation. Spectroscopy allows astronomers to determine the chemical composition of stars, planets, moons, interstellar clouds, and so on. Because the way atoms absorb or emit light is influenced by temperature, line-of-sight motion, the strength of magnetic fields, and other physical conditions, spectroscopy also permits astrophysicists to measure these properties from afar.

Speed of light — light, and electromagnetic radiation of any type, travels at the speed of light, which is 300,000 km/sec (186,000 mi/sec) in a vacuum.

Supersonic — something moving faster than waves traveling at the speed of sound.

Surface gravity — the downward pull or acceleration at the surface of a planet or other celestial body. The acceleration of gravity at the surface of Earth is 9.8 m/sec^2. The strength of the surface gravity depends on both the size and the mass of the body. If a body has the same mass as another but is smaller, it will have the stronger surface gravity because its mass is more concentrated.

Swingby — similar to a flyby, except the term indicates that the course of the spacecraft has been altered by the gravity of the moon or planet as the spacecraft went by.

t

Teleoperation — the operation of a robot from a distance.

Tidal force — the difference between the gravitational tug on the near side of an object compared with the gravitational tug on the far side caused by another nearby body. Tidal forces can heat the interior of a moon, resulting in (for example) the volcanoes on Jupiter's moon Io and the possible ice geysers on Saturn's moon Enceladus.

Trajectory — the curved path a spacecraft follows through space.

Translucent — property of a medium that allows light to pass through, but the light is so diffused that objects cannot be seen distinctly.

u

Ultraviolet (UV) — electromagnetic radiation with wavelengths ranging from approximately 10^{-7} to 10^{-8} m. Cassini has an instrument package called UVIS (ultraviolet imaging spectrograph) to study UV emissions in the Saturn system.

Upper stage — a smaller rocket carried aloft by a larger one (called a booster, first stage, or lower stage). A powerful Centaur upper stage was used with a Titan IV vehicle to send Cassini–Huygens on its trajectory to Saturn.

v

Visible light — electromagnetic radiation with wavelengths ranging from approximately 400 to 700 nanometers. Visible light is the narrow strip of the electromagnetic spectrum in which humans can see. Detecting other parts of the electromagnetic spectrum requires instruments that extend our senses. See *Appendix 4* for an illustration.

w

Watt — a unit of power in the meter–kilogram–second system (see "power").

Wavelength — the distance between one wave crest to the next wave crest (or one trough to the next trough).

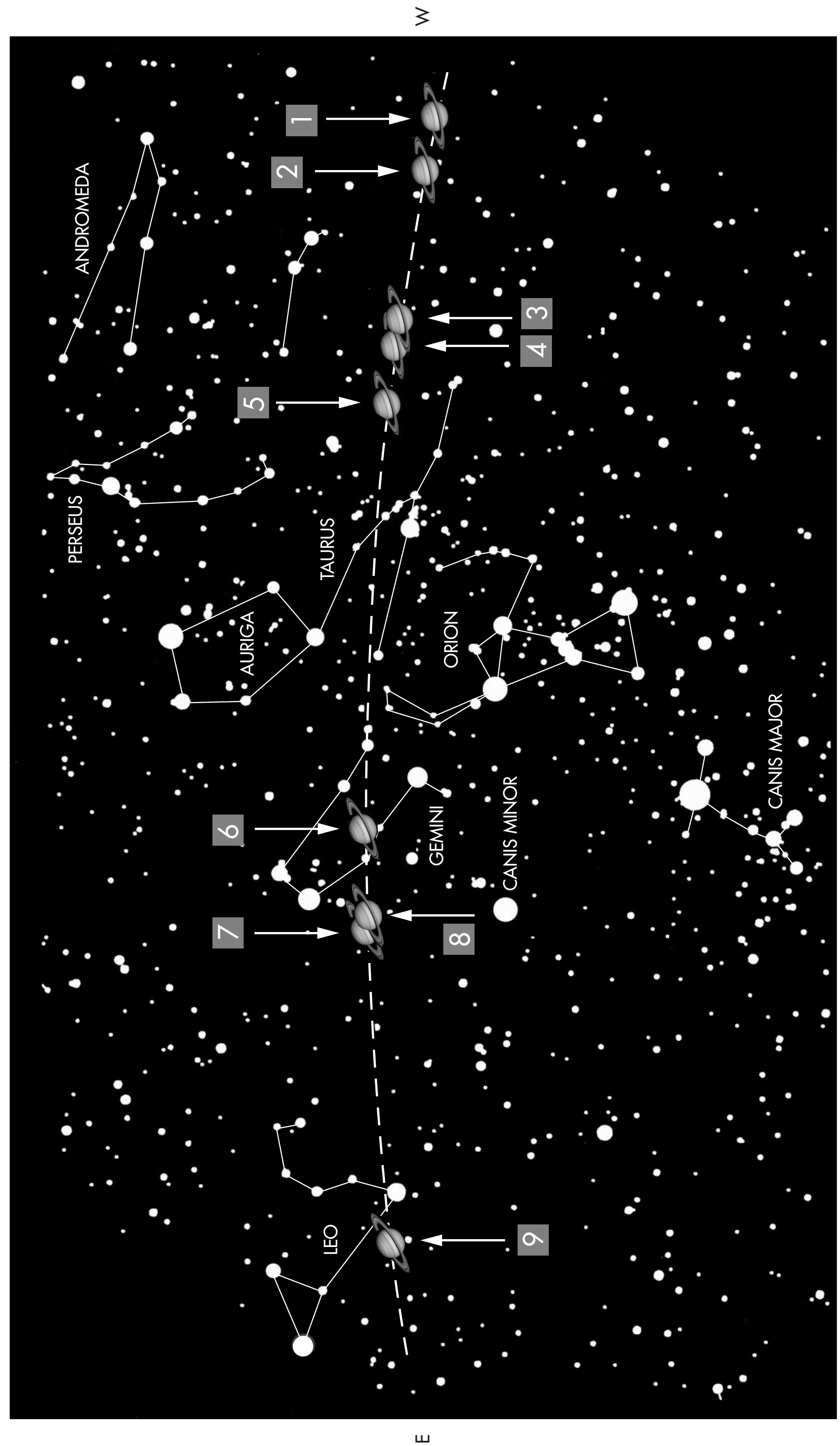
x

X-rays — electromagnetic radiation with wavelengths ranging from approximately 10^{-8} to 10^{-10} m.

APPENDIX

3

Observing Saturn in the Sky



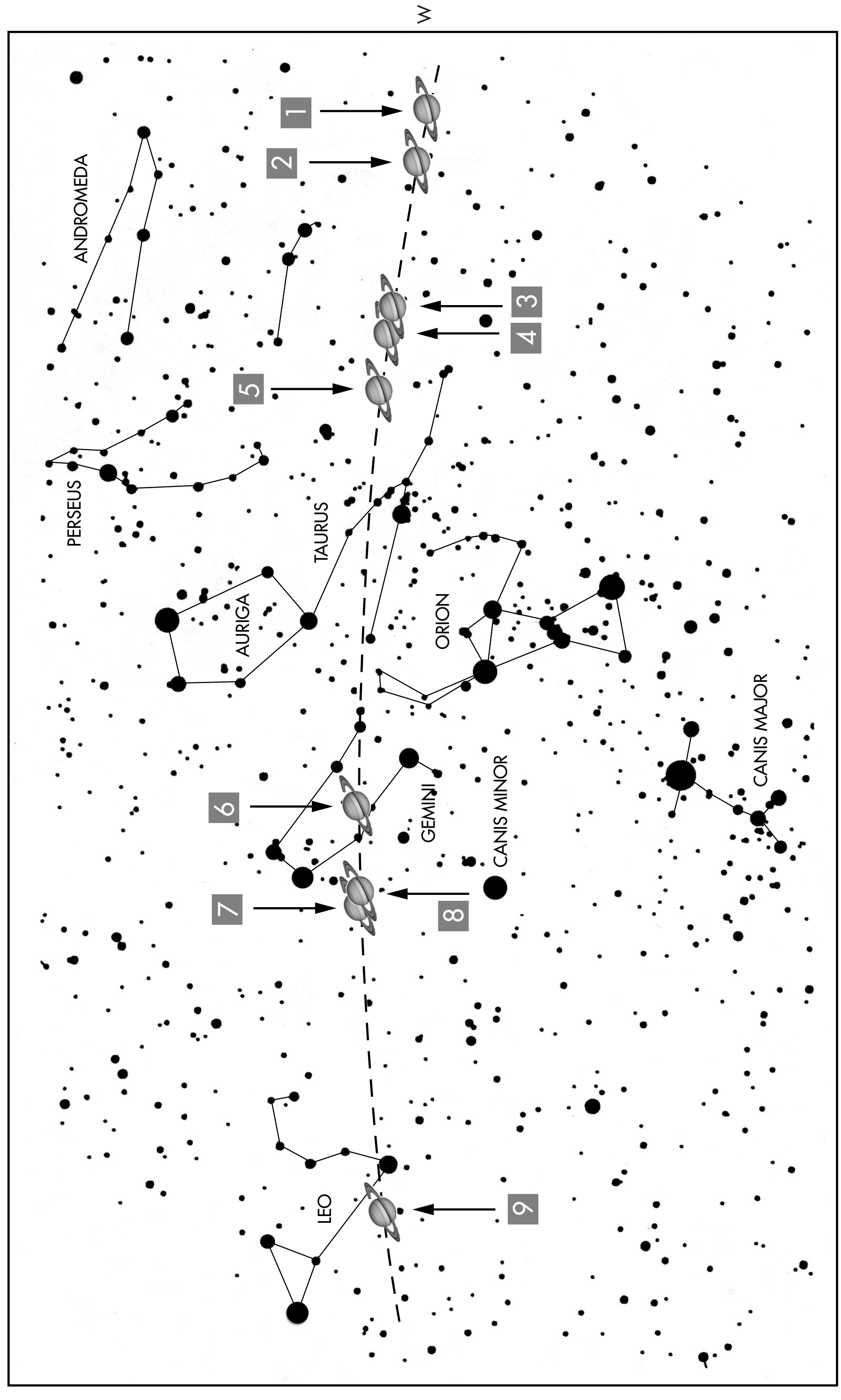
Refer to the table on page 275 for identification of numbered positions.

APPENDIX

3

Refer to the table on page 275 for identification of numbered positions.

Astronomers frequently use "negative" images of star fields for detailed studies because black stars and other celestial objects on a white background are easier to see. At night, "negative" star charts are often easier to use with a flashlight.



APPENDIX 3

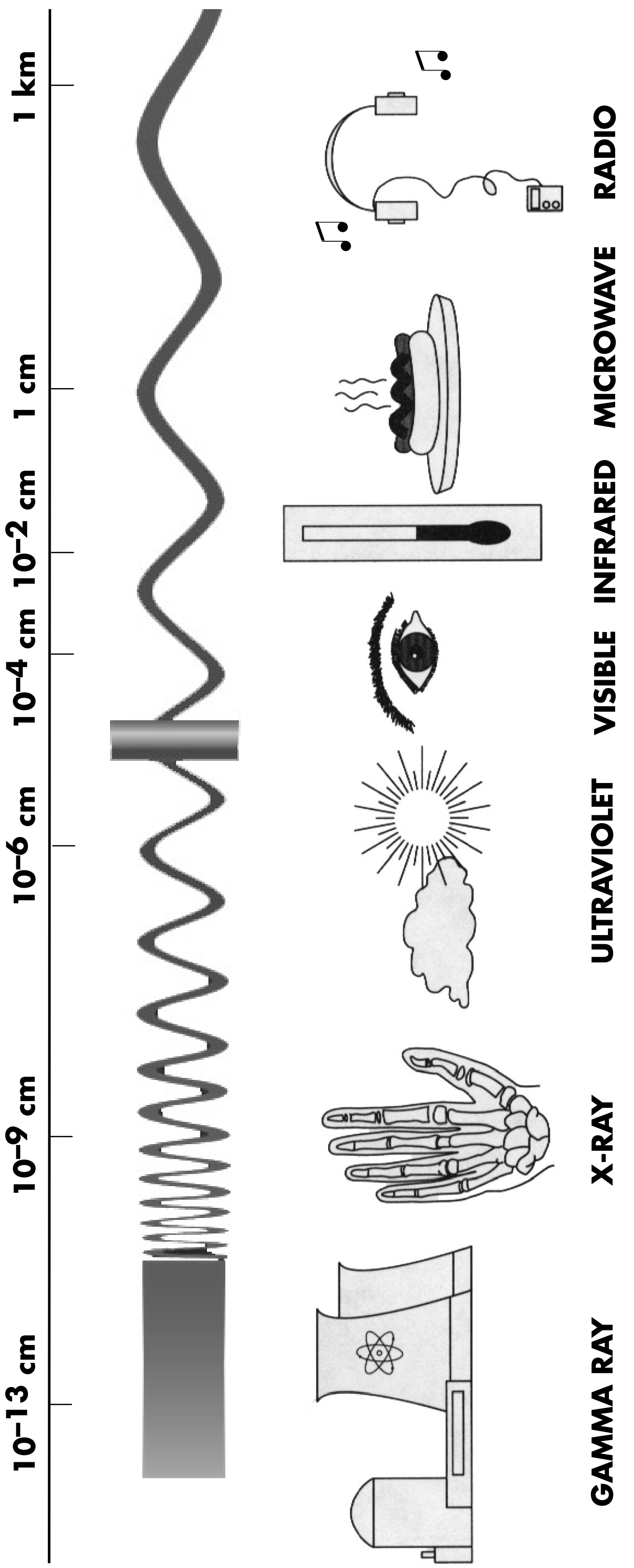
Sky Positions of Saturn During the Cassini Mission

Postion Number	Date	Cassini Mission Event	Observing the Planets
1	15 October 1997	Launch of Cassini	Saturn rises at sunset; Jupiter is high in the Southeast at sunset; Venus sets an hour or two after sunset.
2	26 April 1998	First Venus flyby	Venus is near maximum western elongation, so it will be high in the sky at sunrise and will appear to be near Jupiter in the sky.
3	24 June 1999	Second Venus flyby	Venus will be high and bright in the evening sky.
4	18 August 1999	Earth flyby	(Not applicable)
5	30 December 2000	Jupiter flyby	Jupiter and Saturn are close together in the sky and visible most of the night.
6	1 July 2004	Arrival at Saturn	Saturn won't be visible, since it is on the other side of the Sun (as seen from Earth) when Cassini arrives.
7	6 November 2004	Huygens probe separation	Saturn will rise at 10:00 P.M. and will be up until sunrise.
8	27 November 2004	First Titan flyby	Saturn has not moved much since November 6th. Notice that it is moving westward, "backward" compared with its overall motion across the chart.
9	1 July 2008	End of scheduled mission	Saturn will set shortly after sunset; the other bright planet nearby is Mars.

