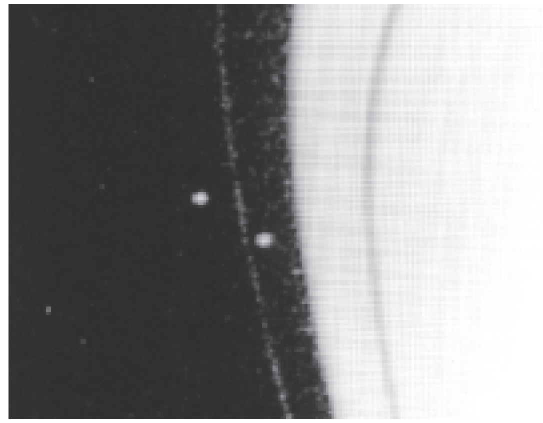
LESSON 3

3–4 hrs

Moons, Rings, and Relationships

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.

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*

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

LESSON 3

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.

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Lesson Plan

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.

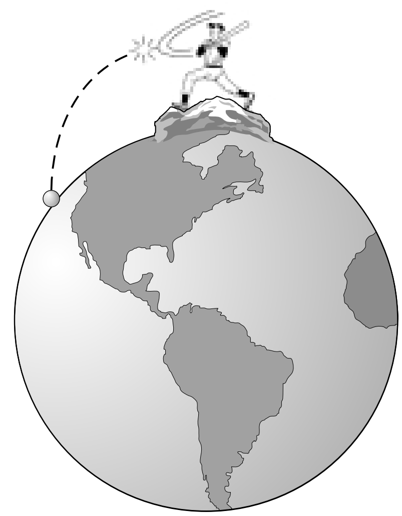
4. To test their predictions, have each student group devise an experiment. When they have completed their planning, distribute one large plastic or rubber ball per group and have them conduct the experiments.

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.)

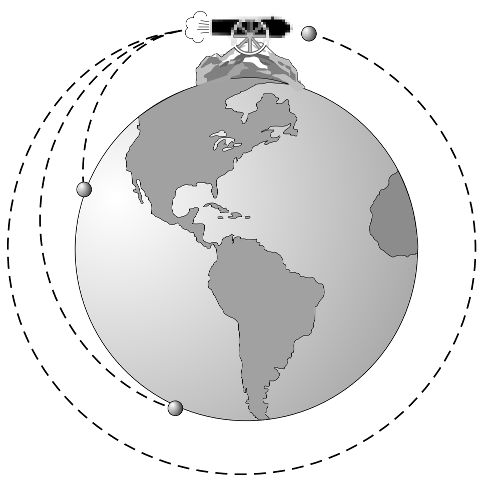
7. Display a transparency of Figure 1, which is the illustration of the baseball player (below) but without the complete trajectory of the baseball. Ask the students to imagine an enlarged mountain on Earth with a baseball player on top who hits a ball that is pitched from space. Tell students that the 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?

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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?

