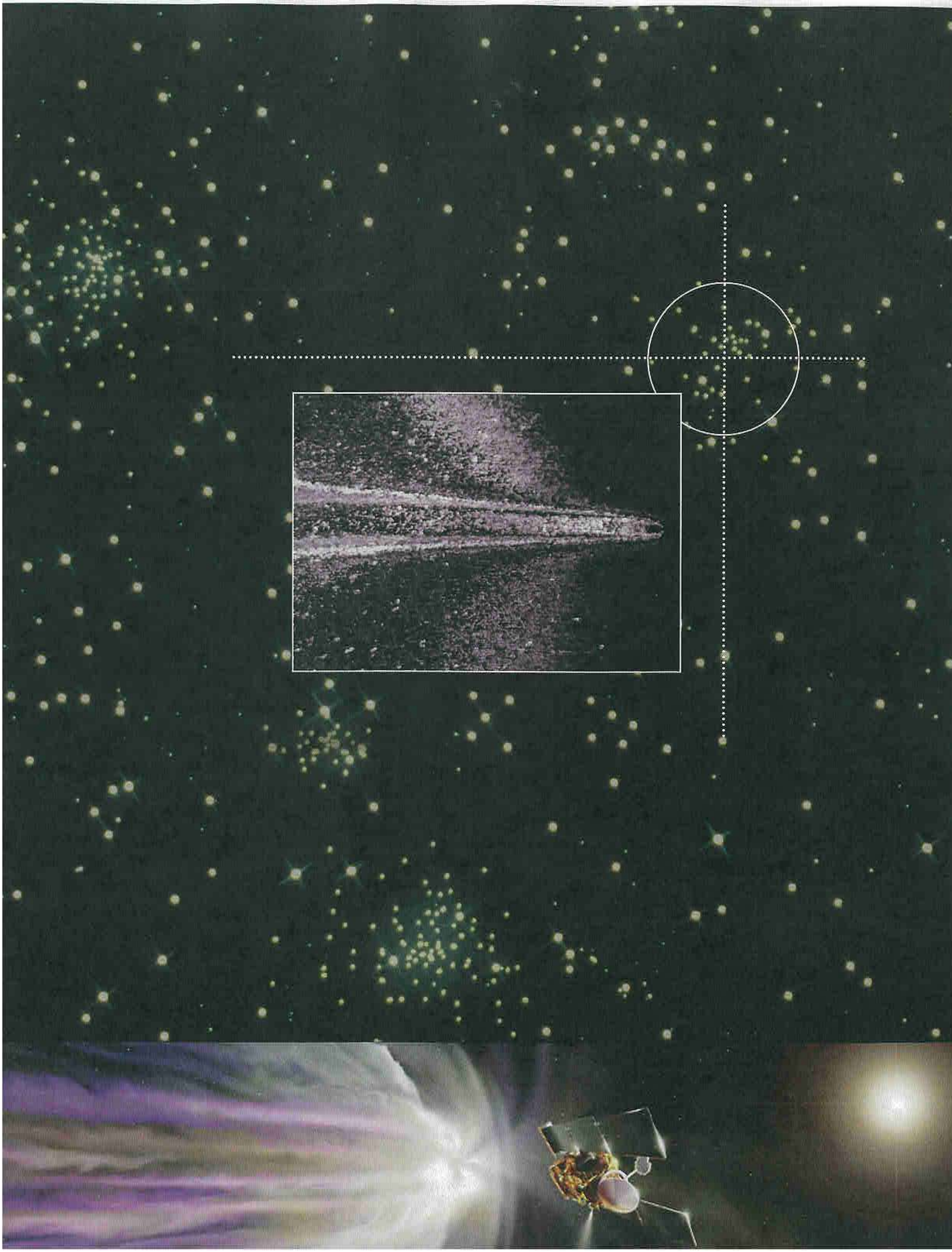
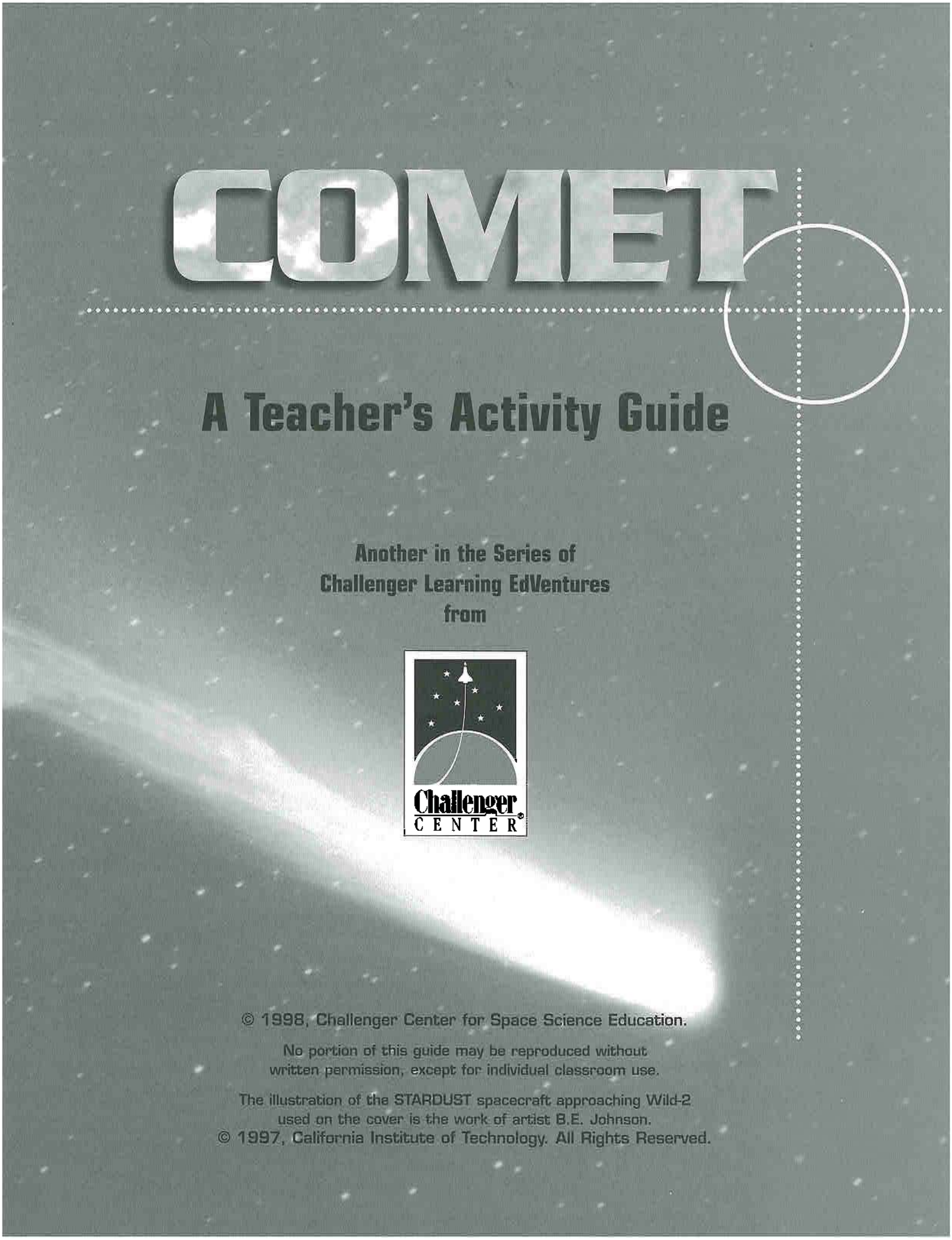
COMET

CHALLENGER CENTER FOR SPACE SCIENCE EDUCATION





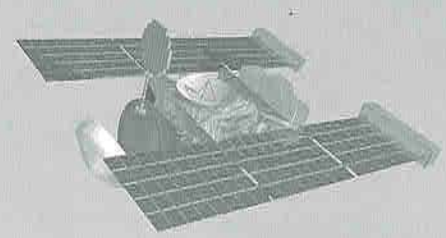
COMET

A Teacher's Activity Guide

Another in the Series of
Challenger Learning EdVentures
from

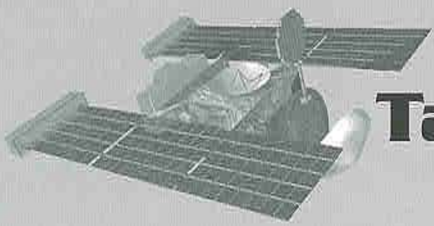
Challenger CENTER

The illustration of the STARDUST spacecraft approaching Wild-2 used on the cover is the work of artist B.E. Johnson.



The creation of these educational activities was made possible through the education and public outreach support of NASA's Discovery Mission Program and the Jet Propulsion Laboratory's STARDUST Mission.

For more information on STARDUST visit http://stardust.jpl.nasa.gov



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Dear Educators

Dear Classroom Educator,

At Challenger Center we believe that in every young mind there is a window on the universe. Encourage that window to open and great things begin to happen. Young people become explorers. We believe exploration is the essence of learning.

The key to opening that window and exploring new frontiers has to do with tapping a young person's natural curiosity. That curiosity is what powers the desire to ask questions and pursue answers.

To help teachers spark that curiosity, Challenger Center has assembled some of its most popular classroom activities into a series called *Learning Frontiers* using the popular space themes of Comets, Earth, Mars, and Moon. Studies have shown that space is one of the most popular and effective themes used to capture students' interest.

Since its founding in 1986, Challenger Center has used the theme of space to engage students in this pursuit, and has been nationally recognized for its innovative approaches to inspiring young people to explore. Challenger Center believes that when all is said and done, there are no tools, no programs, no techniques that will ever replace the direct intervention of a great teacher in a student's life.

That is why we hope you will find the *Learning Frontiers* activities engaging, relevant, and—most of all—fun. These scientifically sound, educationally rich activities were developed to provide teachers with as much flexibility as possible when it comes to classroom implementation. To facilitate classroom use, each activity is correlated to national education standards and formatted to help teachers easily find objectives and key concepts.