Courtesy of Geoff Skelton, Fiske Planetarium, University of Colorado and Glenn R. Miller, Griffith Observatory, Los Angeles, California.

APPENDIX 4

The Electromagnetic Spectrum



Adapted from "Space Based Astronomy" Teacher's Guide, NASA publication EG-102, August 1994.

APPENDIX

5

Resources

If you do not have access to the Internet, please consider seeking out someone who does so that you can take better advantage of the exciting resources on the World Wide Web!

Audiovisual

NASA Television (NTV)
(Cable TV) Offers the public a front-row seat for launches and missions, as well as informational and educational programming, historical documentaries, and updates on the latest developments in aeronautics and space science. NTV is transmitted on the GE-2 satellite, transponder 9C at 85 degrees west longitude, vertical polarization, with a frequency of 3880 megahertz and audio of 6.8 megahertz.

Apart from live mission coverage, regular NASA Television programming includes a Video File from noon to 1:00 pm, a NASA Gallery File from 1:00 to 2:00 pm, and an Education File from 2:00 to 3:00 pm (all times Eastern). This sequence is repeated at 3:00 pm, 6:00 pm, and 9:00 pm, Monday through Friday. The NTV Education File features programming for teachers and students on science, mathematics, and technology. NASA Television programming may be videotaped for later use. For more information on NASA Television, contact:
NASA Headquarters
Code P-2
NASA TV
Washington, DC 20546-0001
Phone: (202) 358-3572
Website: *http://www.hq.nasa.gov/ntv.html*

The Cosmos Television Series
(Videotape) Thirteen episodes on seven 2-hour tapes. Available through the Astronomical Society of the Pacific, telephone 1-800-335-2624.

The Planets
(Videotape and videodisc) Patrick Stewart's narration and Holst's classic score. Dramatizes an incredible array of images from the robotic spacecraft that have toured the planets. Available through the Astronomical Society of the Pacific, telephone 1-800-335-2624.

Powers of Ten
(Videotape) Charles and Ray Eames. A 10-minute masterpiece introducing the 40 orders of magnitude between the scale of the observable Universe to the scale of a proton inside the nucleus of a carbon atom. Available through the Astronomical Society of the Pacific, telephone 1-800-335-2624.

Worlds in Comparison
(Slide set) A set of 20 dramatic slides, comparing planets, satellites, and their geographical features with those of Earth, the Moon, and terrestrial features (for all grades). Available through the Astronomical Society of the Pacific, telephone 1-800-335-2624.

Catalogs

Association for Supervision and Curriculum Development (ASCD) Resources Catalog
Contains numerous books, audio cassettes, videos, and multimedia titles covering a broad range of educational topics, including products dealing with curriculum, instruction, assessment, classroom management, and educational leadership. Call 1-800-933-ASCD or visit the ASCD Online Store at *http://www.ascd.org/*. Click on "ASCD Online Store."

Astronomical Society of the Pacific Catalog
Contains a vast array of current, scientifically accurate astronomy products, including posters, videotapes, slide sets, hands-on teaching aids, software and CD-ROMs. Call the Astronomical

Society of the Pacific (ASP) information and customer service department at 1-800-962-3412. You can browse the catalog at the ASP website at *http://www.aspsky.org/*. Click on "Catalog" to find the online version and information about requesting a free catalog.

Membership & NSTA Publications Catalog
Contains various science resources and standards, products dealing with teaching strategies, software, CD-ROMs, and NSTA releases. Call 1-800-722-NSTA, or browse the NSTA Science Store on line at *http://www.nsta.org/scistore/*.

NASA Central Operation of Resources for Educators (CORE)
Established for the national and international distribution of NASA-produced educational materials. Educators can obtain a catalog and order form by mail, phone, fax, e-mail, or through the website:

NASA CORE
Lorain County Joint Vocational School
5181 Route 58 South
Oberlin, OH 44074
Phone: (440) 774-1051, Ext. 249 or 293
Fax: (440) 774-2144
E-mail: *nasaco@leeca.esu.k12.oh.us*
Website: *http://spacelink.nasa.gov/CORE*

Sky Publishing Corporation Catalog
This catalog contains astronomy books and products such as star atlases, observing guides, videotapes, posters, slide sets, and software, all of which are selected by the editors of *Sky & Telescope* magazine. For a printed copy of the catalog, send a request by e-mail to *catalog@skypub.com*, or call 1-800-253-0245 (US and Canada only) or +1-617-864-7360, or fax 1-617-864-6117. Browse the online version of the catalog by visiting *http://www.skypub.com/index.shtml* and clicking on "SPC Catalog."

CD-ROMs

Astronomy Village: Investigating the Universe (1998). A CD-ROM–based multimedia program developed for the NASA Classroom of the Future by Wheeling Jesuit College that provides teachers and students with 10 complete investigations in astronomy intended to complement and extend the science curriculum in 9th and 10th grade classes. It can also be used at other grade levels. *Astronomy Village* is a Macintosh or Power Macintosh program; minimum system requirements are listed at *http://www.cotf.edu/AV/av1.html.* Copies can be picked up for free from a NASA Educator Resource Center or ordered from NASA CORE or from *http://www.cotf.edu/AV/order.html* for a minimal fee.

***Planetary Image*s** (1996). A multiplatform resource of over 200 digital images of the planets, satellites, asteroids, and comets from planetary and lunar missions. Information: National Space Science Data Center, NASA/GSFC, Code 633, Greenbelt, MD 20771. Telephone (301) 286-6695, or send e-mail to *request@nssdca.gsfc.nasa.gov.*

Views of the Solar System (1996). A hypertext-formatted Mac/Windows CD-ROM by Calvin J. Hamilton featuring comprehensive, up-to-date information on major aspects of the Solar System. Contains special teacher section. Available through the NSTA Publications Catalog; call 1-800-722-NSTA to order.

Welcome to the Planets (1994-95), Version 1.5. Solar System information from NASA's Planetary Data System. Information: National Space Science Data Center, NASA/GSFC, Code 633, Greenbelt, MD 20771. Telephone (301) 286-6695; e-mail: *request@nssdca.gsfc.nasa.gov.*

NASA Educational Products

NASA-produced educational materials are available through Educator Resource Centers (ERCs — see below) or through NASA Central Operation of Resources for Educators (CORE). The NASA CORE catalog can be obtained by mail, telephone, fax, e-mail, or website (see the *Catalogs* section). See the NASA Spacelink website for downloadable materials and more information on NASA educational products: *http://spacelink.nasa.gov/*.

See http://www.mcrel.org/standards-benchmarks/standardslib/science-1.html for Earth and Space Science standards/benchmarks, and links to all other standards.

How to Access NASA's Education Materials and Services is an annual brochure that serves as a guide to accessing a variety of NASA materials and services for educators. Copies are available through the ERC network, or electronically via NASA Spacelink.

NASA Educator Resource Centers

To make additional information available to the education community, the NASA Education Division has created the NASA Educator Resource Center (ERC) network. ERCs contain a wealth of information for educators: publications, reference books, slide sets, audio cassettes, videotapes, telelecture programs, computer programs, lesson plans, and teacher guides with activities. Educators may preview, copy, or receive NASA materials at these sites. Because each NASA Field Center has its own areas of expertise, no two ERCs are exactly alike. Phone calls are welcome if you are unable to visit the ERC that serves your geographic area. Here is a list of the centers by regions they serve:

AK, AZ, CA, HI, ID, MT, NV, OR, UT, WA, WY
NASA Educator Resource Center
Mail Stop 253-2
NASA Ames Research Center
Moffett Field, CA 94035-1000
Telephone: (650) 604-3574

CT, DE, DC, ME, MD, MA, NH, NJ, NY, PA, RI, VT
NASA Educator Resource Laboratory
Mail Code 130.3
NASA Goddard Space Flight Center
Greenbelt, MD 20771-0001
Telephone: (301) 286-8570

CO, KS, NE, NM, ND, OK, SD, TX
JSC Educator Resource Center
Space Center Houston
NASA Johnson Space Center
1601 NASA Road One
Houston, TX 77058-3696
Telephone: (281) 483-8696

FL, GA, PR, VI
NASA Educator Resource Laboratory
Mail Code ERL
NASA Kennedy Space Center
Kennedy Space Center, FL 32899-0001
Telephone: (407) 867-4090

KY, NC, SC, VA, WV
Virginia Air and Space Museum
NASA Educator Resource Center for
NASA Langley Research Center
600 Settler's Landing Road
Hampton, VA 23669-4033
Telephone: (757) 727-0900 x 757

IL, IN, MI, MN, OH, WI
NASA Educator Resource Center
Mail Stop 8-1
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135-3191

AL, AR, IA, LA, MO, TN
US Space and Rocket Center
NASA Educator Resource Center for
NASA Marshall Space Flight Center
PO Box 070015
Huntsville, AL 35807-7015
Telephone: (205) 544-5812

MS
NASA Educator Resource Center
Building 1200
NASA John C. Stennis Space Center
Stennis Space Center, MS 39529-6000
Telephone: (228) 688-3338

CA
NASA/JPL Educator Resource Center
Village at Indian Hill
1460 E. Holt Ave., Suite 20
Pomona, CA 91767
Telephone: (909) 397-4420

CA cities near the center
NASA Educator Resource Center for
NASA Dryden Flight Research Center
45108 N. 3rd Street East
Lancaster, CA 93535
Telephone: (805) 948-7347

VA and MD's Eastern Shores
NASA Educator Resource Lab
Education Complex, Visitor Center
Building J-1
NASA Wallops Flight Facility
Wallops Island, VA 23337-5099
Telephone: (757) 824-2297/2298

Periodicals

Astronomy
Kalmbach Publishing, 21027 Crossroads Circle, PO Box 1612, Waukesha, WI 53187. Includes monthly reports of what's visible in the night sky. Website: *http://www.kalmbach.com/astro/astronomy.html.*

Mercury, the Journal of the Astronomical Society of the Pacific
The Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112. Website: *http://www.aspsky.org/mercury.html.*

Odyssey
Cobblestone Publishing, Inc., 30 Grove Street, Peterborough, NH 03458-1454. An astronomy magazine for children. Website: *http://www.odysseymagazine.com/.*

Planetary Report, The
Published by the Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301. For information on Planetary Society publications, visit the website at *http://planetary.org.* Click on "Publications."

Sky & Telescope
Sky Publishing Corporation, 49 Bay State Road, Cambridge, MA 02138. Includes monthly reports of what's visible in the night sky. Website: *http://www.skypub.com/.*

Publications

Astronomy

Beatty, J. Kelly, Carolyn Collins Petersen, and Andrew Chaikin (1999), ***The New Solar System,*** Sky Publishing, Cambridge, MA. Beautifully illustrated, with articles on all aspects of planetary astronomy.

Chaisson, Eric, and Steve McMillan (1993), ***Astronomy Today,*** Prentice Hall, Englewood Cliffs, NJ.

Ferris, Timothy (1988), ***Coming of Age in the Milky Way,*** Doubleday, New York. A colorful story of how humanity's perspective on the Universe has evolved through time.

Fraknoi, Andrew, David Morrison, and SidneyWolff (1997), ***Voyages Through the Universe,*** Saunders College Publishing, Harcourt College Publishers, Orlando, FL. An enjoyable, readable introductory astronomy text.

Morrison, David, Sidney Wolff, and Andrew Fraknoi (1995), ***Abell's Exploration of the Universe,*** Saunders College Publishing, Philadelphia, PA. An introductory astronomy text with a systems approach.

Raymo, Chet (1982), ***365 Starry Nights: An Introduction to Astronomy for Every Night of the Year,*** Simon and Schuster, New York. A delightfully illustrated way to learn about astronomy and skywatching.

Sagan, Carl (1980), ***Cosmos,*** Random House, New York. Based on the Emmy Award–winning TV series.

Sagan, Carl (1994), ***Pale Blue Dot,*** Random House, New York. A beautifully illustrated book offering an eloquent perspective on what we know about the worlds of our Solar System.

Vogt, Gregory (1991), ***Voyager, Missions in Space***, Millbrook Press, Brookfield, CT. Grade level: 7–10. An "inside look" at the Voyager 1 and 2 missions. Includes beautiful NASA images of the gas giants, their satellites, and deep space.

Wagner, Jeffrey K. (1997), ***Introduction to the Solar System,*** Saunders College Publishing, Harcourt College Publishers, Orlando, FL. A college-level introductory text on Solar System astronomy.

Education Standards & Curriculum Evaluation

Benchmarks for Science Literacy: Project 2061 (1993), American Association for the Advancement of Science, Oxford University Press, New York. Address: Project 2061 BENCHMARKS, AAAS, 1333 H Street NW, Washington, DC 20005. View the full text of the Benchmarks on line by visiting *http://www.project2061.org/*.

National Science Education Standards (1996), National Academy Press, Washington, DC. Available for sale from the National Academy Press, 2101 Constitution Avenue NW, Box 285, Washington, DC 20055. Call 1-800-624-6242 or (202) 334-3313 in the Washington metropolitan area. Also available through the NSTA Publications Catalog: call 1-800-722-NSTA.

Curriculum and Evaluation Standards for School Mathematics (1989), National Council of Teachers of Mathematics, Inc., 1906 Association Drive, Reston, VA 22091.

Educator Guides

Rockets: A Teacher's Guide with Activities in Science, Mathematics, and Technology (1996), NASA EG-1996-09-108-HQ. All the excellent activities you could want on rockets using simple materials. Available from NASA Educator Resource Centers or NASA CORE.

Space-Based Astronomy: Teacher's Guide with Activities
(1994), NASA EG-102. Includes good activities on color, spectroscopy and receiving data back from space missions. Available from NASA Educator Resource Centers or NASA CORE.

Fraknoi, Andrew, editor (1995), ***The Universe at Your Fingertips: An Astronomy Activity and Resource Notebook,*** Project ASTRO, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112, telephone (415) 337-1100 or 1-800-335-2624. An eclectic and comprehensive assemblage of excellent astronomy activities and resources.