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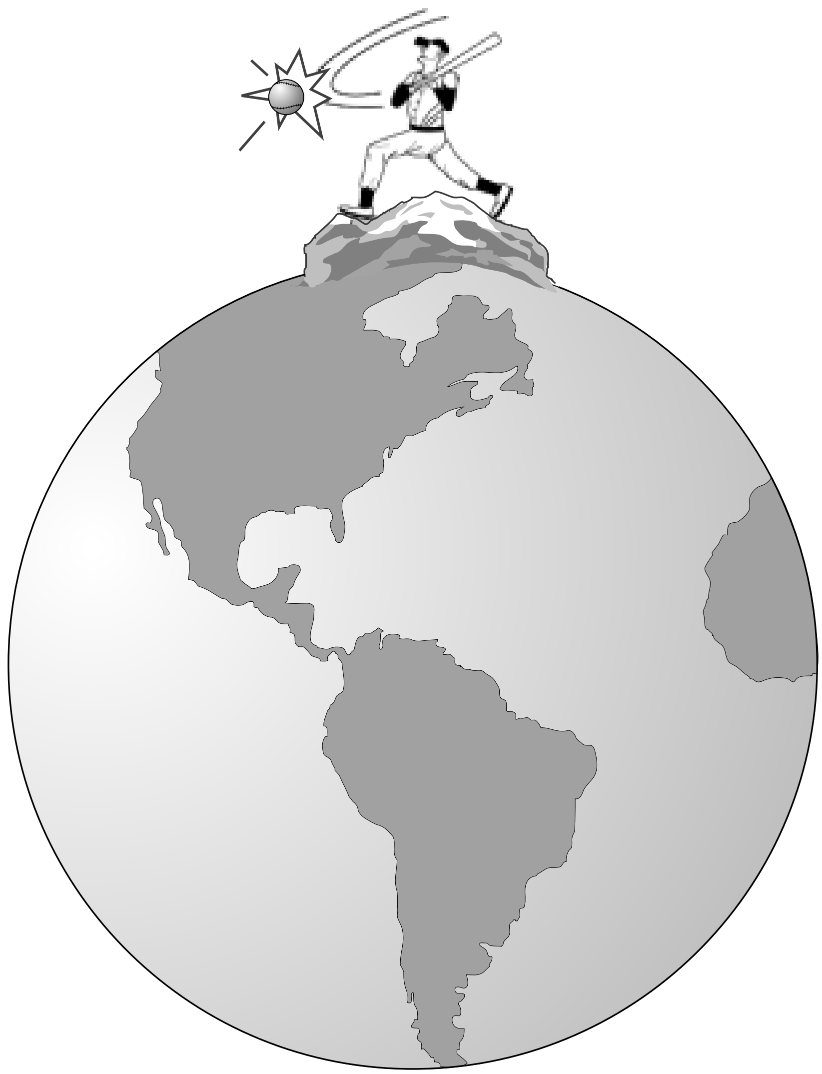
Materials