We would also like to give a special thanks to the NASA Discovery Mission Program and the Jet Propulsion Laboratory's STARDUST Mission for making the creation of these educational materials possible.

We hope these activities will help you open your students' "windows" by using them to create new "learning frontiers" in a way that is appropriate for your classroom. Inspiring. Exploring. Learning. It's Our Mission.

Best Regards,
The Challenger Center Team

In addition to being a great collection of classroom activities for any teacher to introduce the robotic exploration of Comets, this guide was designed to also help prepare students

Challenger Center's Educational Pedagogy

Challenger Center's educational pedagogy promotes scientific literacy by encouraging exploration and inquiry and exciting young people about knowledge and learning. Challenger Center believes exploration is the essence of learning. Our goal is to give teachers the tools to create a "learner-centered" environment and to provide materials that are a framework for embedding subject content in a meaningful and motivational context.

Using our interdisciplinary, inquiry-based approach that incorporates national educational standards, Challenger Center strives to:

- Increase student interest in science, mathematics, and technology.
- Give abstract concepts concrete meaning.
- Help students develop realistic processes of cooperation, communication, critical thinking, and problem solving.
- Increase student autonomy and responsibility for their own learning.
- Encourage students to develop positive perspectives about learning.
- Increase student commitment to learning.
- Help students pose questions and find pathways to answers.

Challenger Center programs are designed to reflect academic standards such as the National Science Education Standards by the National Research Council and the Curriculum and Evaluation Standards for School Mathematics by the National Council of Teachers of Mathematics.

Activity Matrix for National Science Education Standards and Curriculum and Evaluation Standards for School Mathematics (Grades 5-8)

	NATIONAL SCIENCE STANDARDS	Unifying Concepts and Processes	Systems, order, and organization	Evidence, models, and explanation	Change, constancy, and measurement	Evolution and equilibrium	Form and function	Science as Inquiry	Abilities necessary to do scientific inquiry	Understanding about scientific inquiry	Physical Science	Properties and changes of properties in matter	Motions and forces	Transfer of energy	Earth and Space Science	Earth's history	Earth in the Solar System	Science and Technology	Abilities of technological design	Understanding about science and technology	Science in Personal and Social Perspectives	Science and technology in society	History and Nature of Science	Science as human endeavor	Nature of science	History of science	NATIONAL MATHEMATICS STANDARDS	Mathematics as Communication	Mathematical Connections	Patterns and Functions	Algebra	Measurement
Famous Comets			•	•			•									•			•	•		•		•		•						
Cookin' Up a Comet			•	•			•		•	•		•	•	•																		•
Cometary Orbits			•	•	•		•						•																	•		
Investigating Falling Particles			•	•	•	•	•		•	•		•	•	•			•		•	•		•		•	•	•		•				•
Particle Collection			•	•	•	•	•		•	•		•	•	•			•		•	•		•		•	•	•		•				•
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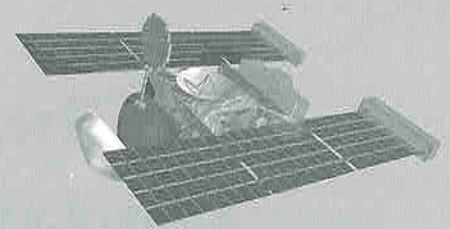
Comet



Comets, with their blurry heads and luminous tails, are mysterious travelers originating from the depths of our Solar System. They appear somewhat suddenly and orbit the Sun in a highly elliptical path, a path unlike any other object in the sky. Historically, comets were believed to be omens for things to come. The fuzzy lights with streaming tails would appear without explanation of where they came from and why, so societies would create their own explanations. A comet could be a sign of war, famine, or even the death of a great leader. Because events such as these happened frequently enough, it was inevitable that many prophecies happened in accordance with a comet sighting.

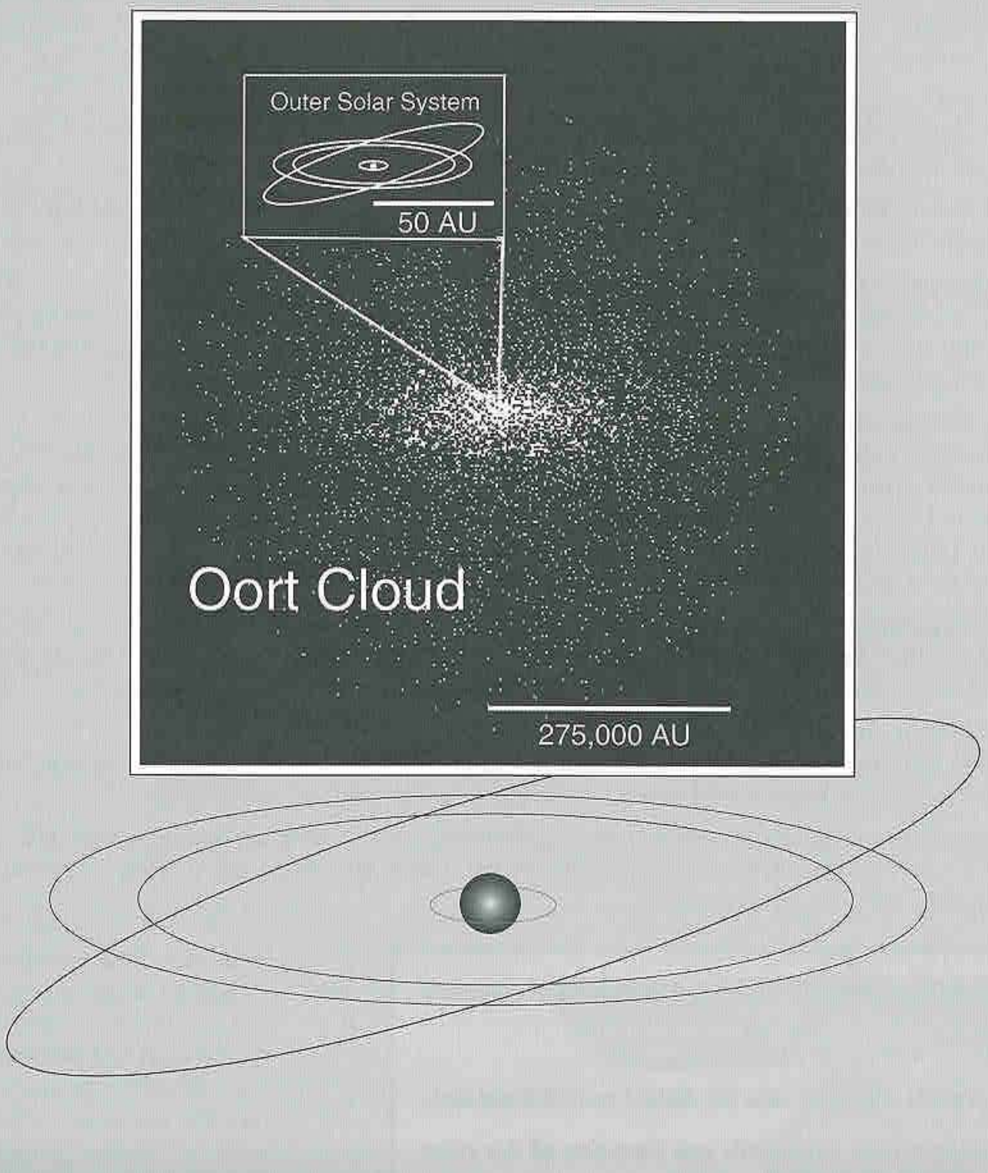
Sir Edmund Halley took the mystique out of the "prophecy-delivering" objects in the sky. He contributed to our present day understanding of comets in 1705 by deducing that some comets return periodically. He looked at past records of comet sightings and theorized that several comets were in fact one comet that appeared every 76 years. He correctly predicted this comet's return in 1758, and sixteen years after his death, his prediction came true. Although he did not discover the comet, it is still called Halley's Comet in his honor.

Comets visible to the naked eye appear, on average, once a decade. Some comets, such as Hale-Bopp have such long bright tails that they are easily spotted. A person is lucky to see one or two such comets in a lifetime. Astronomers both professional and amateur have studied the skies for centuries, investigating the passage of comets in the heavens, and searching the skies for new comets to bear the discoverer's name. Much of our present day knowledge about comets results from this research. In addition, six spacecraft studied Comet Halley the last time it passed by Earth in 1986. Many upcoming missions to comets during the next ten years will lead to new insights and discoveries about these cosmic travelers.

Many comets reside in an area past the orbit of Neptune called the Kuiper Belt. They are so far away and so small and dark that astronomers have a hard time detecting them. Most comets, however, lie in the Oort Cloud which begins past the orbit of Pluto and continues halfway to the nearest star. Unlike the Kuiper Belt, whose inhabitants appear to orbit in an area shaped much like a hula hoop, the Oort Cloud is believed to be a spherical shell of cometary particles. No one has been able see a comet while it is in the Oort Cloud, but the orbits of observed comets indicate that it is there and contains about one *trillion* comets. On occasion, a gravitational disturbance causes one of these bodies to begin a long journey toward the inner Solar System. When comets approach the Sun, their ices begin to sublime, that is, change directly from solid to gas. This forms a cloud of gas and dust particles around the nucleus. The solar wind and radiation pressure pushes these particles away from the nucleus, forming two tails—one of gas and one of dust. When sunlight reflects off of these particles, we can see the comet from Earth much more easily. Some comets will end up crashing into the Sun or will collide with a planet, like comet Shoemaker-Levy 9 did with Jupiter in 1994. Some scientists suspect that some comets may get flung out of the Solar System entirely.