PASS (Planetarium Activities for Student Success)
(1993), Lawrence Hall of Science, University of California, Berkeley. Also available through the *Eureka!* catalog, Lawrence Hall of Science, University of California, Berkeley, CA 94720-5200, telephone (510) 642-1016.

Destiny in Space: A Collection of Information, Activities, and Resources about Exploring Space for Teachers of Grades 4–12
National Air and Space Museum, Teacher Services Coordinator, Educational Services Center MRC-305, Smithsonian Institution, Washington, DC 20560, telephone (202) 786-2524. Epecially good for activities involving robotics and teleoperations.

The Moons of Jupiter
(1993), Great Explorations in Math and Science (GEMS), Lawrence Hall of Science, University of California at Berkeley, CA 94720, telephone (510) 642-7771.

Schatz, Dennis, and Doug Cooper (1994), ***Astro-Adventures: An Activity-Based Astronomy Curriculum,*** Pacific Science Center Explore More Store, 200 Second Avenue North, Seattle, WA 98109-4895, telephone (206) 443-2870, fax (206) 443-3627. Especially good for Moon and Sun observing.

Wright, Russell G., (1996) ***ASTEROID!: An Event-Based Science Module,*** Event-Based Science Project, 850 Hungerford Drive, Rockville, MD 20850, telephone 1-800-EBS-7252. Very interactive, real world, and hands-on.

Richter, Jessica, and Andrew Fraknoi (1996), ***Project ASTRO: How-To Manual for Teachers and Astronomers,*** Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112, telephone (415) 337-1100, fax (415) 337-5205.

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Osterbrock, Donald (1984), ***James E. Keeler: Pioneer American Astrophysicist,*** Cambridge University Press, Cambridge, UK.

Mathematics

Bennett, Jeffrey O., William L. Briggs, and Cherilynn A. Morrow, (1996), ***Quantitative Reasoning: Mathematics for Citizens in the 21st Century,*** Addison-Wesley, Reading, MA.

Websites

Saturn and the Cassini Mission

http://www.jpl.nasa.gov/cassini/
All about NASA's Cassini mission to Saturn. Click on "Products" [*http://www.jpl.nasa.gov/cassini/products*] to find the latest information

about how to obtain many exciting resources, including fact sheets, posters, lithographs, videos, slides, CD-ROMs, and hologram exhibits.

http://lyra.colorado.edu/sbo/mary/Cassini/scale_saturn.html
Classroom-tested directions for making a 3-D scale model of Saturn and its main rings using very basic materials.

http://lyra.colorado.edu/sbo/mary/Cassini/titan_demo.html
Directions for a fish tank demonstration of Titan's atmospheric constituents.

Other Space Science Websites

Amazing Space Web-Based Activities
http://amazing-space.stsci.edu
A set of Web-based activities for all to enjoy. Click on "Solar System Trading Cards" to see an example of just one of the many activities that can be found at this website.

Astronomical Data Center, The
http://adc.gsfc.nasa.gov/adc.html

Astronomy Café
http://www2.ari.net/home/odenwald/cafe.html
Dr. Sten Odenwald's award-winning site that answers questions you may have about astronomy. Click on "Ask an Astronomer."

Astrophysics Data Facility, The
http://hypatia.gsfc.nasa.gov/adf/adf.html

Classroom of the Future, The
http://www.cotf.edu/
The Classroom of the Future (COTF) Program at Wheeling Jesuit University is NASA's premier research and development center for educational technologies, and provides technology-based tools and resources to K–12 schools. The COTF Program is housed in the Erma Ora Byrd Center for Educational Technologies.

Basics of Space Flight Learners' Workbook
http://www.jpl.nasa.gov/basics/
A series of training modules that pertain to space and spaceflight operations: a very comprehensive, accessible course that was devised for new JPL employees. There is no prerequisite.

Earth and Space Science by McREL
http://www.mcrel.org/standards-benchmarks/standardslib/science-1.html
Presents the Earth and Space Science Standards. Click on "Internet Connections — Science" for a listing of many other excellent sites related to the Earth and Space sciences.

4000 Years of Women in Science
http://www.astr.ua.edu/4000WS/4000WS.html
Women are, and always have been, scientists. This website has names, short biographies, and photos of some of the women from our scientific and technical past. The site grew out of public talks given by Dr. Sethanne Howard.

Jet Propulsion Laboratory (JPL)
http://www.jpl.nasa.gov/
Learn about all JPL past, present, and future space missions, including Voyager, Galileo, and Cassini.

NASA Headquarters
http://www.hq.nasa.gov/

NASA Central Operation of Resources for Educators (CORE)
http://spacelink.nasa.gov/CORE

NASA's K–12 Internet Initiative
http://quest.arc.nasa.gov/
Provides support and services for schools, teachers, and students to fully utilize the Internet and

its underlying information technologies as a basic tool for learning.

NASA Observatorium
http://observe.ivv.nasa.gov/nasa/core.shtml
Earth and space data, with pictures of Earth, the planets, stars, and other cool stuff.

NASA Office of Space Science at Headquarters
http://www.hq.nasa.gov/office/oss/

NASA Office of Space Science Education and Public Outreach Ecosystem
http://spacescience.nasa.gov/education/ecosystem.htm

NASA Online Resources for Educators
http://education.nasa.gov/
Educational information and instructional resource materials for teachers, faculty, and students. A wide range of information is available, including science, mathematics, engineering, and technology education lesson plans, historical information related to the aeronautics and space program, current status reports on NASA projects, news releases, information on NASA educational programs, useful software, and graphics files. Educators and students can also use NASA resources as learning tools to explore the Internet, accessing information about educational grants, interacting with other schools that are already on line, participating in online interactive projects, and communicating with NASA scientists, engineers, and other team members to experience the excitement of NASA projects.

NASA's Planetary Photojournal
http://photojournal.jpl.nasa.gov/
Easy access to over 1,000 publicly released images from various Solar System exploration programs. The site was developed as a collaboration between NASA's Planetary Data System Imaging Node, the Solar System Visualization Project, and JPL's Media Relations Office.

NASA Spacelink
http://spacelink.nasa.gov
An electronic information system providing current educational information to teachers, faculty, and students about the aeronautics and space program. Spacelink offers a wide range of computer text files, software, and graphics. For more information, contact the Spacelink Administrator, Education Programs Office, Mail Code CL01, NASA Marshall Space Flight Center, Huntsville, AL 35812-0001, telephone (205) 961-1225; e-mail address is comments@spacelink.msfc.nasa.gov.

National Science Teachers Association (NSTA)
http://www.nsta.org/
NSTA is the largest organization in the world committed to promoting excellence and innovation in science teaching and learning for all. The current membership of more than 53,000 includes science teachers, science supervisors, administrators, scientists, business and industry representatives, and others involved in science education. This site tells you all about it!

Nine Planets, The — A Multimedia Tour of the Solar System
http://seds.lpl.arizona.edu/nineplanets/nineplanets/nineplanets.html
The Nine Planets, created by Bill Arnett, is an overview of the history, mythology, and current scientific knowledge of each of the planets and moons in our Solar System. Each page has text and images, some have sound and movies, most provide references to additional related information. A special "Just for Kids" version of this page exists at *http://www.tcsn.net/afiner/*, created to suit the needs of a younger audience by placing an emphasis on the basic concepts in a "kid-friendly" format.

Planetary Rings Node, The
http://ringside.arc.nasa.gov/
The Rings Node of NASA's Planetary Data System is devoted to archiving, cataloging, and distributing scientific data sets relevant to planetary ring systems. There are some awesome images of Saturn's rings, and a closeup of Jupiter's rings taken by the Galileo spacecraft.

Space Science Institute
http://www.spacescience.org
The Space Science Institute was co-developer of the *Saturn Educator Guide* in collaboration with the Jet Propulsion Laboratory.

Space Telescope Science Institute
http://www.stsci.edu/
All the latest pictures and press releases from the Hubble Space Telescope. The images of the Saturn ring-plane crossings in 1995 are spectacular!

Teacher's Guide for Solar System
http://www.cmnh.org:80/education/teacher-guides/solarsystem.html
Includes information about how to prepare students for a trip to the planetarium and observatory, and also lists several resources available at the Cleveland Museum of Natural History's Science Resource Center.

Telescopes in Education (TIE)
http://tie.jpl.nasa.gov
Through Telescopes in Education (TIE), students around the world can remotely control research-quality telescopes and CCD cameras from computers in their classrooms.

Windows on the Universe
http://www.windows.umich.edu/
A fun and different site about the Earth and space sciences. This site is NASA-funded and intended for use by the general public. Users can visit the site in several ways; entry options include beginner, intermediate, and advanced components. For information on an associated CD-ROM, visit *http://www.windows.umich.edu/about_windows.html*.

Women of NASA
http://quest.arc.nasa.gov/women/
This resource was developed to encourage young women to pursue careers in mathematics, science, and technology. The Women of NASA interactive project showcases outstanding women who are enjoying successful careers and how these women balance personal and professional responsibilities. The site also features profiles, teaching tips, resources, and several other topics. The site has a bilingual component in Spanish.

ENRICHMENT

1

Searching for Saturn

Throughout human history, scientific discoveries have influenced art, culture, and mythology. Sometimes the value and beauty of a discovery or invention is a matter of interpretation. For example, automobiles have been perceived both as pretty machines that represent freedom, power, and progress, or as ugly machines that pollute the air, cause traffic jams, and produce lots of noise. Both points of view can be correct at the same time. The image of Saturn and its rings is familiar to almost everyone; it symbolizes the very idea of a planet. To help students understand how deeply the image of a planet with rings has penetrated concepts of art and design, have them look for Saturn images in everyday objects.

Artist's concept of an imaginary ringed planet.

"When one wishes to use science to enrich our culture, one should view science as a form of art."

Ukichiro Nakaya
(Scientist and inventor of the first artificial snow crystals)

ACTIVITY

How has the appearance of this planet become a familiar part of our lives? How often do we see a Saturn image in modern culture? There is even an automobile called Saturn! Have students search for the shape of Saturn and list the places they find depictions of the planet. Students can cut out examples of Saturn from catalogs and magazines, and put the pictures on a large bulletin board or in a scrapbook. Sources include mail-order catalogs, magazines, and newspapers. Images of Saturn appear on many products, such as garden sundials, blankets and bedspreads, clothing, wrapping paper, candle holders, dinner plates, T-shirts, hanging mobiles, and in advertisements for computer software and other products. The World Wide Web offers another possibility for searching for images of Saturn.

TOPICS

How are the artistic images of Saturn different from real photos of the planet? Compare the Voyager image of Saturn from Lesson 1 with illustrations, painting, or computer art. Are some of the drawings out of proportion, made up of unrealistic colors and patterns, or drawn as cartoons?

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher

Overhead projector

For each student

Catalogs and magazines; scissors

Scrapbook or bulletin board

World Wide Web access

Materials to reproduce

FIGURE	TRANSPARENCY
1	1
2	1
3	1

Background for Enrichment 1

ENRICHMENT

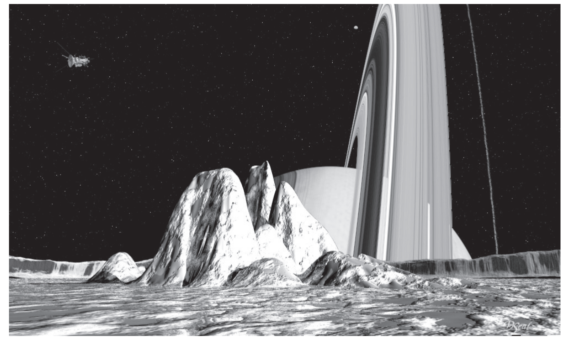
1

Here are three examples of how Saturn has been portrayed using different methods: computer art, painting, and a modern poster that was inspired by a magazine printed in 1926. The three examples can be prepared as transparencies (enlargements appear as Figures 1, 2, and 3 under "Materials"), displayed for the students, and discussed in terms of how Saturn and its moons are portrayed using different media, and how realistic the images are compared with photographs taken by Voyager. The full-color versions can be found on the Cassini website at JPL — each of the three figures shows the website for that figure.

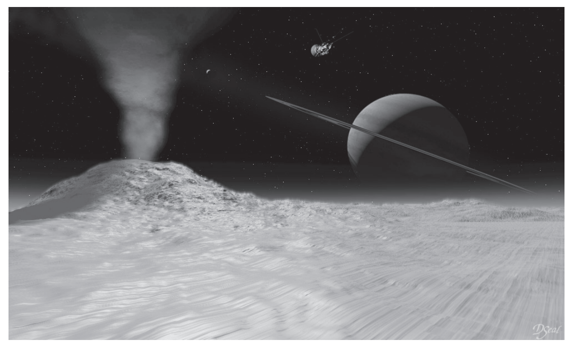
Computer Art

At the Jet Propulsion Laboratory, computer software that had been used to make computer images during the Voyager flybys of Jupiter and Saturn in the 1980s was used to create imaginary space art. The Saturn moon drawings shown here, as well as many other illustrations of Saturn and its moons, can be found on the Cassini website at: http://www.jpl.nasa.gov/cassini/Images.

This computer art shows the surface of Pandora, one of the shepherd moons of Saturn's F ring. The F ring is the bright, wispy material on the left side of the picture. Prometheus, the companion shepherd moon, can be seen at the top of the picture on the inner side of the F ring. The Cassini spacecraft is at the upper right.



This artist's view is from the surface of Mimas, whose unusual appearance inspired its nickname as the "Death Star" moon. This computer art shows the icy central mountains of the crater Herschel, with the crater walls visible in the distance. The Cassini spacecraft is at the upper left.