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

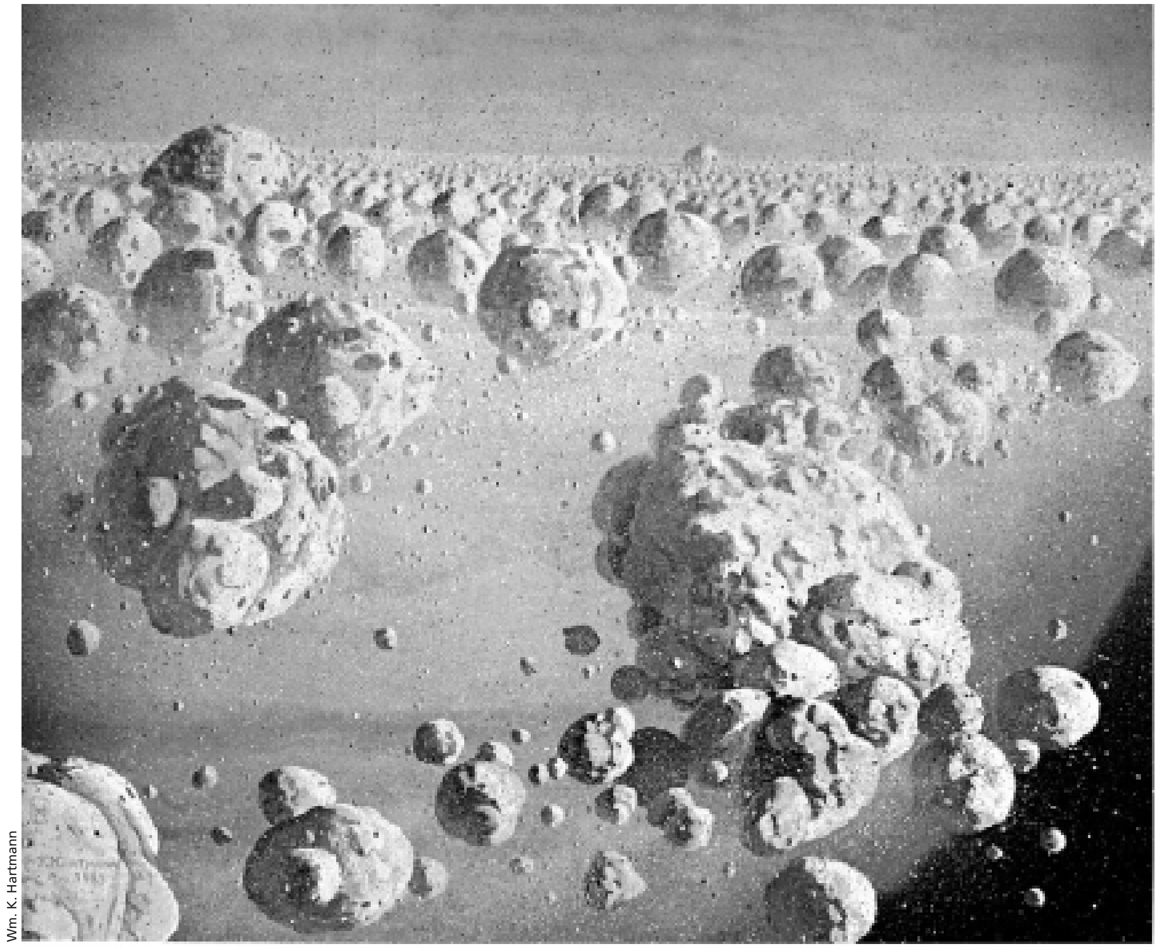


LESSON 3

Figure 2

Cannon Shooting a Cannonball

LESSON 3


Wm. K. Hartmann

LESSON 3

Figure 4

Moon and A Ring Data — for Students

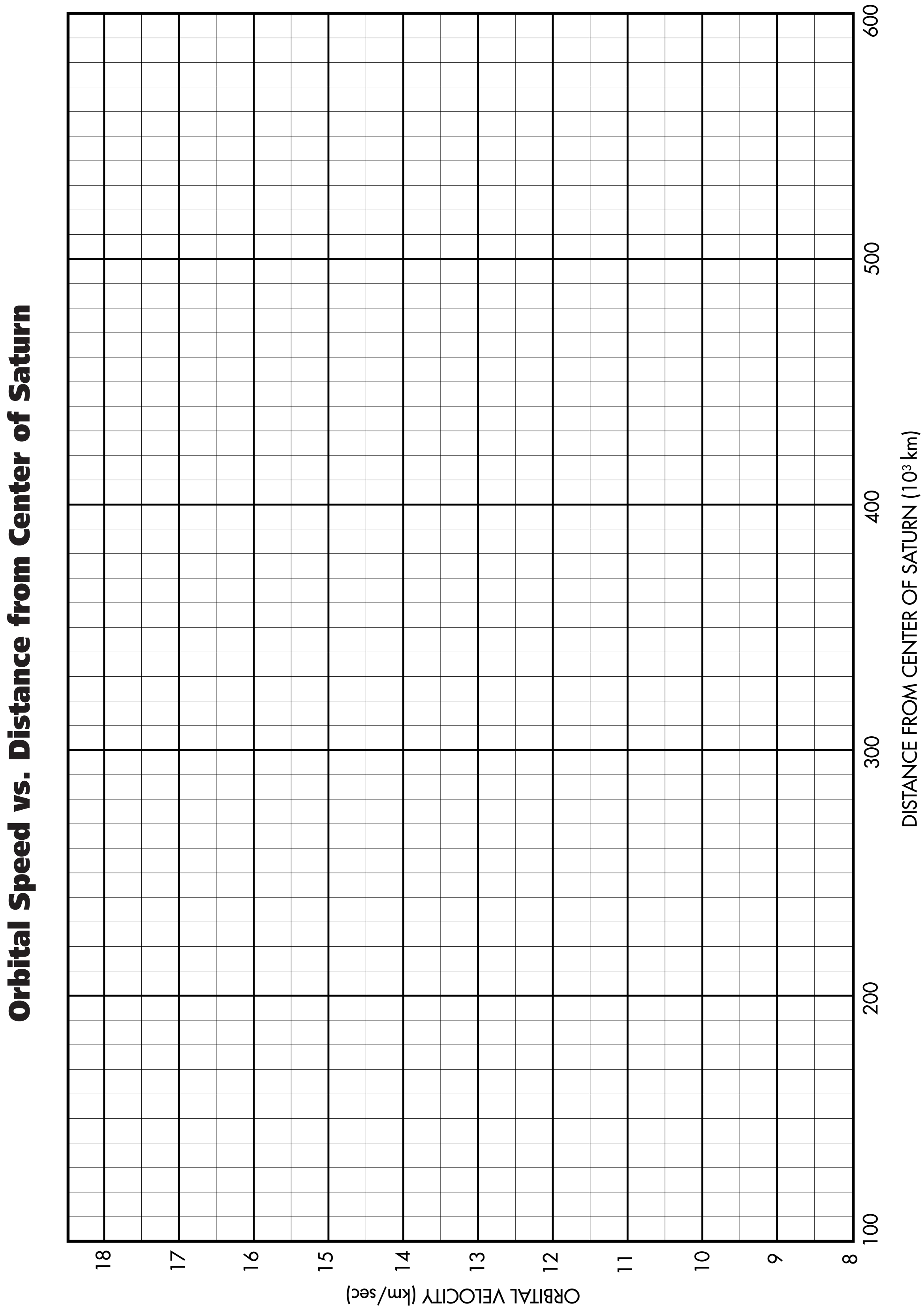
Use this information to complete your plot of Orbital Speed vs. Distance from Center of Saturn.