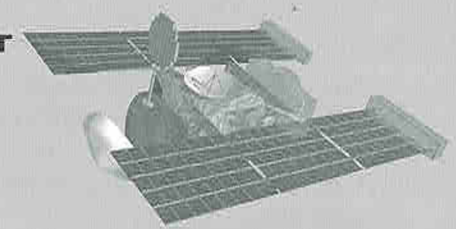
When a comet impacts a planet or another body in the Solar System, it may cause major changes in atmospheres and ecosystems. The landscape of our cratered Moon was formed by many years of comets and asteroids impacting it. Earth has been hit by comets as well. One theory for the extinction of the dinosaurs is that the Earth was hit by a comet or asteroid so large that it abruptly changed Earth's climate, wiping them and numerous other species out.

Comets are the oldest, most primitive objects in the Solar System. They are remnants from the nebula that formed our Solar System. These remnants may have served as building blocks in the formation of planets in our Solar System. They are organically rich, providing molecules that could have contributed to the formation of life. The volatile elements (ices) comets contain may play a role in forming atmospheres and oceans. For these reasons and many more, scientists want to study particles from comets to gather information that may shed light on the evolution of Earth and the formation of the Solar System.



FACT SHEET

Comet



The coma is the head of the comet. It contains the nucleus and a large halo of gases and dust that sublimes off the icy nucleus as the Sun heats the comet.

The solar wind blows a gas tail off the coma, directly opposite from the Sun.

Dust particles are blown off the coma by pressure from sunlight. These particles form a second, gently curving dust tail.

Comets are literally dirty, cosmic snowballs—small, irregularly shaped, chunks of rock, various ices, and dust. The nucleus of a comet is usually only a few kilometers wide. When a gravitational force disturbs a comet in the Kuiper Belt or the Oort Cloud, it may begin a long, eccentric orbit that brings it close to the Sun.

Where do comets come from?
Short period (less than 200 year orbits) comets are believed to originate in the Kuiper Belt, located beyond Neptune's orbit.

Long period (more than 200 year orbits) comets are thought to originate in the Oort Cloud, which scientists theorize is a spherical cloud of comets that stretches halfway to the nearest star.

Do all comets have tails?
No! Comets only develop tails when they travel within the inner Solar System (near or within the orbit of Jupiter) because there the Sun's energy is strong enough to sublime off the dirty ices into gases and dust.

Why are comets important?
Comets are believed to be the oldest, most primitive bodies in the Solar System. They are remnants preserved from the earliest days of star and planetary formation. From what we know of their composition, comets may provide clues about the building blocks of life and of our Solar System. In addition, the impact of a large comet could cause major changes in the climate of a planet or a moon.

How frequently do "spectacular" comets become visible?
"Spectacular" comets come along only a few times in a lifetime—roughly every 20 years or so. This assumes that "spectacular" is as bright or brighter than a crescent moon.

How does a comet get its name?
Comets are normally named for their discoverers. Since amateur astronomers continually discover comets, you could have a comet named after you!

A Japanese amateur astronomer named Yuji Hyakutake discovered his second comet with a pair of 25 X 150 binoculars in January, 1996. The Central Bureau for Astronomical Telegrams designated it Comet C/1996 B2 (Hyakutake):

C —	Indicates a long period comet
1996 —	Indicates the year of discovery
B —	Means that the comet was discovered in the second half-month of January. Half months are given as letters, with "A" covering Jan 1-15, "B" covering Jan 16-31, "C" covering Feb 1-15, etc.
2 —	Means it was the second comet discovered in 1996.

STARDUST™ plans to fly by comet Wild 2, and bring samples of cometary material back to Earth.

These samples may provide a window into the distant past that unravels some of the mysteries surrounding the birth and evolution of the solar system and the emergence of life.

Milestone Dates: Launch-2/99; Encounter-1/04; Return-1/06.

Investigating a Comet

Objectives

Students will:

- Create a thinking web
- Explain their knowledge of a comet

Overview

Brainstorm and create a Thinking Web that demonstrates students' knowledge of comets. This is an opening exercise to introduce comets to students and to assess prior knowledge.

Key Questions

- Why study comets?
- What would one need to study comets?

Procedures

1. Reproduce student worksheet and give each student a copy.
2. Have students complete each question on the map and encourage them to draw illustrations to go with their answers.
3. You can use students' answers as an informal method to assess prior knowledge by starting a class discussion. Students' answers will vary. Below are some examples of where to lead the discussion:

Examples of Student Responses	Discussion Points
A comet is a big rock.	Review the parts and composition of a comet.
A comet is like a small planet.	Cover the difference between comets and planets.
We should study comets because one might hit the Earth.	Discuss impact craters and the extinction of dinosaurs.
Comets and asteroids have different sizes.	Cover the differences between comets and asteroids.

Investigating a Comet

A comet is . . .

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A comet looks like . . .

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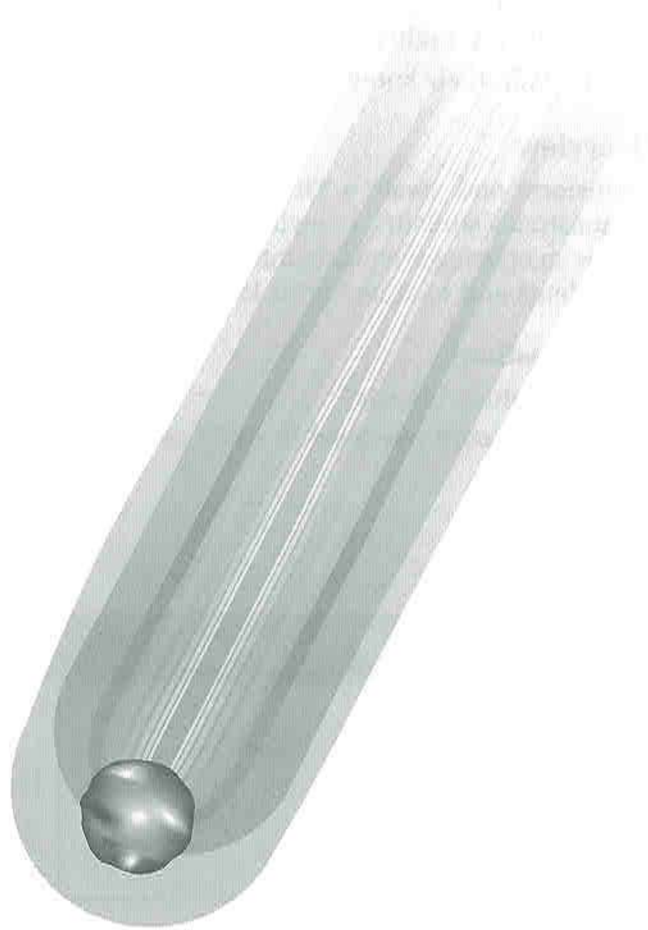

We should study comets because . . .

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A comet is different from an asteroid because . . .

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Famous Comets

Background

Comets, to be sure, are unique visitors to our skies. Unlike any other object in our Solar System, they appear as points of light surrounded by a fuzzy haze. Often they seem to be trailed by an even more diffuse tail. Also unusual is their tendency to appear at irregular intervals. Before people really understood the physical nature of comets, they often evoked fear and superstition in those who observed them. People developed their own creative explanations for these lights in the sky, considering them omens of war, famine, or even precursors to the death of a ruler.

The physical appearance of comets also conjured up some interesting descriptions. Halley's Comet, which approached Earth in the year 66, was described as a sword that hung over Jerusalem. Others felt that the tails of comets suggested long, flowing hair.

Great strides were made in appreciating the true nature of comets when in 1577 Tycho Brahe showed that comets were independent members of our Solar System. Prior to his time, most people had believed that comets were a phenomena of the Earth's atmosphere. Brahe used observations and a little bit of geometry to explain how comets must be located very far away from Earth—at least farther away than the Moon.

Edmund Halley continued to change the common understanding of comets when, in 1705, he published a paper entitled *A Synopsis of the Astronomy of Comets*. In this paper he combined his knowledge of the laws of gravity (as recently developed by Isaac Newton) and data from historic observations of comets. He had realized that the known orbital characteristics of the comets of 1531, 1607, and 1682 were similar, and that the appearances of each comet were separated by nearly identical amounts of time. He postulated that the three comets were really one comet which approached the inner Solar System roughly every 76 years. This theory was verified when, according to his prediction, a comet appeared near the end of 1758, sixteen years following his death. In his honor, this comet is now known as Halley's Comet.

Today, comets are considered bad omens by only a rare few. Instead, scientists look upon them as relatively untapped sources of information about our Solar System. Comets are believed to be remnants of the formation of the Sun and planets, putting them among the oldest objects in our Solar System. Because of this, there are many missions slated to investigate a sampling of comets in the next decade. If the predictions of astronomers are correct, by understanding more about comets, our understanding of the early years of the Solar System will increase dramatically.

Topics

Comets have always been a part of our history.

As technology increases, scientists can better analyze and interpret phenomena.

Objectives

Students will:

- Research comets that are historically, scientifically, or otherwise significant.
- Write a creative narrative based on their research.

Overview

In this lesson students research some of the more notable comets such as: Wild 2, Halley, and Shoemaker-Levy 9. Using the Internet and other research materials students will write and report on their findings about a selected comet.

Key Questions

What roles have famous comets played in history?

How can technology alter our interpretation of phenomena?

How can celestial phenomena affect our culture?

Key Concepts

- Scientific understanding is not constant. We are continually learning about the universe we live in.
- Comets have played a significant role in human history.
- Cycles and patterns; comets are either short or long period.
- Many comets return on a regular, periodic, and predictable basis.

Materials & Preparation

- Student worksheet for each team
- Comet Fact Sheet for each student from page viii
- Computers with access to the World Wide Web for each team

1. Review comets using the Comet Fact Sheet. Discuss the parts, location, orbital paths, and composition of comets.
2. Discuss with students the history of comets and how the appearance of comets impacted social life.
3. Assign students to cooperative groups to study one of the following comets:
   - Comet Hale-Bopp
   - Comet Halley
   - Comet West
   - Comet Shoemaker-Levy 9
   - Comet Tempel-Tuttle
   - Comet Encke
   - Comet Wild 2
4. Make arrangements for each team to have at least one hour of Internet access.
5. Have students answer the questions on the student worksheets using the internet.
6. Based on the information on the Comet Fact Sheet or from what they gathered, have the teams write a creative narrative about their comet.
7. Have the team reporter share their story with the rest of the class.
8. Conclude the entire lesson with Reflection & Discussion questions.