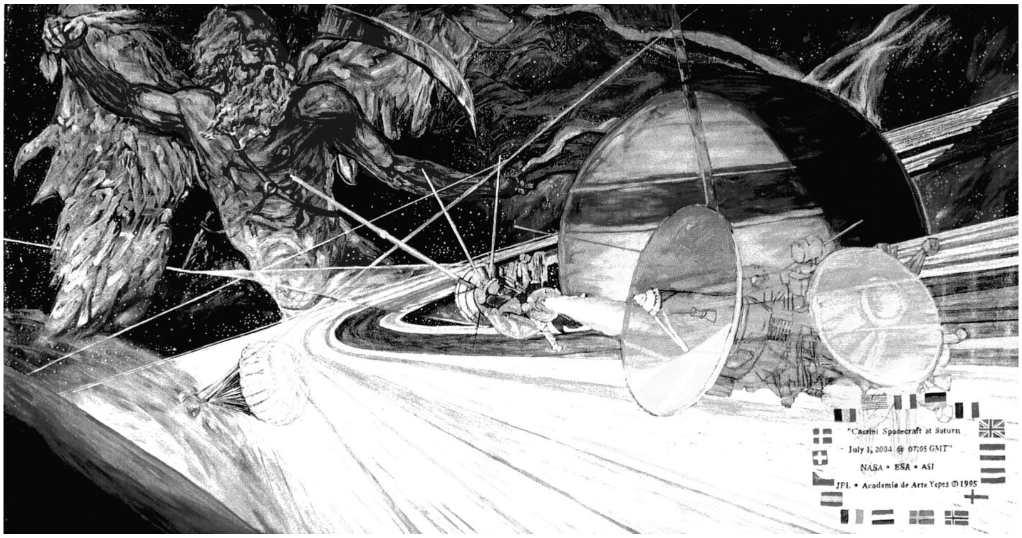


This computer illustration shows the bright surface of Enceladus, with an ice geyser shooting a jet of vapor into space. Ice geysers may be responsible for supplying the E ring's tiny ice particles. The Cassini spacecraft can be seen above and to the left of Saturn.

Painting

The Cassini mural resulted from a collaboration between the Cassini–Huygens mission and eight young master painters of the Academia de Arte Yepes in Los Angeles. The artists are Gabriel Estrada, Ulysses Garcia (leader), Abel Gonzales, Daniel Gonzales, Octavio Gonzales, Rebeca Robles, Juan Solis, and Francisco Vasquez.

The Academia de Arte Yepes gives promising young Hispanic painters an opportunity to develop their talents and skills. The idea of a mural designed around Cassini and Saturn gave the



The Cassini mural was a collaboration between the Cassini–Huygens mission and eight young artists.

painters a chance to try out their artistry in combining science and mythology. In the mural, the mythological Roman god Saturn is represented as the symbol of Time drawing back a veil to allow the Cassini spacecraft to reveal the mysteries of the vast Saturn system. The Cassini spacecraft is shown firing its main engine to brake into orbit around Saturn in July 2004. Beneath the spacecraft lies the sheet of icebergs and particles that make up the magnificent rings. Nearly transparent images of the spacecraft and the Huygens Titan probe represent important moments in the mission. Flags of some of the countries participating in the Cassini–Huygens mission are painted in the lower right-hand corner.

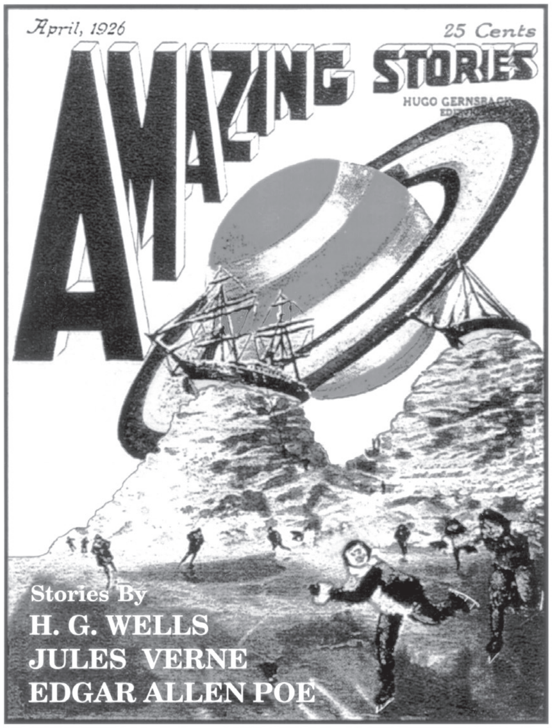
The "AMAZING SATURN" Poster

AMAZING STORIES was a science-fiction magazine first published in April 1926. The cover's appearance was distinctive, with its title in large block letters appearing to shrink into the distance. AMAZING STORIES brought science, technology, and the idea of space exploration to the general public, and had readers all over the world. The legacy of the original AMAZING STORIES and its art style can be seen in such movies as *War of the Worlds*, *Forbidden Planet*, *2001: A Space Odyssey*, *Raiders of the Lost Ark*, and *Star Wars*.

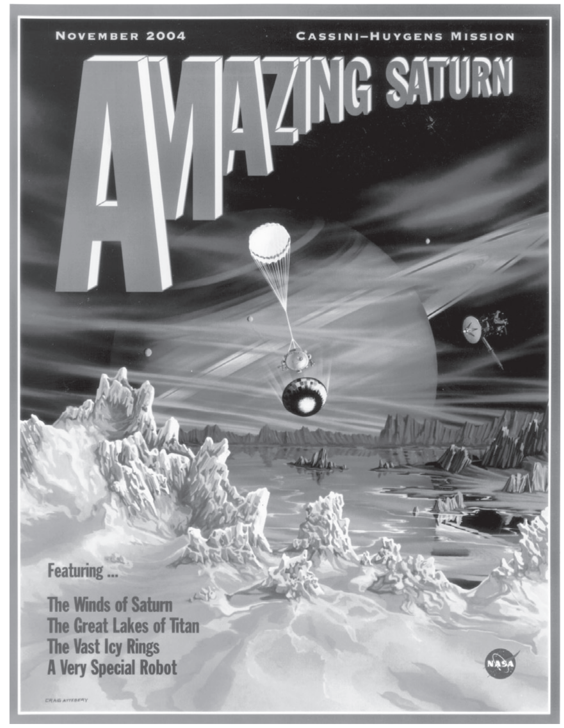
The Cassini–Huygens poster uses a painting of Saturn rising behind the moon Titan as the Huygens probe parachutes to the surface. TSR, Inc., the company that owns the distinctive trademark, gave permission to copy the art style for the poster's title.

To create a dramatic image, the artist exaggerated certain features:

- The painting portrays the Huygens probe nearing the surface of Titan after being released from its parachute. (The probe is due to land on Titan in November 2004 after a 2.5-hour descent through the atmosphere.) In reality, the deployment of the Huygens probe's heat shield would happen much higher up in Titan's atmosphere than is depicted in the painting.
- The angular size of Saturn in the Titan sky is correctly portrayed, but the rings are tilted more than they would be. In reality, Titan



The cover of the first issue of AMAZING STORIES, April 1926, shows happy space travelers skating on the icy surface of a moon of Saturn. AMAZING STORIES is a registered trademark of TSR, Inc. (Used with permission.)



The AMAZING SATURN poster, with a title in the style of AMAZING STORIES, shows an imaginary concept of the Huygens probe descending to the surface of Titan, with Saturn and the Cassini spacecraft in the background.

orbits so close to the ring plane that the rings would appear as a mere wisp of an edge. Actually, Titan's atmosphere is probably too thick for an imaginary traveler to see Saturn from the surface, and certainly it would be too hazy to permit Saturn to be seen close to the horizon.

- Tremendous artistic license has been taken in showing the Cassini orbiter in the sky. In reality, Cassini would appear more like a star, but in any event, it could not be seen through Titan's clouds.
- Many scientists hypothesize that there are cold lakes of liquid hydrocarbons on Titan, as shown in the painting. The hills are probably more rounded than depicted. The brownish, orangish (in the color version) organic sludge on the terrain is a real possibility.

Materials

ENRICHMENT 1

Figure 1	**Saturn Moons (2 pages)**
Figure 2	**The Cassini Mural**
Figure 3	**AMAZING STORIES and AMAZING SATURN**

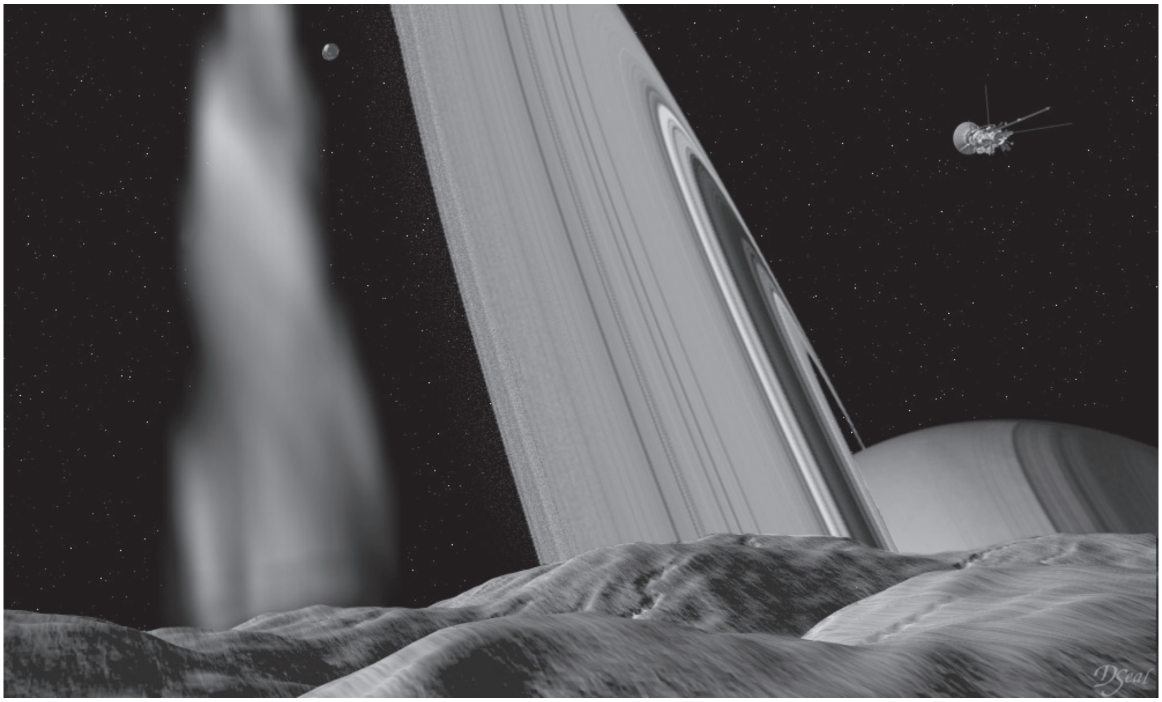
Saturn Moons (1 of 2)

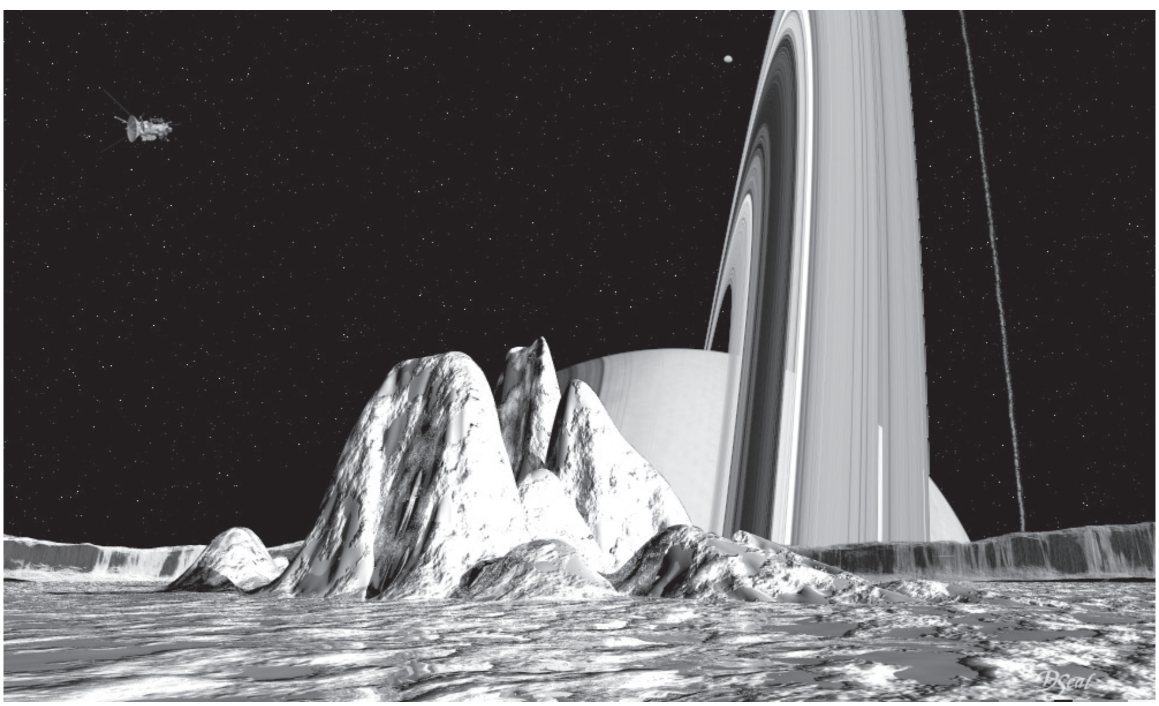
ENRICHMENT

1

Figure 1

See the full-color versions on the Cassini website at: http://www.jpl.nasa.gov/cassini/Images/artwork



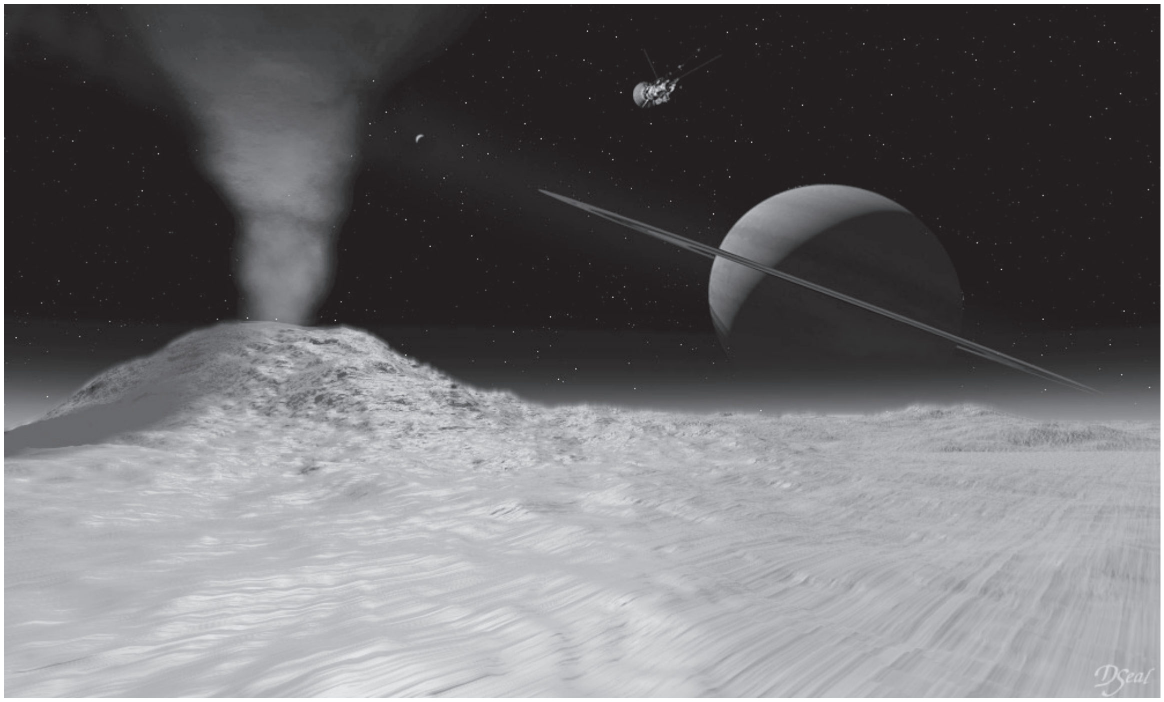


Saturn Moons (2 of 2)