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
Prometheus	Shepherd moon; helps keep the F ring narrow	139.4	16.53
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

LESSON 3

LESSON 3

Figure 7

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

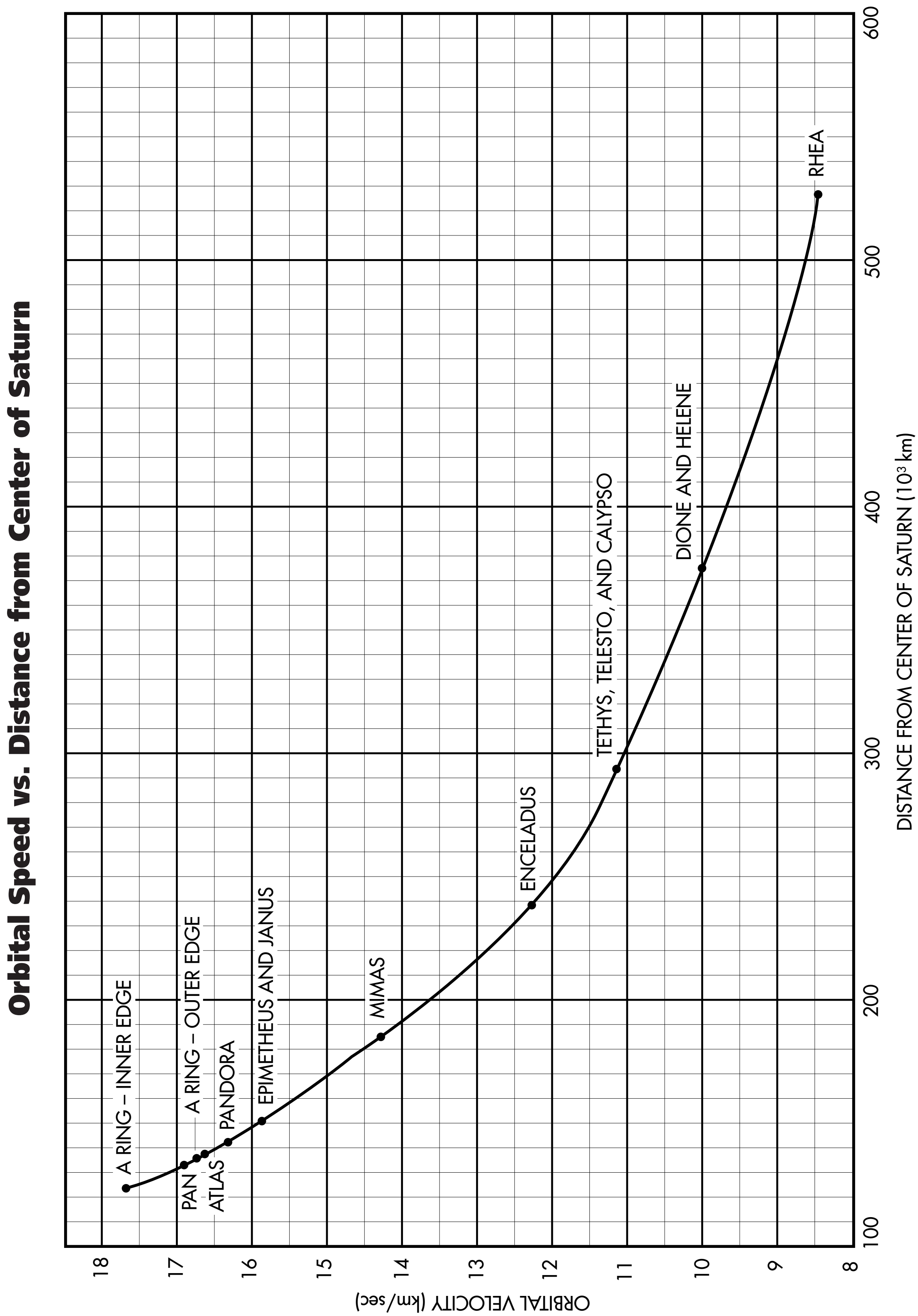