Management

Allow students plenty of time to research their comet. If necessary, encourage them to work on their project after-hours. Many libraries have a wide range of books on comets as well as Internet access.

Reflection & Discussion

1. What do comets have in common? How are comets different?
2. Do you think that a comet may hit a planet sometime in the future? Why or why not?
3. Does a comet's tail ever point towards the Sun? Why not?
4. Do you think that we see a lot of the Solar System's comets or only a few? Why can't we see the other ones?
5. If you were alive 1,000 years ago and you saw a comet, how would you feel? Would you be excited? Scared?
6. Do you think we will ever know all there is to know about comets? Or will we always be learning?
7. Did you think that some of the old ideas about comets were strange? Why? Do you think that people will someday think that *our* ideas about comets are strange?
8. What effect does the Sun have on comets?
9. What was the most recent visible great comet?
10. What comets will appear in the night sky over the next three years?

Transfer/Extension

1. Explore how other astronomical objects such as the Sun, Moon, planets, and stars were interpreted by ancient cultures.
2. Research examples of artists' noting comets in paintings, literature, tapestries, and photographs.
3. Invite amateur astronomers into the classroom and ask them to talk about their hobby.

Famous Comets

Student Procedures

1. Decide which team member will perform each of the following roles:

Recorder:	Records the results of the team's research.
Computer Operator:	Uses the computer to navigate the Internet and print out any essential materials.
Literary Supervisor:	Records team's input for the story.
Reporter:	Presents the team's story to the rest of the class.

2. Name of your team's comet:____

3. Using the Internet, answer as many of the following questions as possible. Have the recorder write down what the team learns on a separate sheet of paper. It may help to use the following websites:

Comets and Meteor Showers
http://medicine.wustl.edu/~kronkg/index.html

Comets and Asteroids at National Space Science Data Collection
http://nssdc.gsfc.nasa.gov/planetary/planets/asteroidpage.html

Comet Observation Home Page
http://encke.jpl.nasa.gov/

Challenger Center for Space Science Education Comet Links
http://www.challenger.org/cometl.html

STARDUST Home Page
http://stardust.jpl.nasa.gov

- When was the comet discovered?
- Who discovered the comet? What country was the discovery from? Is the discoverer a professional or amateur astronomer?
- What makes this comet unique?
- How long is this comet's period?
- How did you determine the comet's period?
- Have any major events in history happened when the comet has appeared? What were they?
- How did this comet change the way astronomers think about comets or the Solar System? How did technology change the way we think about comets?
- Print out a picture of the comet. Label its coma, gas tail, dust tail, and nucleus (if visible).

4. Use the following writing prompts to help your team write a two-page story about your comet. Have the Literary Supervisor write the story as the rest of the team provides ideas and suggestions. Base your story on actual facts and science concepts.

- Imagine you are a reporter writing a headline story about sighting this comet.
- Imagine that you belong to another culture in another century when your comet appears. Describe what you see, what you think it is, and how you feel.
- Imagine you are an amateur astronomer watching the night sky when you think you discover a comet. How do you feel? Who do you tell?
- Imagine you are the comet. Talk about where you would travel during your entire orbit.
- Think of your own story!

5. If available, illustrate your story with the photo you printed of your comet. Make sure that its parts are labeled.

Comet Halley, Image courtesy of NASA.

Cookin' Up a Comet

Background

As long as the night sky is clear, we can see that it is filled with twinkling stars. Other objects can be seen too, such as the Moon or planets depending on the timing. One of the more exciting and rare things to see in the night sky is a comet, which appears as a fuzzy light with a tail streaming behind.

Why do comets look so undefined when other objects are clearer and unchanging? The answer lies in what comets are made of and what happens to them when they get close to the heat of the Sun. We often hear of comets described as "dirty snowballs," a model that Harvard astronomer Fred Whipple came up with in 1950 that describes comets as being made of rock and ice. Today, by studying the light that comes from the comets, scientists can determine the presence of specific substances: frozen water, frozen carbon dioxide and other frozen gases, dust and rock, and organic (carbon-based) substances.

The comet takes on its familiar shape as it nears the Sun. When a comet moves through the Solar System, the Sun's heat begins subliming the ice and releasing gas and dust from the core of the comet, called the nucleus. As the ices turn to gas, they shoot away from the nucleus in jets. This process is called out-gassing. A fuzzy cloud of dust and gas forms around the nucleus and is called the coma. The solar wind and pressure from sunlight push the coma of the comet away from the Sun, forming two tails, a yellowish dust tail and a blue tail of gas particles.

Topics

Composition of comets
Physical features of comets

Objectives

Students will:

- Compare and identify the parts of the comet model to the parts of a real comet.
- Describe how comets change over time.

Overview

Students will learn the basic components of a comet and demonstrate how the comet's head and tail form by building a comet model.

Key Question

What are the parts of a comet?

Key Concepts

- We can use models to investigate distant or large objects at a scale that is easily used by humans.
- Comets are made of dust, rock, and ice, which changes to a gas when it comes close enough to the Sun.

Materials & Preparation

- 5 lbs (~ 2 kg) dry ice pellets or block
- 3 cups of water
- A few drops of ammonia
- A handful of sand
- A can of soda (cola)
- A large wide mixing bowl
- A large wooden or plastic spoon for stirring
- A hammer
- A large metal tub
- Heavy dishwashing gloves
- Protective eye goggles (1 pair per student)
- Cloth or paper towels
- Optional: Overhead projector, hair dryer, and plastic wrap

CAUTION! Dry ice is -79° C (-110° F). Any more than brief exposure will cause "burns." Everyone handling dry ice should wear heavy rubber dishwashing gloves! Be sure to discuss safety precautions with students when working with dry ice.

1. **Put on rubber gloves.** Using a hammer, crush the dry ice pellets or block in the large metal tub to the consistency of snow. Everyone should wear protective eye goggles. **DO NOT HANDLE THE DRY ICE WITH-OUT PROTECTIVE GLOVES!!**

2. Pour 18 oz (2.5 cups) of water into the mixing bowl. Add a handful of sand, a little ammonia, and the cola, mixing as you pour.
3. Add 2.5 cups of dry ice to the mixture, stirring carefully. Vapor will form as you stir, and the mixture will get slushy. Keep stirring for a few seconds while it thickens.
4. Use the mixing spoon to clean the slush away from the sides of the bowl into the bottom. Reach in and pack the slush into a ball. Keep packing and forming until you have a ball that forms a big lump. Too dry and the mixture is not sticking, add water. Too wet and slushy, add more dry ice.
5. **DO NOT HANDLE DRY ICE MIXTURE WITH BARE HANDS!**
6. Observe the behavior of your miniature comet nucleus.
7. Cool Comet Viewing Tip: So the whole class can watch the gas jetting out of the comet, use an overhead projector. Be sure to protect the overhead projector by covering the glass with plastic wrap.**CAUTION! Do not leave the comet on the projector long; the dry ice could damage it.**
8. Blowing hard on the comet gives a sense of simulating a comet tail. Some teachers use a hair dryer set on a low setting. Experiment for yourself. Discuss the parts of a comet using the Comet Fact Sheet on page viii.
9. The ingredients used to "build" a comet nucleus represent our current understanding of some of the components found in actual comets: frozen water, frozen carbon dioxide, ammonia, dust and rock, and organic (carbon-based) molecules.
10. Scientists have studied the spectrum of light coming from real comets' comas and tails to determine the presence of these substances. The research carried out in the Comet Halley fly-by missions and the ICE mission to Comet Giacobini-Zinner provided further evidence of comet composition.
11. As the comet in this experiment melts, you can see little jets of gas coming off the model comet nucleus just like the observed "out-gassing" of real comets, which can actually affect the movement of the comet. After further melting of the experimental comet, the nucleus will begin to break apart just like real cometary nuclei after many passes by the Sun.
12. Discuss the Reflection & Discussion questions as a class.

Management

THIS SHOULD ONLY BE DONE AS A TEACHER DEMONSTRATION.

Purchase dry ice from ice companies or ice cream parlors the day of or evening prior to the demonstration. If possible, get the pellet form of dry ice. Be sure to purchase five pounds of dry ice, although more will be needed if purchased the evening before. You will want to get enough extra for a test run at home the night before.

Store the dry ice in an ice chest. Place an inch or so of newspaper between the dry ice and the container to prevent the container from cracking.

Conduct this activity before using it in the classroom to get a feel for the correct amount of water to use.

Reflection & Discussion

1. When you place the comet on the tray to observe, what part of the comet does it represent?
2. Describe changes, if any, in the comet after five minutes have elapsed.
3. Use the hair dryer to represent the Sun. Set the dryer on the low setting and blow air on the comet. What part of the comet begins to form? What happens when you move the hair dryer closer to the comet?
4. What does the air from the hair dryer represent?
5. What components of real comets are represented by each of the ingredients in your comet?

Transfer/Extension

1. Research the differences between this model and a real comet. Experiment to see if you can come up with a better model.
2. Investigate where comets are believed to have spent the majority of their lives—either in the Kuiper Belt or the Oort Cloud.
3. Choose some other object, system, or phenomena, and ask your students to model it. How do models help us understand the world we live in?

Cometary Orbits

Background

Johannes Kepler, who was born in 1571, was an astronomer who struggled to find a mathematical way to describe how the planets moved around the Sun. For many years, astronomers believed that the planets moved in perfect circles. However, Kepler eventually realized that this wasn't the case. In 1609 he stated his first of three laws of planetary motion. It said, "The orbit of each planet is an ellipse, with the Sun located at one focus."