ENRICHMENT

1

Figure 1

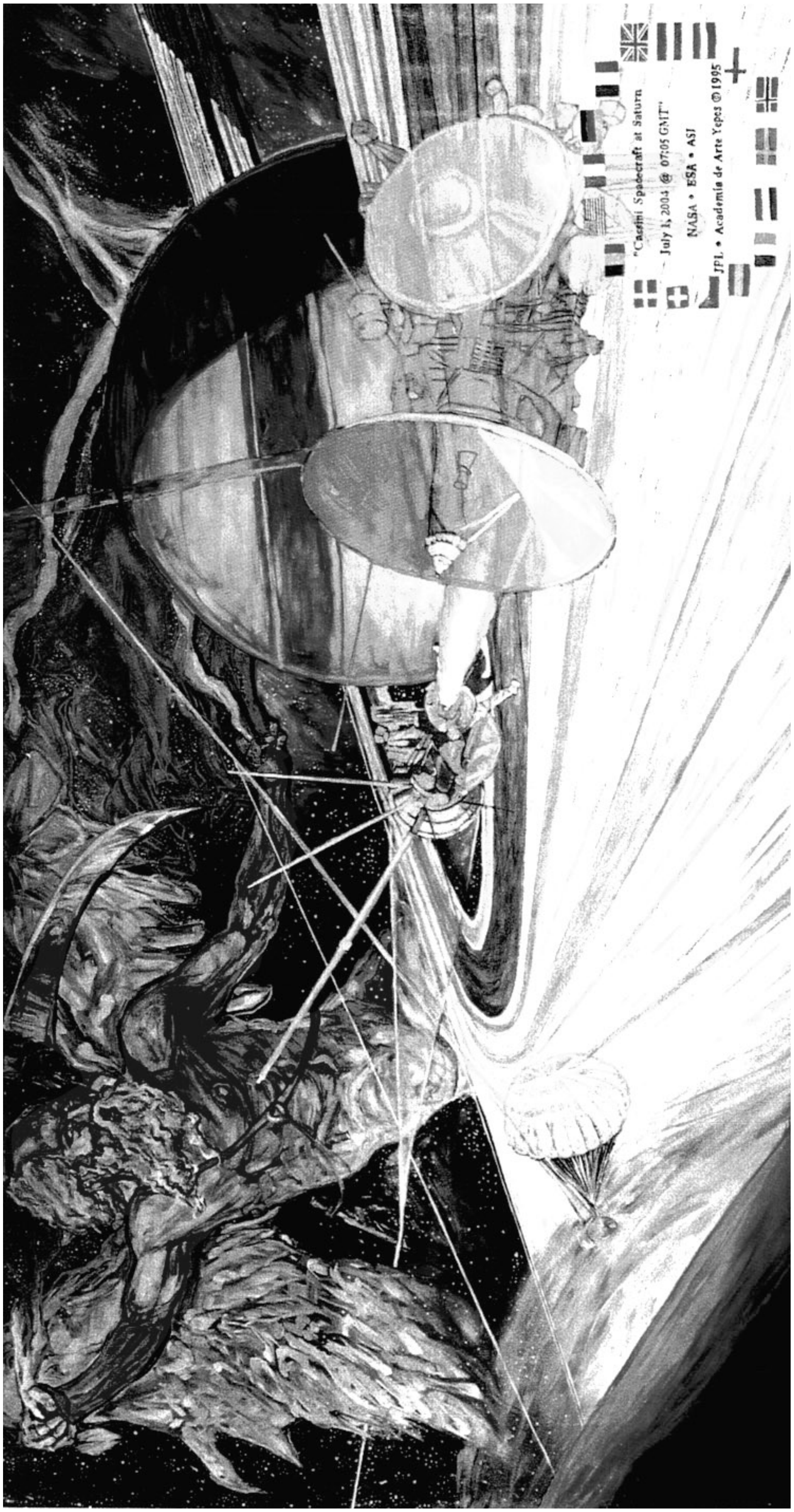


ENRICHMENT

1

Figure 2

The Cassini Mural



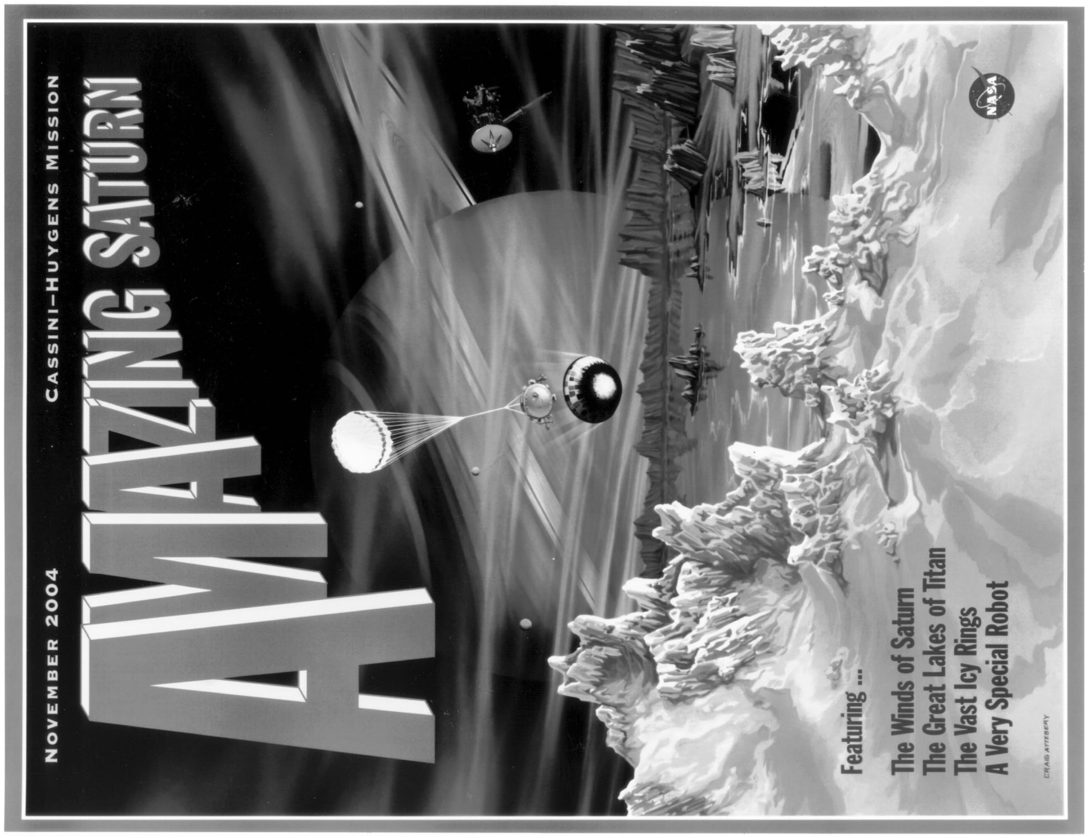
See the full-color version on the Cassini website at: http://www.jpl.nasa.gov/cassini/what/whatshot.html

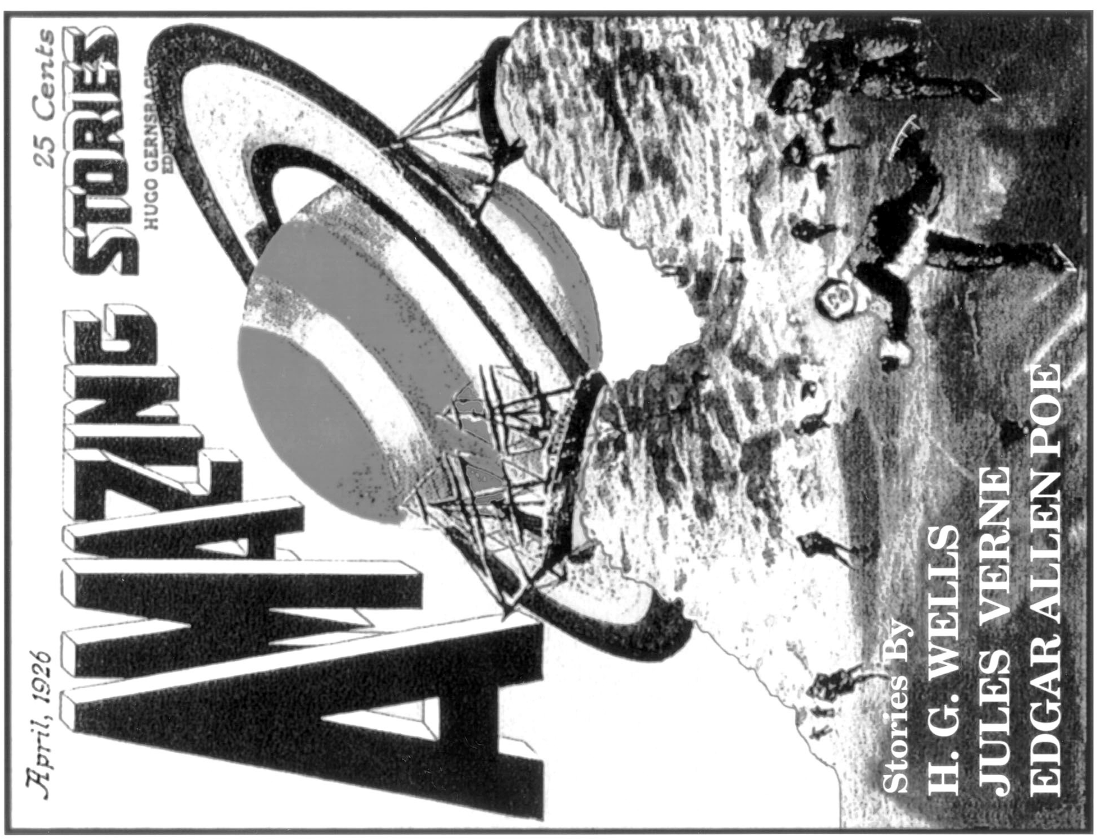
AMAZING STORIES and AMAZING SATURN

ENRICHMENT

1

Figure 3





See the full-color version of the poster on the Cassini web site at: http://www.jpl.nasa.gov/cassini/what/whatshot.html

ENRICHMENT

1

ENRICHMENT 2

Saturn Puzzles

Huygens' Anagram

In the spring of 1655, the Dutch astronomer Christiaan Huygens (pronounced HOY-genz) announced his discovery that Saturn had a moon orbiting it. (This was the first moon of Saturn found, and was in fact the largest moon, later called Titan.) Huygens used an interesting method for this announcement — he sent a coded message, an anagram, to his fellow astronomers. An anagram is a word or sentence in which the letters have been moved around to make a new word or sentence. An anagram doesn't have to make sense; for example, the sentence "Garbage smells bad" could be made into the perfectly meaningless anagram "Dear gas bell gambs." In Huygens' time, astronomers and other scientists would use anagrams to pass around the news of their discoveries. No one else could claim to be the discoverer in the meantime, because no one else even knew what it was that had been discovered. After everyone had received the anagram, the scientist told them how to unscramble it, revealing the message.

Huygens' anagram was: "ADMOUERE OCULIS DISTANTIA SIDERA NOSTRIS UUUUUUU CCCRRHNBQX." When the anagram is unscrambled, it reads, in Latin, "Saturno luna sua circunducitur diebus sexdecim horis quatuor," which means "Saturn's moon revolves in sixteen days and four hours." This was how Huygens told the world that he had discovered a moon that orbited around Saturn in a little more than 16 days. Huygens' moon was not given its official name, Titan, until almost 200 years later.


Huygensmuseum, Hofwijck

Christiaan Huygens, discoverer of Titan.

ACTIVITY

After you have written out Huygens' anagram and explained it, have students devise their own anagrams for the English translation of Huygens' announcement of discovery: "Saturn's moon revolves in sixteen days and four hours." For example: EVOLVE ADDRESSERS ANTITOXINS HUMOROUS FUNNY SONAR.

EQUIPMENT, MATERIALS, AND TOOLS

For the teacher	*For each student*
Chalkboard, whiteboard, or easel with paper	Paper
Chalk or markers	Pencils

ENRICHMENT

2

Saturn Crossword Puzzle

This crossword puzzle (see Figure 1) has references to Saturn and to the Cassini–Huygens mission.

ACTIVITY

Students can try out the crossword puzzle to practice spelling and puzzle-solving capabilities.

Make a copy of the blank puzzle (Figure 1) for each student, or make one copy per group and have students work in teams to solve the puzzle. Figure 2, the *Saturn Crossword Puzzle Answer Key*, can be prepared as a transparency for display and discussion.