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Figure 8

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

Figure 9

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

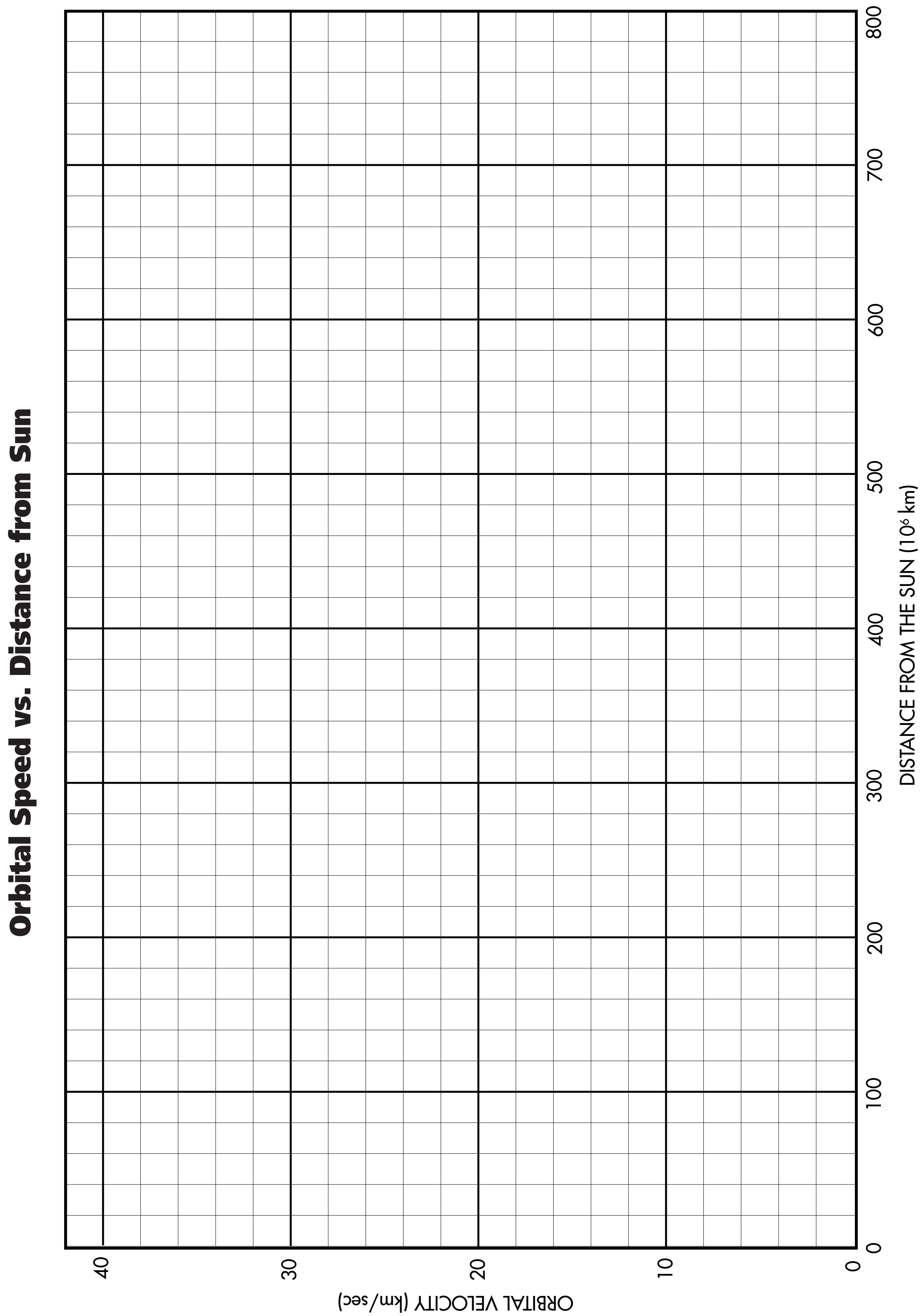

Figure 10

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