An ellipse is a geometrical shape that looks much like a stretched out circle. To draw one, it is easiest to drape a loop of string around two tacks that are placed in a piece of paper. With a pencil, draw a curve by pulling the string taught and sweeping it around the paper. [See diagram on p. 10] The place where the two tacks are located are called the ellipse's foci (plural of focus). The length of the long axis of the ellipse is called its major axis. The small axis perpendicular to the major axis is called the minor axis.

How stretched out an ellipse is, can be quantified by a value called eccentricity. An ellipse's eccentricity is calculated by dividing the length between the ellipse's foci by the length of the major axis. If an ellipse has an eccentricity of zero, it is a perfect circle. If an ellipse has an eccentricity close to one, it is very long and narrow. Ellipses cannot have eccentricities greater than or equal to one, or less than zero.

While Kepler's First Law only mentions planets, it is true that it also applies to any other object that may orbit the Sun, including comets. One of the distinctive features of the comets we commonly see from Earth is that their orbits are generally much more eccentric than the orbits of the planets.

Topics

Orbits of objects in the Solar System
Geometry

Objectives

Students will:

- Create ellipses and use them as models of real orbits.
- Apply mathematics to determine properties of ellipses.
- Compare the orbits of planets and comets.

Overview

This activity introduces the geometrical concept of an ellipse to students. It asks them to use mathematics to generate their own ellipses, and then use these ellipses as orbital models of planets and comets.

Key Questions

How are the orbits of comets different than the orbits of the planets?
How are the orbits of long period and short period comets different?

Key Concepts

- All objects in orbit around the Sun travel in ellipses.
- Eccentricity describes how "stretched out" an ellipse is.
- The eccentricity of the orbits of comets are generally much different from the eccentricity of the orbits of the planets.

Materials & Preparation

Each student will need:

- A Student Worksheet entitled Cometary Orbits
- 25 cm x 30 cm piece of cardboard
- 3 blank, white sheets of 8.5 x 11 paper
- Pencil
- 20 cm long piece of string
- 2 push pins
- Pencil
- Ruler
- Tape

1. Review the student procedures, as listed on the Student Worksheet.
2. Collect corrugated cardboard boxes and cut out pieces approximately 25 cm x 30 cm.

3. Gather the materials listed above.
4. Make copies of the Student Worksheet.
5. Before starting this lesson, students must have a solid understanding of the properties of ellipses and how they relate to comets. Review the information in the Background section with the students. Explain that all objects in the Solar System travel around the Sun in an ellipse. If possible, show a diagram of the orbits of planets, asteroids, and comets as an example.
6. Choose student helpers to assist you in distributing the materials for the lesson.
7. Briefly demonstrate how to use the pencil, string, and thumbtacks to draw an ellipse. As a class, note the foci and major and minor axes of the ellipse.

Management

Push pins are sharp. Be sure to keep track of them closely and make sure that they have not fallen onto the floor or into a chair before moving on to the next lesson.

Reflection & Discussion

1. If the Sun is at one of the foci of an orbital ellipse, is there anything at the other focus?
2. What do you think an orbit with an eccentricity of 0.95 would look like? Of 0.25?

Transfer/Extension

1. Kepler's Third Law says that the square of the time it takes an object to orbit the Sun in years is equal to the cube of half of the length of the orbit's major axis, if the length of the axis is in astronomical AU. In other words:

   $(\text{Orbital Period in years})^2 = (1/2 \times \text{Length of Major Axis in AU})^3$
2. Using this formula, calculate the periods of the planet and comets in this activity.
3. An ellipse is an example of a "conic section." Investigate what a conic section is, and find examples of other conic sections.

Cometary Orbits

Student Procedures

1. Tie the ends of the string together so that they make a loop.
2. Fold the paper in half vertically and draw a vertical line on the fold to locate the mid-line of the paper.
3. Determine the midpoint of the vertical fold line. Mark the point with a pencil. This point will be the center of the ellipse.
4. Tape the corners of the piece of paper to the cardboard.
5. Put the yellow push pin into the cardboard at the midpoint.

Orbit of object	Distance between foci (cm)	Length of major axis (cm)	Eccentricity
Orbit 1	1cm		
Orbit 2	6cm		
Orbit 3	7cm		

6. Place the white push pin in the cardboard 1 cm from the yellow push pin.
7. Loop the string around the push pins.
8. Using your pencil, draw around the string, as shown in the diagram on page 10.
9. According to Kepler's First Law, what object in the Solar System should one of the foci represent? Label one of the foci this object.
10. Remove the white push pin and string from your diagram and label it "Orbit #1".

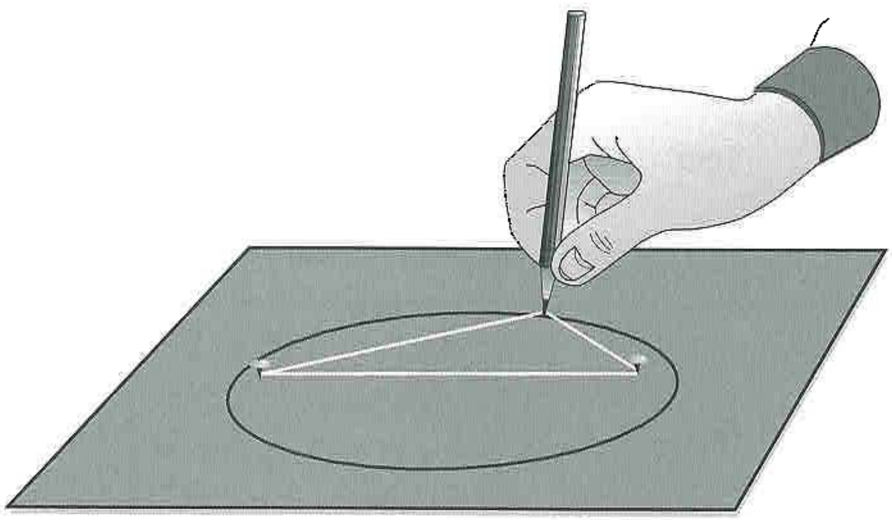
11. Repeat steps 6-9 for the rest of the orbits. The second time place the white push pin 6 cm from the yellow push pin in a different direction then the first. The third time place the white push pin 7 cm from the yellow push pin in a different direction than the first and the second.

12. When you are finished, measure the length of the major axes of each of the three orbits, in centimeters. Record your answers in the table. To ensure that you measure the full length of the major axis, line up your ruler along the ellipse's foci.

13. The eccentricity of an ellipse is given by the following equation:

$$\text{Eccentricity} = \frac{\text{distance between foci}}{\text{length of major axis}}$$

Use this equation to calculate the eccentricities of the three orbits. Record your answers in the table above.



Questions & Conclusions

1. Which of the objects in the table are most likely comets?

2. Which might be something else? What could it be?

3. Look at the shapes of the different orbits you have drawn and examine their relation to the Sun. How do you think Earth would be different if it had an eccentricity like that of object two or three?

Investigating Falling Particles

Background

Often in their careers, scientists must find creative solutions in order to accomplish their research. For instance, how might you measure the size of something that is too small to be seen, like an atom, or extremely large, like the Sun? How do you determine the composition of a planet that is too far away to be visited by spacecraft? How will you learn about the sleeping habits of an animal that sleeps only when it is too dark to see it?

One problem posed to scientists a few years ago was this: How can you collect fast-moving dust particles without causing changes in their physical structure when they hit the collection device? The solution to this problem is at the heart of the STARDUST Mission, a spacecraft that will fly to a comet and collect particles from its coma, as well as capture interstellar dust particles during its journey.

In order to develop an effective collection device, scientists must first have a good understanding of what the properties are of the material they are trying to collect, particularly those properties that could change when captured. Once these properties are known, they can proceed to design a collection device that will minimize or eliminate the possibilities of changes.

Topic

Impact of falling objects

Objectives

Students will:

- Investigate the characteristics of a clay ball.
- Examine what happens to a ball of clay that is dropped from different heights.
- Measure the height, depth, and width of a clay ball before and after a drop.

Overview

Students will measure a clay ball, and then drop it from different heights to examine how the impact changes the clay ball. Through class discussion, students will relate this to capturing comet particles.

Key Question

How might an impact of a fast-moving object change the characteristics of the object?

Key Concept

- The impact of a falling object will change the physical characteristics of that object.

Materials & Preparation

- Paper towels or newspapers to cover the floor
- A softball-size clay ball
- Student worksheets entitled Investigating Falling Particles (1 per student)
- Meterstick
- 2 rulers
- 2 index cards
- Toothpick

1. Students will observe what happens to the clay ball when it hits a hard surface at different heights.
2. Use the last ten minutes of class to have each team's reporter share the results of their experiments.
3. The students should conclude that clay is malleable. It changes shape easily. The greater the drop height the harder the clay hits the ground, and the more the shape changes.

Management

This activity can be completed in one class period. Use caution when dropping the clay from three and four meters. This activity works best if you can drop the clay off the bleachers in the gym.