EQUIPMENT, MATERIALS, AND TOOLS

For the students

Pencils

Materials to reproduce

FIGURE	TRANSPARENCY	COPIES
1		1 per student or group
2	optional	

Materials

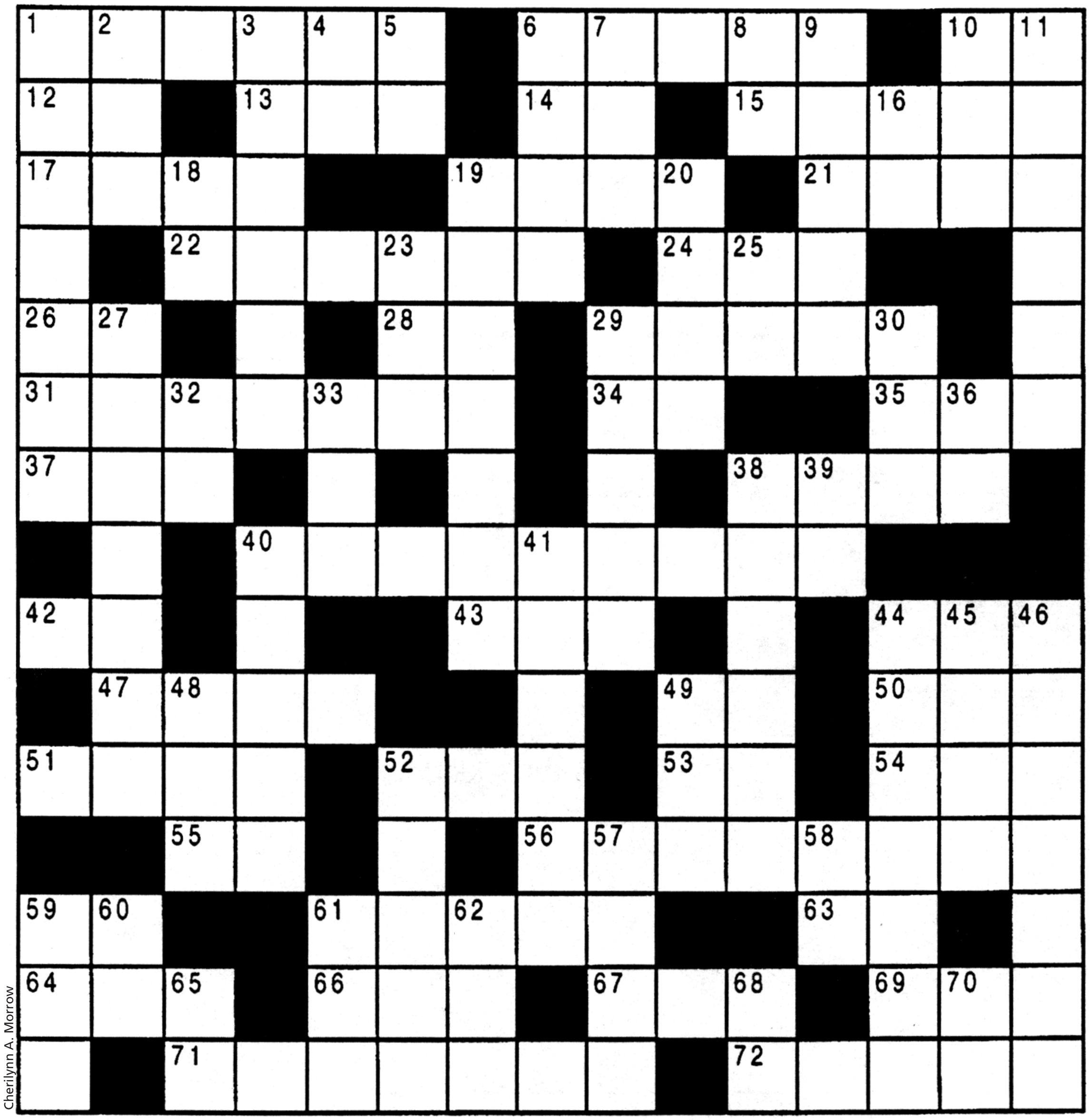
Figure 1	**Saturn Crossword Puzzle (3 pages)**
Figure 2	**Saturn Crossword Puzzle Answer Key**

ENRICHMENT

2

Figure 1

Saturn Crossword Puzzle (1 of 3)



Cherilynn A. Morrow

ACROSS

1 The ringed planet with 18 moons, named for a Roman god.

6 Kepler showed that the shape of a planetary ________ is an ellipse.

10 Associate of Arts (abbr), a two-year college degree.

12 Recorded device used to play music in your home (abbr). A related technology, DVD, is carrying the signatures of 600,000 Earthlings to Saturn aboard the Cassini spacecraft.

13 Coded information sent from a spacecraft to Earth before analysis or refinement is referred to as _____ data.

14 The state of Virginia (abbr).

15 Huygens discovered these around Saturn in 1659.

17 Often symbolized by a lit-up light bulb.

19 There are many of these in Saturn's ring system — the most prominent is known as the Cassini Division.

21 Links or connections.

Saturn Crossword Puzzle (2 of 3)

ENRICHMENT

2

Figure 1

22 A living organism that is not a plant is probably an ________.

24 If the Sun were the size of a large grapefruit, Saturn would be about the size of a _________.

26 North Pole or neptunium (abbr).

28 U.S. Vice President from 1993–2001: ____ Gore.

29 There are 18 of these currently known in Saturn's system, and probably more to be discovered by Cassini.

31 NASA's newest mission to Saturn, named for a 17th century Italian–French scientist.

34 He, she, ___.

35 A small child is a tiny _____.

37 The ____ of the Cassini mission is July 1, 2008, but many scientists are hoping it will be extended.

38 A big hug and a _____.

40 This smooth, shiny moon may have ice geysers whose eruptions feed Saturn's E ring.

42 If everything is working properly, then the launch director will say, "All systems are __!"

43 Organization of American States (abbr).

44 ____, skip and a jump.

47 Unusual.

49 Direction you look to see the sky.

50 United Barcode Industries (abbr); also Latin for "where."

51 Not the whole.

52 Organization (abbr).

53 Common Era (abbr).

54 ____-Hoo! An expression for getting attention; also a chocolate soft drink.

55 The last two letters of an abbreviated word that serves as a general term for things like arithmetic, geometry, algebra, trigonometry, and calculus.

56 This lightest of elements is the primary constituent of Saturn.

59 Year before Sr. year in school (abbr).

61 Saturn is less ______ than water, and thus would float if it were placed in a large enough ocean.

63 Pronoun for a male.

64 A cat or dog is usually this.

66 Long ___ and far away.

67 American Geophysical Union (abbr) — an organization of scientists devoted to the study of Earth.

69 Opposite of South–Southwest (abbr).

71 Name of the two deep space missions to explore Saturn in the 1980s. They may have inspired the name for Captain Janeway's starship (of *Star Trek*).

72 The blind chief engineer of the starship Enterprise, Geordi LaForge, wears one so that he can see.

DOWN

1 Arthur C. Clarke's *2001: A Space Odyssey* is a classic example of __________ fiction.

2 Opposite of subtract.

3 The next planet out from the Sun after Saturn, discovered by musician and astronomer William Herschel in 1781.

4 Right ascension (abbr); longitude on the celestial sphere.

5 Northwest (abbr).

6 Some orbits have this sort of shape.

7 A modern style of music, or an open conversation: a ____ session.

8 Abbreviation for infrared radiation. The Cassini instruments called the Composite Infrared Spectrometer (CIRS) and the Visible and Infrared Mapping Spectrometer (VIMS) will measure the infrared light coming from Saturn and its moons.

Saturn Crossword Puzzle (3 of 3)

9 Saturn's largest moon, whose name refers to mythological giants.

10 The _____ of the Solar System is about 4.6 billion years.

11 The Cassini spacecraft uses gravity ________ at Venus, Earth, and Jupiter to help it get to Saturn without using too much rocket fuel.

16 The element nickel (abbr).

18 The ___ ring is Saturn's outermost ring; the ring just outside the Cassini Division is named the _____ ring.

19 In 1610, he thought Saturn's rings resembled "ears" or "handles."

20 Jupiter has a Great Red ______ — a huge storm whose diameter is larger than Earth's.

23 "That's one small step for a ______; one giant leap for mankind." These were the words spoken by Neil Armstrong as the first human to set foot on the Moon.

25 Equal Opportunity (abbr).

27 One of the shepherd moons of Saturn's F ring, named for the woman of Greek mythology whose opened box unleashed troubles upon humanity.

29 This moon has a huge crater that inspired its nickname, the "Death Star" moon. (The Death Star was a space station of the evil Empire in the movie *Star Wars*.)

30 Space Transportation System (abbr); the formal name for the Space Shuttle.

32 State where Mount Rushmore is located (abbr).

33 A charged atom; also the ______ and Neutral Mass Spectrometer (INMS), a Cassini instrument that will analyze the gases in Titan's up per atmosphere.

36 The densest known metal, osmium (abbr).

38 He discovered Titan's atmosphere in 1944. NASA named an airborne infrared observatory after him.

39 I am, you are, she ___.

40 Humans live on this planet — the third planet from the Sun.

41 What a true friend does in response to your funny joke.

44 Name of the probe that will explore Titan's atmosphere; also the name of the scientist who discovered Titan in 1655.

45 Woodwind instrument.

46 Name of the first deep space mission to visit Saturn; also, an American who ventured westward in the 19th century.

48 The Cassini mural, painted by eight Hispanic students, is an example of this.

49 University of Colorado at Denver (abbr).

52 Last letter of the Greek alphabet.

57 The time it takes for Earth to orbit the Sun once.

58 ____ my! An expression of surprise.

59 Jet Propulsion Laboratory (abbr) — the place in California where the Cassini spacecraft was assembled.

60 Do ___ Mi Fa So La Ti Do.

61 We call the time taken for one rotation of Earth a _____.

62 A cold drink consisting of eggs beaten up with sugar and cream is called egg ____.

65 Short for television.

68 Short for ultraviolet radiation. A Cassini instrument called the Ultraviolet Imaging Spectrograph (UVIS) will study the ultraviolet sunlight reflected off Saturn's rings.

70 "____ man is an island." — John Donne.

ENRICHMENT

2

Figure 2

Saturn Crossword Puzzle Answer Key

1 S	2 A	T	3 U	4 R	5 N	■	6 O	7 R	B	8 I	9 T	■	10 A	11 A
12 C	D	■	13 R	A	W	■	14 V	A	■	15 R	I	16 N	G	S
17 I	D	18 E	A	■	■	19 G	A	P	20 S	■	21 T	I	E	S
E	■	22 A	N	I	23 M	A	L	■	24 P	25 E	A	■	■	I
26 N	27 P	■	U	■	28 A	L	■	29 M	O	O	N	30 S	■	S
31 C	A	32 S	S	33 I	N	I	■	34 I	T	■	■	35 T	36 O	T
37 E	N	D	■	O	■	L	■	M	■	38 K	39 I	S	S	■
■	D	■	40 E	N	C	E	41 L	A	D	U	S	■	■	■
42 G	O	■	A	■	■	43 O	A	S	■	I	■	44 H	45 O	46 P
■	47 R	48 A	R	E	■	■	U	■	49 U	P	■	50 U	B	I
51 P	A	R	T	■	52 O	R	G	■	53 C	E	■	54 Y	O	O
■	■	55 T	H	■	M	■	56 H	57 Y	D	R	58 O	G	E	N
59 J	60 R	■	■	61 D	E	62 N	S	E	■	■	63 H	E	■	E
64 P	E	65 T	■	66 A	G	O	■	67 A	G	68 U	■	69 N	70 N	E
L	■	71 V	O	Y	A	G	E	R	■	72 V	I	S	O	R

Cherilynn A. Morrow

ENRICHMENT

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Saturn Poetry

Two poems are provided to analyze and discuss. Students can write their own poetry about Saturn and Cassini. See Figures 1 and 2 under "Materials" (page 213) for the full-size poem texts to reproduce.

Poem 1 — A Sense of Grandeur

TOPIC

Ask students to analyze and discuss the poem. The discussion can be approached from both the scientific and the poetic aspects. Use information from the *Questions and Answers* (*Appendix 1*) to stimulate students' questions and responses.

ACTIVITY

Have students write their own poems about Saturn, the rings, and the moons, and what Cassini might discover.

A Sense of Grandeur

A giant world of hydrogen,
One gaseous ball in space
A thousand Earths would fit within
This massive, ring-ed place.

This planet's av'rage density
You may indeed me quote
Is less than that of water, so
You see, it'd have to float!

And many moons do orbit round
This cold and golden sphere:
Eighteen of them, so far were found
With 'scopes afar and near.

And oh! the rings, such splendid things
Now thousands, not just one
Whose icy bits and boulders swing,
Reflecting rays of Sun.

What wonders 'wait our robot's eye
A billion miles away?
Such treasures will Cassini spy
With Saturn on display!

— Cherilynn Morrow, 1997

Poem 2 — Sensing the "Titan-ic"

DISCUSSION AND ACTIVITY

Ask students to analyze the poem. Have them write down a list of facts they have discerned from the poem, and also a list of questions they have. See *Background for Poem 2* for supplementary material that includes facts the students might discern, along with supporting notes to assist your discussion with the students and to answer questions that may arise from their studies of the poem. The *Glossary* provides help with technical terms.

Sensing the "Titan-ic"

I. What wonders 'wait our robot's eye
A billion miles away?
What treasures will Cassini spy
With Titan on display?

II. Old Huygens was the first to view
Great Saturn's largest moon.
In 1655 he knew
It kept with Kepler's tune.

III. Then Kuiper would at Titan peer
With "eyes" of infrared,
Detecting there an atmosphere —
Perhaps it wasn't dead!

IV. A prebiotic earthly place?
The thought of this astounds.
A moon, unlike our Old Man's face,
Where nitrogen abounds.

V. No Voyager or Pioneer
Could penetrate the haze
And make the surface features clear,
So now Cassini plays.

VI. Equipped with fancy radar "eyes"
We hope Cassini sees
The Titanscape o'er which it flies,
So veiled for centur-ies.

VII. A probe called Huygens also goes —
Cassini takes it there —
To fall through Titan's winds and flows;
To "taste" and "smell" the air.

VIII. When through the clouds
Our Huygens breaks
A camera wheel will turn,
And all the images it makes
Will serve our quest to learn.

IX. Will mountains drape the scenery?
Will brown organic goo?
Will hydrocarbon oceans be
A chilly ethane stew?

X. Feel you the curiosity?
The deep desire that's shown
When senses of humanity
Extend beyond the known?

— Cherilynn Morrow, 1997

EQUIPMENT, MATERIALS, AND TOOLS

For each student	*Materials to reproduce* FIGURE	COPIES
Paper		
Pencils	1	1 per student
	2	1 per group

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Background for Poem 2

Sensing the "Titan-ic"

- Ask students: Why do you think the poet chose this title? Is there more than one way of interpreting the title? For example, an interpretation might be that we are sensing Titan with Cassini–Huygens instruments (sensors), and sensing the monumental nature of exploring an unknown world. To support their interpretations, have students look up the definition of the word "titanic."