Reflection & Discussion

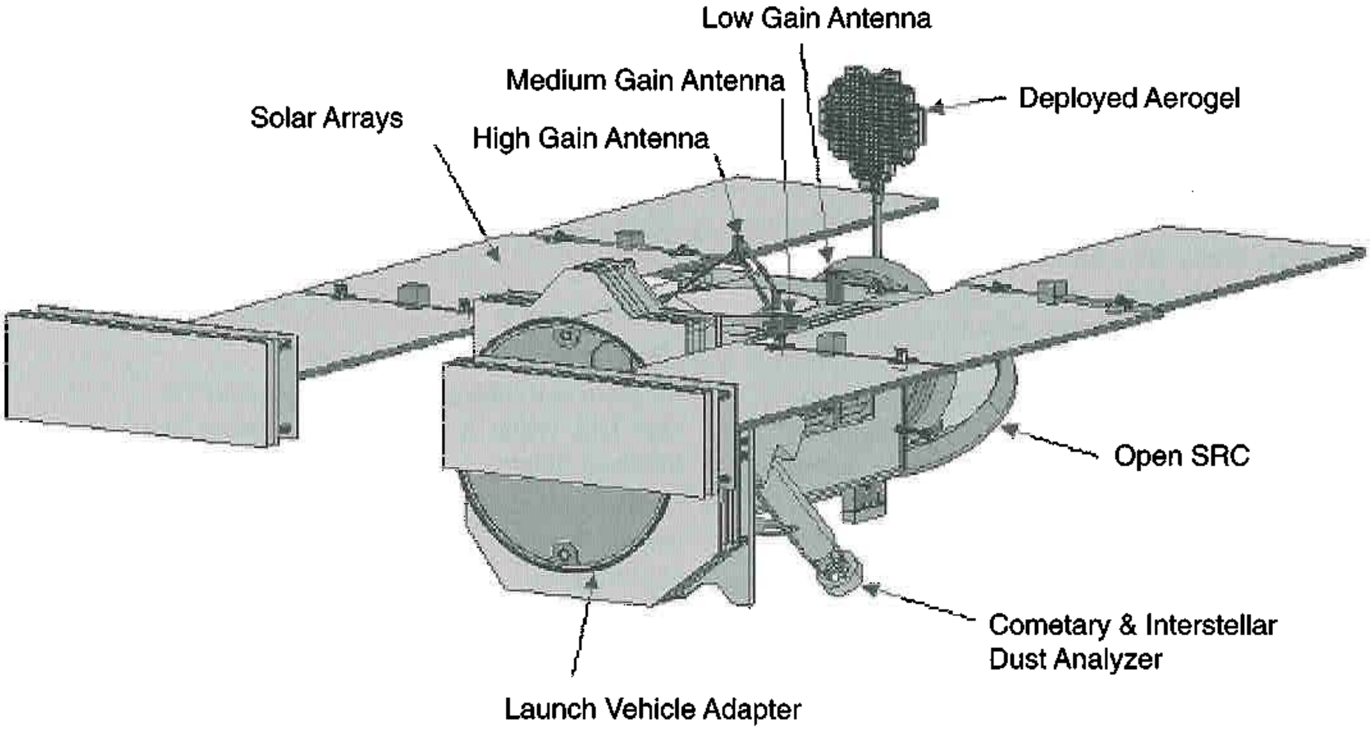
1. Explain what happened to the clay ball when it was dropped.
2. How did increasing the drop height change the results of the experiment?

3. What do you think would happen if you threw the clay ball at the ground at different speeds?
4. What would be the problems with a moving spacecraft trying to capture moving comet particles?

Transfer/Extension

1. Have students experiment with dropping other sizes of clay particles to see if the size changes the results.
2. Have students drop clay with different hardnesses, if possible.

Encounter Configuration



The STARDUST spacecraft will collect cometary particles in aerogel without changing the size or shape of the particles. Photo courtesy of NASA/JPL.

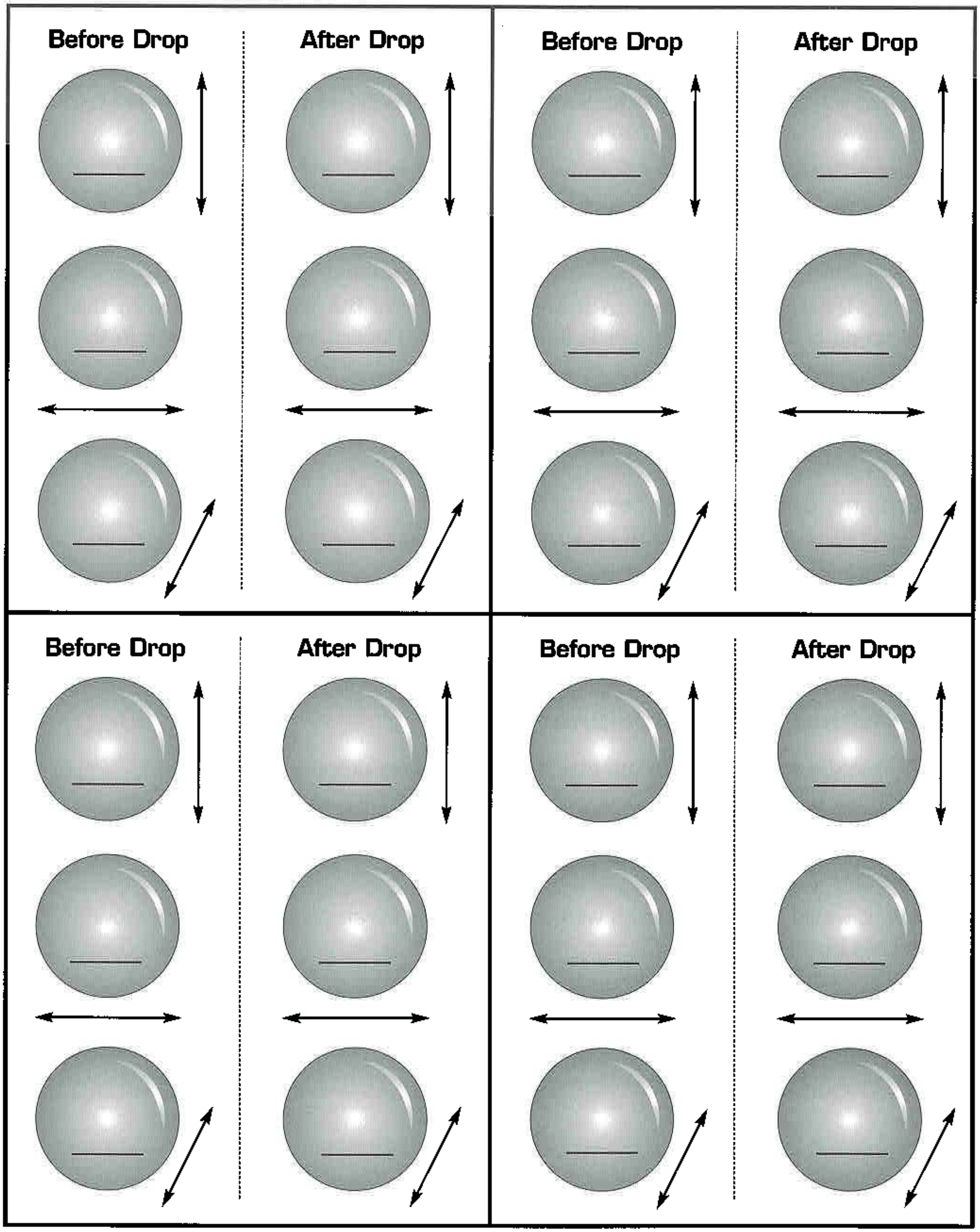
Investigating Falling Particles

Student Procedures

1. When you receive your clay be sure that it is as round as possible. If needed roll it between your hands to round out the clay.
2. Use a toothpick to draw a T in the top of the clay ball and a B in the bottom.
3. Place the two index cards on the top and bottom of the clay ball. Measure the distance between the two cards in centimeters. Record this as the height in the chart below.
4. Place the two index cards to the left and right of the clay ball. Measure the distance between the two cards in centimeters. Record this as the width in the chart below.
5. Place the clay ball between the two index cards (front to back). Measure the distance between the two cards in centimeters. Record this as the depth in the chart below.
6. Drop the clay ball from a height of 1 meter.
7. Using the index cards and the ruler, re-measure the height, width, and depth after the fall. Record in the chart below.
8. Repeat steps 1-7, dropping the clay ball from a height of 2, 3, and 4 meters.
9. As a team, complete the Questions and Conclusions below.

Questions & Conclusions

1. Explain what happened to the clay ball when it was dropped.
2. How did increasing the drop height change the results of the experiment?
3. What do you think would happen if you threw the clay ball at the ground at different speeds?
4. What would be the problems with a moving spacecraft trying to capture moving comet particles?


Before Drop
After Drop
Before Drop
After Drop
Before Drop
After Drop
Before Drop
After Drop

Particle Collection

Background

How could you capture particles from a comet? Would a huge net work? Well, the particles are microscopic. How about sticky fly paper? The particles travel so fast that they would tear through the thin paper. How about buckets of syrup or water? Syrup or water would freeze in the vacuum of space or evaporate from the heat of the Sun. The scientists really had a problem—a challenge—to find a good collection medium.

Collecting materials from a comet's coma is no easy feat! The impact velocity of the particles as they are captured can be up to 6 times the speed of a bullet fired from a rifle. These particles are smaller than grains of sand. High-speed capture could alter their shape and chemical composition or vaporize them entirely. Scientists needed something that would capture very tiny delicate particles without damaging their shape. The substance had to be strong to survive the launch into space, lightweight to keep liftoff costs low, and composed of materials that couldn't melt or freeze in the extreme temperatures of space. Also the substance needed to allow the scientists to find the particles easily.

Topic

Scientific Investigation

Objective

Students will:

- Test various mediums to collect falling particles without changing the characteristics of the falling particles.

Overview

Student teams examine mediums to capture a falling clay ball without changing it to simulate how Aerogel will capture particles during the STARDUST Mission. Teams test collection mediums and then share their findings with the class using visual aids.

Key Question

How do you capture a fast-moving object without changing its characteristics?

Key Concepts

- Capturing cometary particles requires development and testing of new technology such as Aerogel.
- Unique challenges require unique solutions.
- Many issues must be taken into account when designing an effective scientific investigation.
- It is important to test ideas before putting them into use.

Materials & Preparation

- Assorted materials to use as collection mediums (as determined by the students)
- 1 large diameter bucket
- Meterstick
- Clay ball about the size of a softball

1. Students will brainstorm what types of collection medium should be used so that the clay ball does not change shape when dropped from a height of 3 meters.
2. Students need to consider the following:
   - The substance has to be strong to survive the launch into space.
   - Lightweight to keep liftoff costs low.
   - Will not melt or freeze in the extreme temperatures of space.
   - Relatively transparent so the particle will be found easily.
3. Students will then test each material by dropping the clay ball from 3 meters into a bucket filled with the collection medium.
4. Students will then prepare and present a report to the rest of the class.