I. What wonders 'wait our robot's eye
A billion miles away?
What treasures will Cassini spy
With Titan on display?

II. Old Huygens was the first to view
Great Saturn's largest moon.
In 1655 he knew
It kept with Kepler's tune.

FACTS

1. Cassini is the name of the robotic spacecraft that will study Titan.

2. Titan is a billion miles away.

3. Titan is Saturn's largest moon, so Saturn must be a billion miles away as well, and Cassini must be going to visit the Saturn system.

4. Huygens discovered Titan in 1655.

5. Huygens knew of Kepler's Laws of orbital motion and applied them to learn of Titan's orbit.

SUPPORTING NOTES

- Saturn is actually a bit less than a billion miles away, but this is the correct order of magnitude. It is more like 0.87 billion miles = 870 million miles (1.4 billion kilometers) from Earth on the shortest straight-line path. However, the Cassini spacecraft will use gravity assists from Venus (twice), Earth, and Jupiter, and thus must travel nearly three times this far before reaching Titan. The trip will take nearly 7 years.

- Titan is Saturn's largest moon by far. Its diameter (5,150 kilometers) is more than three times greater than that of any other moon of Saturn. Ganymede, a moon of Jupiter, is the largest moon in the Solar System; Titan is second largest. Titan's diameter is about 25% larger than that of Earth's Moon. The distance around Titan is a little less than halfway around Earth.

- In spring 1655, Dutch astronomer Christiaan Huygens (HOY-genz) announced the first discovery of a moon of Saturn.

- "Kepler's tune" is an allusion to Kepler's original motivation to reveal the "music of the spheres" as he studied Tycho Brahe's extensive observational data looking for the planetary laws of motion he would eventually discover.

III. Then Kuiper would at Titan peer
With "eyes" of infrared,
Detecting there an atmosphere —
Perhaps it wasn't dead!

FACTS

1. Kuiper looked at Titan with a telescope and used a detector sensitive to near-infrared wavelengths. He discovered evidence of an atmosphere.

2. If Titan has an atmosphere, perhaps there could be life there.

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SUPPORTING NOTES

- Gerard Kuiper (KOY-per), Dutch-born American astronomer, was a pioneer in infrared astronomy. He was interested in finding out if any of the moons in the Solar System had an atmosphere. He studied the light reflected off the 10 largest moons, and in 1944 reported that Titan alone had an atmosphere that could be easily detected. Kuiper observed the spectral signature of methane on Titan.

- We can infer that Kuiper's observation was made no earlier than the 1930s because scientists only observed the sky in wavelengths of visible light until then. Today, we view the Universe across the entire electromagnetic spectrum — radio, microwave, infrared, visible, ultraviolet, x-ray, and gamma ray. See the *Glossary* for more information; the *Appendices* include an illustration of the electromagnetic spectrum.

- With a detectable organic compound like methane in the atmosphere, it was very natural to raise the question about whether life existed there, had existed there, or might yet exist there.

IV. A prebiotic earthly place?
The thought of this astounds.
A moon, unlike our Old Man's face,
Where nitrogen abounds.

FACTS

1. Titan might be like Earth before life evolved here ("prebiotic earthly place").

2. Titan is not at all like our Moon ("our Old Man's face" refers to the Old Man in the Moon).

3. Titan's atmosphere is abundant with nitrogen.

SUPPORTING NOTES

- A "prebiotic earthly place" would be rife with organic chemistry.

- Our Moon has no substantive atmosphere, and to our knowledge neither do any of the other 60 or so moons in the Solar System. Titan is unique and holds the possibility of teaching us something about the origin of life on Earth.

- Before Voyager 1's flyby of Titan in 1980, only methane and a few other simple hydrocarbons had been detected on Titan. Radio and infrared observations from Voyager 1 showed that Titan's thick atmosphere was roughly 90% nitrogen, plus the inert gas argon (at most 1%), and methane (a few percent). On Earth, methane is found bubbling out of marshes or swamps. Voyager 1 also determined that Titan's atmosphere is nearly 10 times deeper than Earth's atmosphere. At Titan's surface, the atmospheric pressure is about 60% higher than that of Earth.

V. No Voyager or Pioneer
Could penetrate the haze
And make the surface features clear,
So now Cassini plays.

FACTS

1. Voyager and Pioneer were spacecraft that visited the Saturn system.

2. These spacecraft could not see through the haze in Titan's atmosphere to discern the surface features.

3. Cassini now comes "into play" with greater capabilities than the earlier spacecraft.

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SUPPORTING NOTES

- The dates of the Saturn flybys of the earlier spacecraft are: Pioneer 11 in 1979, Voyager 1 in 1980, and Voyager 2 in 1981.

- Despite Voyager 1's close pass to Titan, the moon's surface features remained a mystery because spacecraft instruments could not see through Titan's thick haze. Scientists think this uniform haze layer is similar to the smog found over many cities on Earth.

- "Voyager" and "Pioneer" lend themselves to a play on words, suggesting that even these hearty explorers could not reveal the mysterious surface beneath Titan's haze — now there is the promise of Cassini. We are primed to anticipate what the Cassini mission might be able to do.

VI. Equipped with fancy radar "eyes"
We hope Cassini sees
The Titanscape o'er which it flies,
So veiled for centuries.

FACTS

1. Cassini is equipped with a radar imager that will be able to see through haze to measure the surface features of Titan.

2. "So veiled for centuries" signifies that although the moon was discovered more than three centuries ago, we have not had a chance to "see" Titan's surface until now. (Huygens discovered Titan in 1655, the Cassini–Huygens spacecraft arrives at Saturn and Titan in 2004 — 349 years later).

SUPPORTING NOTES

- Cassini's radar instrument is similar to the one used by the Magellan spacecraft in the early 1990s to peer through the thick clouds of Venus and map the surface terrain. Radar does not see like the human eye, but sends out radio waves that penetrate the atmosphere and reflect off the surface back to the spacecraft. Using careful techniques to time the radio waves' journeys to and from Titan, scientists can map surface features and determine their altitudes.

- Information from Magellan's radar imaging of Venus has been brought to the public quite dramatically in the IMAX film, *Destiny in Space*. On a 50-foot screen, the audience experiences what it would be like to fly over the mountains, volcanoes, craters, and chasms of Venus' terrain.

- The Cassini orbiter will make many close passes of Titan over the course of its four-year observational tour of the Saturn system (2004–2008). Indeed, gravity assist from Titan is essential to the capability of touring the system as extensively as is planned.

VII. A probe called Huygens also goes —
Cassini takes it there —
To fall through Titan's winds and flows;
To "taste" and "smell" the air.

VIII. When through the clouds our Huygens breaks
A camera wheel will turn
And all the images it makes
Will serve our quest to learn.

FACTS

1. The Cassini spacecraft carries a probe called Huygens (named for the moon's discoverer).

2. The Huygens probe will be released into Titan's atmosphere where its instruments will analyze ("taste and smell") the winds and composition of the atmosphere.

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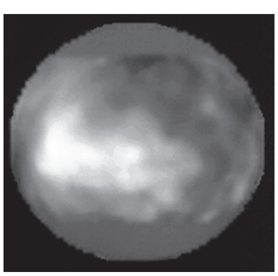
3. As the Huygens probe breaks through the cloud deck, a camera will capture pictures of the Titan panorama.

S U P P O R T I N G   N O T E S

- The Huygens probe, supplied by the European Space Agency, carries a well-equipped robotic laboratory to observe the clouds, atmosphere, and surface of Titan. The probe is like a flattened, rounded cone that measures 2.7 meters (8.9 feet) in diameter at its base.

- As the probe enters Titan's atmosphere, it will begin taking measurements in the haze layer above the cloud tops. As it descends — first on a main parachute and later on a drogue chute for stability — various instruments will measure the winds, temperature, pressure, density, and energy balance in the atmosphere.

- Instruments on the Huygens probe will also be used to study properties of Titan's surface remotely — and perhaps directly, should the probe survive the landing. Many scientists think that Titan may be covered by lakes or oceans of methane or ethane, so the Huygens probe is designed to function even if it lands in liquid. If the battery-powered probe survives its landing, it will relay measurements from Titan's surface until the Cassini orbiter flies beyond the horizon and out of radio contact.



HST infrared image of Titan.

- A map of Titan was composed using infrared data from NASA's Earth-orbiting Hubble Space Telescope (HST). One of the HST instruments detects the Sun's infrared light that passes through the haze and reflects off Titan's surface. The map shows a bright area that may be a large land mass, and the surrounding areas might be mainly lakes or oceans of liquid ethane and methane. Scientists have fortuitously aimed Cassini's Huygens probe for a landing near the edge of the bright area.

IX. Will <u>mountains</u> drape the scenery?
Will brown <u>organic goo</u>?
Will <u>hydrocarbon oceans</u> be
A <u>chilly ethane</u> stew?

F A C T S

1. We wonder what Titan's landscape will be like. Will it have mountains? Organic goo?

2. Will Titan have cold, liquid ethane oceans?

S U P P O R T I N G   N O T E

- Scientists' speculations about what Titan looks like are engaging. Imagine a world with misty orange skies, air with the same primary gas as Earth's air (nitrogen), a colorful surface that may look a little like the "Old Faithful" geyser basin in Yellowstone National Park, large hydrocarbon lakes with their surfaces rippling in the wind, and possibly an enormous ringed planet dimly visible through the high clouds. Perhaps the surface is covered with organic sediment ("organic goo") that has settled down from the clouds where or ganic chemical reactions are powered by the energy of sunlight. Titan temperatures hover around –292° Fahrenheit (–180° Celsius). At these temperatures, organic compounds like ethane and methane are in a liquid state ("chilly ethane stew"). On Earth, these chemicals are gases that bubble out of marshes or swamps.

X. Feel you the <u>curiosity</u>?
The deep desire that's shown
When <u>senses of humanity</u>
<u>Extend</u> beyond the known?

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SUPPORTING NOTES

- Voyager 1 scientists had been so intrigued by what they might find at Titan that they were willing to sacrifice the possibility of sending the spacecraft on to other planets — the close flyby of Titan made it impossible to use Saturn's gravity to send the spacecraft on to Uranus and Neptune. Ask students — what would you be willing to sacrifice to explore an unexplored place?
- As the instruments of the Cassini orbiter and the Huygens probe peer at a never-before-seen landscape, they extend the senses of humanity to a world a billion miles away.

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Materials

Figure 1 **"A Sense of Grandeur"**

Figure 2 **"Sensing the Titan-ic"**

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Figure 1

A Sense of Grandeur

A giant world of hydrogen,
One gaseous ball in space
A thousand Earths would fit within
This massive, ring–ed place.

This planet's av'rage density
You may indeed me quote
Is less than that of water, so
You see, it'd have to float!

And many moons do orbit round
This cold and golden sphere:
Eighteen of them, so far were found
With 'scopes afar and near.

And oh! the rings, such splendid things
Now thousands, not just one
Whose icy bits and boulders swing,
Reflecting rays of Sun.

What wonders 'wait our robot's eye
A billion miles away?
Such treasures will Cassini spy
With Saturn on display!

— *Cherilynn Morrow, 1997*

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Figure 2

Sensing the "Titan-ic"

I. What wonders 'wait our robot's eye
A billion miles away?
What treasures will Cassini spy
With Titan on display?

II. Old Huygens was the first to view
Great Saturn's largest moon.
In 1655 he knew
It kept with Kepler's tune.

III. Then Kuiper would at Titan peer
With "eyes" of infrared,
Detecting there an atmosphere —
Perhaps it wasn't dead!

IV. A prebiotic earthly place?
The thought of this astounds.
A moon, unlike our Old Man's face,
Where nitrogen abounds.

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Could penetrate the haze
And make the surface features clear,
So now Cassini plays.

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We hope Cassini sees
The Titanscape o'er which it flies,
So veiled for centur–ies.

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Cassini takes it there —
To fall through Titan's winds and flows;
To "taste" and "smell" the air.

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Our Huygens breaks
A camera wheel will turn,
And all the images it makes
Will serve our quest to learn.

IX. Will mountains drape the scenery?
Will brown organic goo?
Will hydrocarbon oceans be
A chilly ethane stew?

X. Feel you the curiosity?
The deep desire that's shown
When senses of humanity
Extend beyond the known?

— *Cherilynn Morrow, 1997*

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ENRICHMENT 4

Mythology of Saturn

What we call mythology was a living truth for other peoples in other times. Images of beauty, innocence, courage, and honor handed down from antiquity attract us; images of depravity, cruelty, violence, and evil in the same tales repel. The ancients, just like ourselves, wished to perceive "divine order" in the chaotic world of nature and humanity. It was often the poets who spun the narratives that explained the creation of the Universe and the place of humans in it. These narratives provided answers to the deep questions posed in days long past.

The ancient Roman culture was a powerful civilization; thus, European culture accepted Roman names for the visible planets and many of the stars. As telescopes improved what could be seen in the sky, European astronomers continued to choose names from Roman mythology. Modern astronomy followed the European tradition of selecting Roman names for new celestial objects. Today, names are selected and approved by a group of astronomers (the Working Group for Planetary System Nomenclature of the International Astronomical Union). Two exceptions are: comets, which take the names of their discoverers; and asteroids, which are named by their discoverers with the approval of the Working Group.

Almost all human cultures have their own names for, and stories about, the Sun, the Moon, the planets, and the stars. For example, the ancient Egyptians named the planet we call Saturn after their god of light, Horus, who often appeared in the form of a hawk. Many of the star names that astronomers use today are ancient Arabic names.

Saturn about to devour one of his children, from a woodcut published in Germany in 1599.

TOPICS

Collect sky and star myths of many cultures through libraries, museums, observatories, the Internet, and by speaking with persons from various cultures. Share the star stories and have students discuss the similarities and differences. For example, both ancient Arabs and Native Americans imagined the constellation of the Big Dipper as part of a large bear. Have students consider: if western culture had used names for the stars and planets of, say, Hindu gods or Australian spirits, would astronomical research change? Would we in the 20th century view the Universe differently? It's clear that despite diverse visions and interpretations, the composition of the Saturn system, indeed the Solar System and beyond, remains dependent on physical laws. The real Universe is accessible to scientific observation and exploration, no matter what names we use.