Management

This activity will take two to three class periods to complete. During first class period students will brainstorm what types of material will work as particle collection medium. Afterwards, the students will test the mediums. Use care when dropping the clay from the different heights.

Reflection & Discussion

1. Did each of the collection mediums you chose perform as expected? Why / Why not?
2. Why did you choose each of the collection mediums?
3. How does your medium differ from Aerogel?

Transfer/Extension

1. Try dropping the clay ball into the collection medium from greater heights to see if the medium will continue to perform as needed.
2. If you use a liquid as a medium, add Alka-Seltzer to the clay ball and test to see if the collection medium changes the chemical composition of the clay ball in any way.

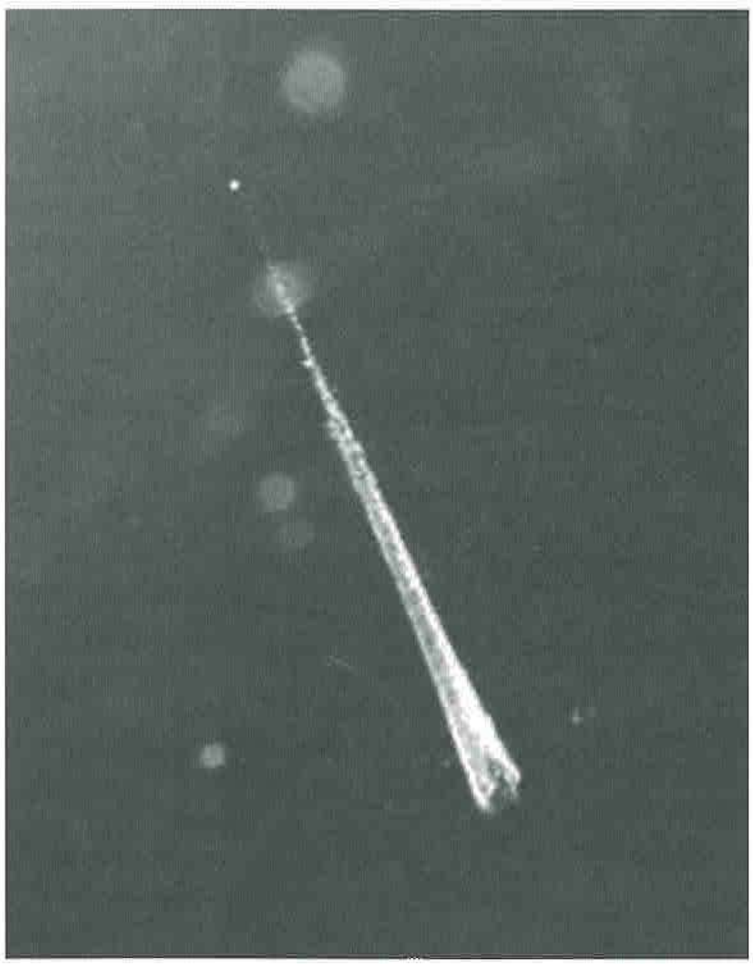


Image courtesy of NASA/JPL.

Particle Collection

Student Procedures

1. What types of collection medium would you like to test? Your goal is to pick a medium that does not change the shape of the clay ball when it is dropped from a height of 3 meters.

2. Consider the following as you brainstorm:
- The substance needs to be strong to survive the launch into space.
- Lightweight substances keep liftoff costs low.
- The substance should not melt or freeze in the extreme temperatures of space.
- The medium should make it relatively easy to find the collected particles.
- Will the medium change the particles in any manner?

3. Based on your brainstorming, choose four or five items to test as collection mediums.

4. Gather the materials you need for your test.

5. Test each material by dropping the clay ball from 3 meters into a bucket filled with the collection medium.

6. Record your results in the chart below.

Questions & Conclusions

1. Of all the collection mediums you tested, which would be the best? Why?

2. What characteristics of the collection medium were the most important in preventing the ball from changing shape?

3. Prepare a written conclusion and present your findings to the rest of the class. Your report should include a summary of each test and clear reasons why you chose each of the mediums for testing.

Collection Medium	Weight of 600 ml of collection medium	Will the medium freeze?	Will the medium melt?	Does the medium allow you to see the particles?	Did the medium break into smaller particles when the clay ball was dropped?	Did the clay ball change?	Did the collection medium prevent the clay ball from changing?

Aerogel

Background

Aerogel, a silicon-based substance generated by only a few scientists throughout the world, has progressively been proving itself a very useful substance to space scientists. One thousand times less dense than glass, a figure achieved by being made of 99 percent air, it is the most lightweight solid known. Despite its weight, Aerogel is particularly strong and is able to withstand the jostling of space travel and exposure to the extreme environment of space. Continued improvements to the fabrication process make it simpler and safer to produce.

One of the useful properties of Aerogel is its superior insulation power. One inch of Aerogel has the insulating power of six inches of fiberglass. Aerogel has been utilized for this during previous space missions, including the Mars Pathfinder mission.

However, Aerogel has also proven itself as an excellent collector of high-speed particles. Although very tiny, the particles move so swiftly that they are very difficult to collect without damaging the particles or the collector itself. Tests done in labs on Earth and on the Space Shuttle show that, if engineered properly, Aerogel virtually eliminates both of these issues. When a particle hits Aerogel, it buries itself in the material, creating a carrot-shaped track as it comes to a stop. Because Aerogel is almost completely transparent, it is relatively easy to find these tracks and locate the particle at the tip of the "carrot."

Because Aerogel has so many unique properties, it is particularly difficult to find a substance that models it accurately. In this activity, "aerogel-lo" is used as an example, although there are many differences between the two. Among these are its high water content, which would not allow it to travel intact in the extreme environment of space, and its relatively large weight.

Topics

Aerogel Technology

Objective

Students will:

- Compare and contrast aerogel-lo and Aerogel.

Overview

This demonstration uses gelatin and steel pellets to show how STARDUST's Aerogel collector will capture comet particles. Then use a Venn Diagram to compare and contrast aerogel-lo and Aerogel.

Key Question

How is Aerogel used to capture fast-moving particles?

Key Concept

- Technology helps scientists in research

Materials & Preparation

- 1 packet unflavored gelatin
- Hot water
- 2 clear plastic cups (NOT the soft, opaque plastic ones)
- A spoon
- A plastic straw
- A scrap of clean pantyhose and tape to secure it
- Steel pellets (available at sporting goods stores)
- Safety goggles for you and each student

1. For a successful demonstration, the gelatin must have the right consistency.
2. Follow the directions on the gelatin packet to achieve the proper consistency.
3. Pour the gelatin into two cups, one for class, one for practice. Be sure to prepare the gelatin before doing the activity in class. This does two things; first it allows enough time for the gelatin to set. Second, you have time to test the gelatin and make another batch if it does not have the right consistency.
4. To test the consistency, attach a clean scrap of pantyhose over one end of the straw using

tape. This precaution is to keep you from inhaling a pellet by mistake.

5. After putting on safety goggles, place a pellet in the straw.
6. Tip the straw so the pellet slides to the covered end. Pinch the straw, trapping the pellet at the top of the covered end.
7. Blow the pellet into the aerogel-lo with a quick, sharp blow.
8. Gelatin has the right consistency if the pellet enters the gelatin easily, the gelatin stops the pellet, and the track from the pellet remains visible. If the pellet bounces off the bottom of the container, the gelatin is too watery. Make another batch of gelatin using less water. If the pellet bounces off the surface of the gelatin or hardly penetrates it, add more water to the next batch.
9. **CAUTION:** This demonstration can be dangerous if not done correctly. Have your students wear safety goggles.
10. Put on safety goggles and take out the cup of gelatin, straw, and pellets.
11. Place a pellet in the straw. Tip the straw so the it slides to the covered end. Pinch the straw, trapping the pellet at the top of the covered end.
12. Hold the cup so students can see it or pass the cup around the room.
13. Take a big breath and at the same time, stop pinching the straw and blow the pellet into the aerogel-lo with a quick, sharp blow. Shoot several pellets into the cup.
14. Have students observe track marks made by the pellets.
15. If possible, show the image of the track from the STARDUST website at: http://stardust.jpl.nasa.gov/spacecraft/Aerogel.html.
16. Give students a copy of the Aerogel fact sheet and discuss Aerogel with the students.
17. Using a Venn Diagram have students compare and contrast the aerogel-lo to Aerogel.

Management

This activity should be done as a teacher demonstration.

Reflection & Discussion

1. What makes Aerogel special?
2. How does Aerogel stop a comet particle?
3. What did scientists and engineers have to consider when picking a material to capture comet particles?

Transfer/Extension

1. Research Aerogel and write a report about its development and how it has been used in past space missions.
2. Find a picture of the STARDUST spacecraft then design and build a model of the spacecraft.

Aerogel Fact Sheet

What is Aerogel?

Aerogel is a lightweight, nearly transparent substance that has many uses in space science. At one-thousand times less dense than glass, a result of being made of 99 percent air, it is the lightest solid in existence. It has superior insulating qualities (an inch of Aerogel insulates as well as six inches of fiberglass!), and has proven particularly useful for collecting small particles traveling at high velocities.