Background for Enrichment 4

Naming Distant Worlds

The ancient religions, which lost their grip on humans even before the Classical Age was over, continued to be useful in providing a reservoir of appellations for the objects seen in the sky. The planets visible to the naked eye received the names of the principal gods of the Roman pantheon. The custom of giving the names of the gods and heroes of antiquity to newly observed celestial objects originated in the 17th century with the discovery of the four large moons of Jupiter, which were named after companions of the god Jupiter. Five moons of Saturn were also discovered in the 17th century, but they didn't receive their mythological names immediately. Christiaan Huygens simply called the satellite he had found *Saturni luna* ("Saturn's moon"), and Jean-Dominique Cassini named the four moons he discovered *Lodicea sidera* ("stars of Louis XIV"). The satellites also received numerical designations, 1 through 5. The naming convention for Saturn's moons had to wait until 1847, when the astronomer Sir John Herschel, the son of William Herschel (discoverer of moons 6 and 7), proposed that the numerical designations be supplanted with the names of Saturn's "brothers and sisters, the Titans and Titanesses."

In Search of the Real Saturn

Saturn (also known as Saturnus) has been represented as a Roman god of harvest and described as a strong old man with a long gray beard who wields a scythe. In reality, there is extensive controversy regarding the origins of Saturn and his Greek counterpart, Kronos (in Latin, Cronus), who has frequently been represented as Father Time. It is important to understand that the gods and mythological creatures of ancient Greece and Rome were not always well-defined personalities. They were composites of multiple myths and local traditions that varied from place to place and changed over time. In addition, the interpretations of "modern" scholars have been influenced by the surviving works of the ancient poets (most notably Homer and Hesiod) and accuracy has been limited by translations of ancient languages into English. Many of the mythology books available today base their conclusions on translations of stories that, despite their popularity, were never historically correct. Some of the ancient myths were filled with more violent and racy themes than can be found in modern movies and soap operas, encouraging traditional classic scholars to "modify" the stories into more socially acceptable forms.

Current research provides no evidence that the Roman god Saturn was a harvest god, as popularly represented. In fact, few stories about Saturn survive. The scythe carried by Saturn was not necessarily a farm implement. Scythes were also used as weapons, particularly for the beheading of monsters and giants. Kronos may have become identified with Saturn because the Greeks and Romans held similar festivals, usually at harvest time, to honor their respective gods. The Kronia and Saturnalia celebrations were alike in several ways. The modern celebration of Christmas may have originated with the Saturnalia holiday, when evergreen trees were decorated with ornaments and candies, gifts were exchanged among friends and family, and it was customary to forgive debts and make donations to charities.

The Greek god Kronos had a violent family history. Gaia (the Earth) gave birth to Ouranos (the Sky). With Ouranos, Gaia then produced 12 immortal children (the Titans). Kronos was her youngest child and described as "devious and devising, the most terrible of her children." Gaia was not happy with Ouranos, so she convinced Kronos to attack and castrate his own father (who was also his half-brother!) with a stone-bladed sickle she provided. Ouranos could no longer father children and was vanquished.

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Kronos became supreme ruler of the world and married his sister Rhea. However, both his mother and father had foretold that Kronos would be dethroned by his own child. To prevent the prophecy from coming true, each time Rhea gave birth to one of his children, Kronos would swallow the baby whole. Grief-stricken and enraged by the loss of her children, Rhea escaped to a cave in Crete, where she gave birth to her son Zeus. Rhea returned to Kronos with a baby-sized stone wrapped in a blanket that Kronos mistook for his son and swallowed.

When Zeus, raised in secret by nymphs, was full-grown, he conspired to drug the food eaten by his father, Kronos. When Kronos became ill, he regurgitated the stone and then all the children he had swallowed (miraculously, as immortals, still alive). With his rescued sisters and brothers, Zeus waged a long and bloody war against his father and all the other Titans. Zeus won the war and imprisoned his father and the Titans in Tartarus (a great fortress of iron with gates of unbreakable stone, located in a dismal pit at the edge of Earth). Zeus and his siblings then ruled the world from Mount Olympus.

So where did the image of Saturn as old Father Time come from? The Greeks and Romans both named the stars and planets after their gods and all sorts of mythological creatures. A bright "star" that appeared to move slowly across the field of other stars was named Kronos by the Greeks. Its progression across the sky became associated with the inevitable passing of time and the seasons. Perhaps people confused and combined Kronos with some lesser known deity. Whatever the reason, the modern image of Saturn as old Father Time is as valid as any ancient myth. It is the very nature of myths and stories to change and become whatever people imagine them to be.

Many Names for Saturn

Here are some names for Saturn in various languages, with pronunciations transliterated into English.

Albanian	*Shtundi*
Arabic	*Zuhal* ("one that withdraws") or *ath-Thāqib*
Basque	*Saturnu*
Chinese	*T'u-hsing* ("earth-star") (Mandarin)
Cyrillic	*Byamba* or *Sancir*
Egyptian	*Heru-ka-pet* ("star of the West which traverseth heaven"; Horus)
French	*Saturne*
Gaelic	*Satarn*
German	*Saturn*
Greek	*Phaínōn* ("luminous")
Hebrew	*Shabtha'i* or *Kiwan*
Hungarian	*Szaturnusz*
Japanese	*Dosei* ("earth, soil")
Korean	*T'osong* ("earth, soil")
Latin	*Lucidus, Sāturnus, stella solis*, or *Sāturni*
Mongolian	*Bimba* (Tibetan-derived), or *Sanicar* (Sanskrit-derived)
Persian	*Zahl*
Russian	*Satúrn*
Sanskrit	*Sani* ("slow-moving"), *Sauri* ("hero" or "son of the Sun"), plus 26 other names!
Spanish	*Saturno*
Sumerian	*Lu-bat-sag-ush* ("omen [planet]–steady" or "omen–slow-moving")
Tibetan	*Snenpa*
Turkish	*Zuhal*
Vietnamese	*Tho-tinh* ("earth, soil")
Welsh	*Sadwrn*

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Moons of the Planet Saturn

The first of Saturn's moons to be discovered — by Christiaan Huygens in the mid-17th century — was named "Titan" by Sir John Herschel 200 years later. The original numerical designations for the satellites had become confused and cumbersome, and Herschel's plan was to name the moons after the god Saturn's siblings. Titan is Saturn's largest moon, so it seemed appropriate to choose a name that recognizes this characteristic. The four moons found by Jean-Dominique Cassini were named Iapetus, Rhea, Dione, and Tethys. The inner satellites, discovered by Sir John's father, William Herschel, were named Enceladus and Mimas. In the 19th century, two more satellites were found and were named Hyperion and Phoebe. In the 20th century, Epimetheus and Janus were discovered; observers confused them at first because the two moons exchange orbits. Additional satellites were found in the Voyager images of the 1980s: Pan, Atlas, Prometheus, Pandora, Telesto, Calypso, and Helene. To date, Saturn has 18 named satellites, but only Iapetus, Rhea, Tethys, Hyperion, and Phoebe are Titans as portrayed by the ancient poet Hesiod. Thus, John Herschel's original proposal — to name all of Saturn's moons after the Titans — was fulfilled only in part. Individual satellites are listed below, in order of increasing distance from Saturn.

PAN was a satyr (a creature resembling a man with the hind legs and hooves of a goat). He was the Greek god of nature and the forest.

ATLAS (AT-less) was a son of Iapetus. After the defeat of the Titans, Zeus (zoos) ordered Atlas, "at earth's uttermost places, near the sweet-singing Hesprides" to uphold the vault of the sky. The poet Hesiod refers here to the Pillars of Hercules, the westernmost end of the world known to the ancient Greeks. Atlas was so strong that he supported the weight of the Universe on his shoulders.

PROMETHEUS (pro-MEE-thee-uss) was a son of Iapetus, presented by Hesiod as an immortal who sided with the mortals and as a prankster who liked to annoy Zeus, his cousin. The ultimate annoyance was stealing "the far-seen glory of weariless fire" and giving it to mankind. For this, Zeus fastened Prometheus to a mountain in the Caucasus, and he let loose on him "the wing-spread eagle, and it was feeding on Prometheus' imperishable liver, which by night would grow back to size from which the spread-winged bird had eaten in the daytime."

PANDORA (pan-DOR-uh), whose name means literally "many gifts," was a work of art who was transformed into a human by the gods. Her curiosity was said to have loosed all manner of ills upon the world when she let evil creatures out of a locked box; however, she is also responsible for "hope" entering the world ("hope" had been the last "creature" in the locked box).

EPIMETHEUS (epp-ee-MEE-thee-uss), brother of Prometheus, was a Titan and one of the three original judges of dead souls. Epimetheus married Pandora.

JANUS (JANE-uss) was an exalted Roman god, a figure of great antiquity and obscure origin. Always represented as having two faces — one looking forwards, the other backwards — Janus presided over the past, present, and future, over gates, doorways, entrances, and beginnings in general, and over war and peace. At every sacrifice, in every prayer, he was the first god invoked, taking precedence before Jupiter. When war was declared, the portals to the sanctuary of Janus on the Roman Forum were opened. The portals were again closed on the declaration of peace. During the entire history of Rome, this happened on only a handful of occasions. As the most ancient of kings, Janus is supposed to have given the exiled Kronos a warm welcome in Italy, and to have offered Kronos a share of the royal duties.

MIMAS (MY-muss) was a giant and son of the Titans, those older gods preceding the Olympian gods led by Zeus (whom the Romans called Jupiter). During the war in which Zeus and his kind conquered and vanquished the Titans, Mimas was killed by the crippled god Hephaestus (heh-FESS-tus), called Vulcan by the Romans. Hephaestus was a blacksmith and poured molten metal from his forge onto Mimas, who instantly became petrified into a massive rocky hill.

ENCELADUS (en-SELL-uh-duss), like Mimas, was a giant and son of the Titans. His name literally means "battle-cry." He was human in appearance, except that he had serpents (large snakes) for feet! In the war between the Olympian gods and the older Titans, the goddess Athena struck Enceladus with a large rock, knocking him unconscious. She then buried him alive under so much rock that the island of Sicily was formed in what is now Italy. Enceladus struggled to escape, but remained trapped under all the rocks. It was believed that his violent movements caused earthquakes and the hiss of his breath produced the steam and periodic eruptions of Mt. Etna, a volcano on Sicily.

TETHYS (TEE-thiss) was the wife of the powerful Titan Oceanus (oh-SEE-uh-nus) who ruled the seas before the Olympian god, Poseidon (poe-SIGH-don), called Neptune by the Romans. Tethys is closely associated with the Babylonian goddess Tiamat, and was known as "the lovely Queen of the Sea." She was the mother of all sea nymphs and of all the rivers on Earth. She was also the mother of Meatus (mee-AH-tus), a minor goddess who represented practical wisdom.

TELESTO (tel-LESS-toe) was a muse whose "specialty" has been forgotten (muses were minor goddesses that represented some human activity, such as music or medicine).

CALYPSO (kuh-LIP-soh) was a nymph whose name means "I hide." She lived alone on her island until she fell in love with the mortal sailor and explorer Odysseus (called Ulysses by the Romans; his name means "one who suffers"). Calypso helped Odysseus find his way home after his long voyage and many dangerous adventures.

DIONE (die-OH-nee) was an ocean nymph and possibly a daughter of the Titan Atlas. Dione was loved by Zeus before he married the goddess Hera (HERE-uh). Dione became the mother of Zeus' daughter, the Olympian goddess Aphrodite (aff-roe-DIE-tee), called Venus by the Romans. Some believe she later became a powerful Earth goddess who ruled over both land and sea.

HELENE (huh-LEE-nee) was a powerful Indo–European Earth goddess who, with her twin sister Clytemnestra (kly-tem-NESS-tra), had been hatched from a large egg. Her brothers, the famous Gemini twins Castor and Pollux, had also been hatched from a large egg. The Greeks believed Helene to be the Helen of Troy who was so beautiful that the Trojan War started over her.

RHEA (REE-uh) was the most important Earth goddess of Asia Minor. She was the wife of the Titan Kronos (who the Romans called Saturn!) and the mother of the Olympian gods Zeus (called Jupiter by the Romans), Poseidon (called Neptune by the Romans), Hades (HAY-dees; called Pluto by the Romans), and the goddesses Demeter (deh-MEE-ter), Hera (HERE-uh), and Hestia (HESS-tee-uh). Rhea is closely associated with Cybele (SIB-oh-lee) who was also known as the great mother goddess Terra (Earth). Rhea was compassionate towards mortals and was often called "the good goddess."

TITAN (TIE-ten) is not a single deity, but a generic name for the sons of Ouranos (oo-REH-nuss) and Gaia (GAY-uh). Other treatments of the myth of the Titans (in addition to that of Hesiod) have survived. In the Orphic version, the Titans are the ancestors of the human race. The Titans devoured the limbs of Dionysos (die-oh-NYE-suss), the son of Zeus by Persephone (per-SEH-fon-ee). Zeus intended the child to have dominion over the world. Enraged, Zeus struck the Titans with lightning. The fire burned them to ashes, and from the ashes man was formed.

HYPERION (high-PEER-ee-on) was a Titan, one of the older gods that ruled before Zeus and the other gods of Mount Olympus. He was the father of the Sun, the god Helios (HEE-lee-os); the Moon, the goddess Selene (suh-LEE-nee); and the Dawn, the goddess Eos (EE-os). Helios ruled before Apollo, the Olympian god of the Sun, and Selene ruled before Artemis (AR-tuh-muss), the Olympian goddess of the Moon. Hyperion's name literally means "dweller on high."

IAPETUS (eye-APP-eh-tuss) was a Titan, one of older gods that ruled before the Olympian gods. He was the father of the Titan Atlas. Iapetus was also the father of the three Titans who judged the souls of the dead in Hades (the underworld). The three judges were Menoetius (men-oh-EE-shuss), Prometheus, who gave fire to humankind, and Epimetheus, the husband of Pandora. Iapetus fought Zeus in the war between the Titans and the Olympian gods. He was vanquished and imprisoned with the other Titans after they lost that war.

PHOEBE (FEE-bee) is another name for the goddess that the Greeks knew as Artemis and the Romans called Diana. She was the youthful goddess of Earth's Moon, forests, wild animals, and hunting. Sworn to chastity and independence, she never married and was closely identified with her brother, Apollo (God of the Sun, prophecy, music, and poetry).

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