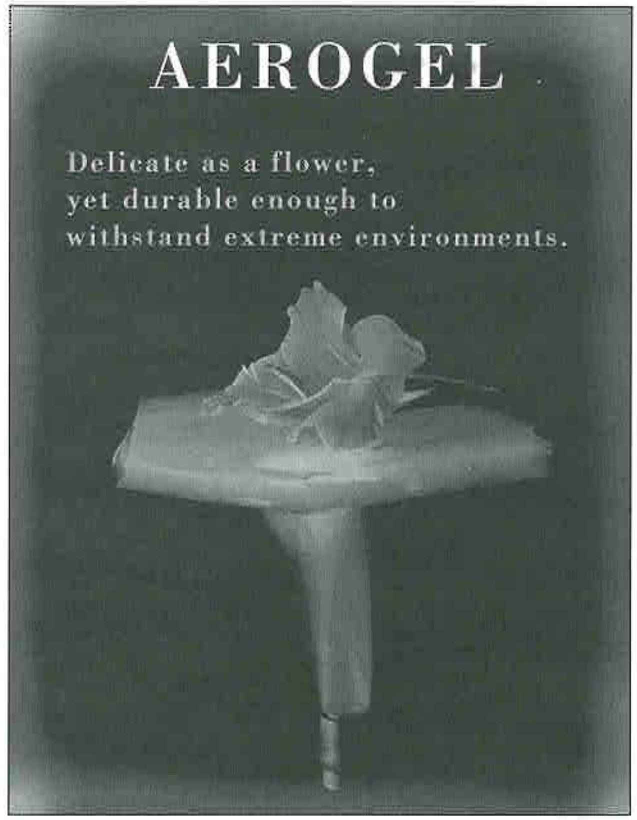


Image courtesy of Ernest Orlando Berkeley National Laboratory.

How does Aerogel act as a mechanism for capture?

Aerogel has proven itself as an excellent collector of high-speed particles. Although very tiny, these particles move so swiftly that they are very difficult to collect without damaging the particles or the collector itself. Tests done in labs on Earth and on the Space Shuttle show that, if engineered properly, Aerogel virtually eliminates both of these issues. When a particle hits Aerogel, it buries itself in the material, creating a carrot-shaped track as it comes to a stop. Because Aerogel is almost completely transparent, it is relatively easy to find these tracks and locate the particle at the tip of the "carrot."

The limitations of the aerogel-lo model

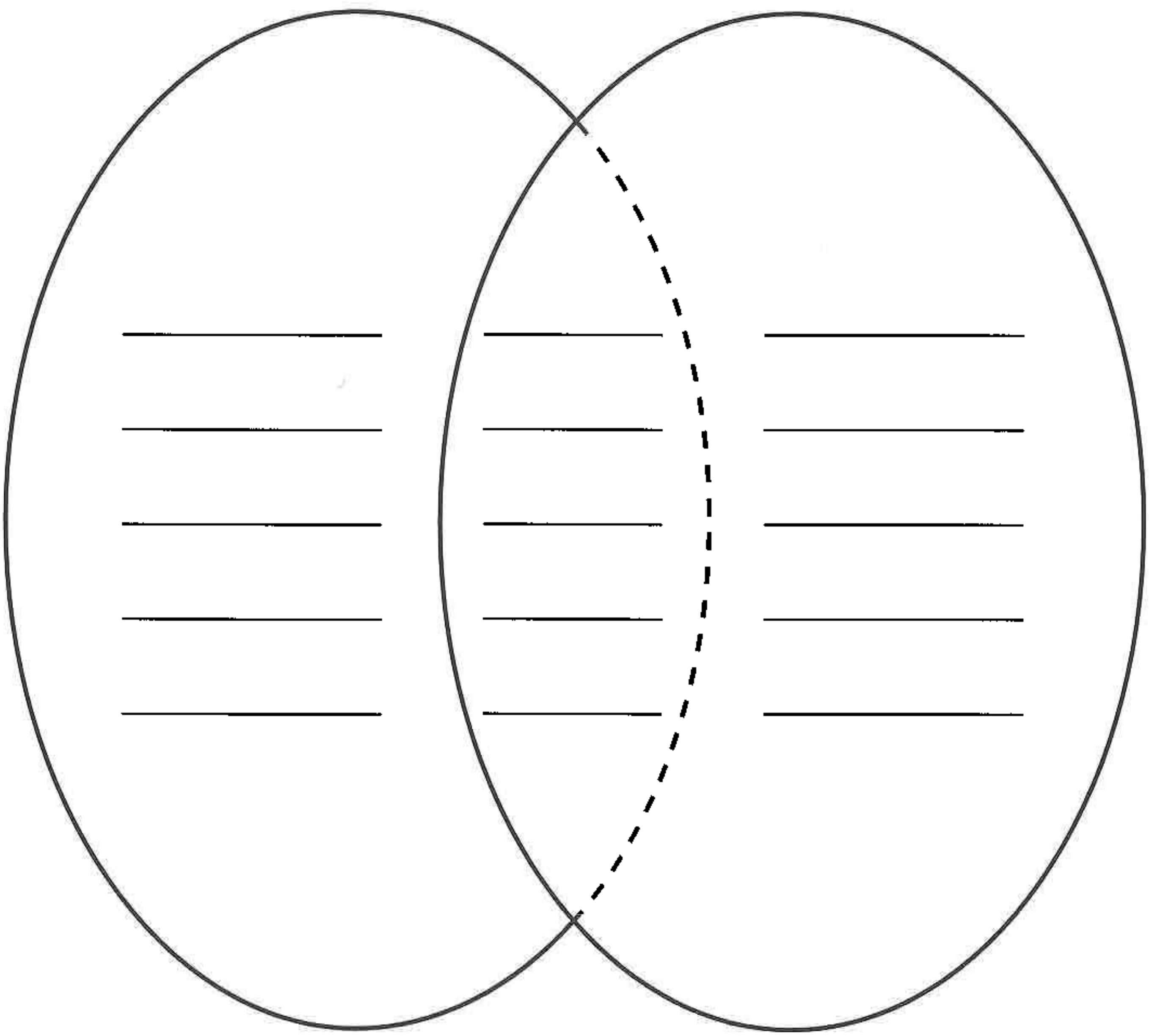
Because Aerogel has so many unique properties, it is particularly difficult to find a substance that models it accurately. In this activity, "aerogel-lo" is used as an example, although there are many differences between the two. Among these are its high water content, which would not allow it to travel intact in the extreme environment of space, and its relatively large weight.

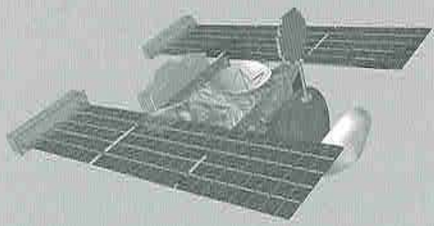
Aerogel

Student Procedures

1. Observe track marks made by the pellet in the teacher demonstration.
2. If possible, view the image of the track from the STARDUST website at: http://stardust.jpl.nasa.gov/spacecraft/Aerogel.html.
3. Read the Aerogel Fact Sheet and discuss Aerogel.
4. Using the Venn Diagram compare and contrast aerogel-lo to Aerogel.

aerogel-lo **Aerogel**





Extending The Mission

Suggested Extensions

After you complete the activities in this book, there are many directions in which to lead your students to learn more about comets. Below are guidelines for two extension activities. The first is a discussion that can potentially lead to a debate. The second is a hands-on activity for individuals or small groups.

Suggestion #1: Debate

Because comets are among the oldest objects in the Solar System, small bodies may help us understand how the Solar System formed and evolved.

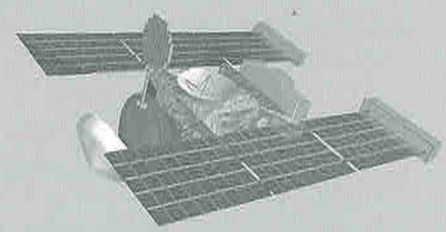
- Discuss with students the possible role of comets in the extinction of the dinosaurs.
- Discuss comet fact and fiction based on recent comet movies.
- Could comets have contributed to the formation of the oceans and atmosphere on Earth?

Suggestion #2: Press Kit

Have each student imagine that he or she is a team member of a mission to a comet. This press kit will represent every aspect of the fictional mission from beginning to end. The way it is presented should be up to the student, but below are some guidelines to get started:

- A press release announcing the mission and its team members.
- A biography sheet of the student with title of job and how the job relates to the mission.
- A mission statement including a timeline, plan for research, and goals.
- Pictures of the spacecraft, both inside and out.

Glossary



Aerogel—A silicate dioxide material with the lowest known density of any solid, made of 99 percent air. Sometimes referred to as solid blue smoke, Aerogel is strong and has more insulating power than fiberglass. The STARDUST spacecraft will use Aerogel to capture microscopic, high-velocity particles from the coma of a comet and from interstellar dust.

Asteroid (also "planetoid")—A rocky body orbiting the Sun, usually greater than 100 m in diameter. Most asteroids orbit between Mars and Jupiter, roughly 2–4 AU from the Sun.

Astronomical unit (AU)—One AU is equal to the average distance between the Sun and Earth, approximately 150 million kilometers (93 million miles).

Circle—A geometric shape, where all points on a plane are the same distance from the center.

Coma—A cloud of dust and gas that forms around a comet's nucleus due to solar heating.

Comet—An object found in our Solar System (and possibly other systems) that is composed of dust, rock, and ice and is generally only a few kilometers across. The comets we typically observe from Earth have highly eccentric orbits and venture into the inner Solar System. However, most are located far beyond the most distant planet and travel in more circular paths. See long period and periodic comets.

Density—The mass of a substance for a given volume.

Eccentricity—A numerical value for the shape of an orbit ranging from 0 (zero) which equals a circular orbit to nearly 1 (one) which equals a long, flattened orbit. Planets (except Pluto and Mercury), moons, asteroids, and short period comets have eccentricity values close to 0 (zero). Long period comets have eccentricity values of 0.5 or more.

Ellipse—A geometrical shape where all the points on a curve is the constant sum of the distances from two fixed points, called focal points.

Ejecta—The debris that is ejected from the site of impact when a crater forms.

Gravity—Force of attraction between two objects that is proportional to the mass of the objects. Gravity holds us on Earth and keeps the planets orbiting around the Sun. Just as Earth pulls on you, you pull on Earth with the exact same amount of force.

Kuiper Belt—A belt-shaped region roughly 30 to 100 AU from the Sun (past the orbit of Neptune) containing many small icy bodies. It is believed to be the source of short period comets.

Long period comets—A comet with an orbital period of more than 200 years. Long period comets are believed to originate in the Oort Cloud. Examples: Comet Hale-Bopp, 4,000-year orbit; Comet Hyakutake, more than a 65,000-year orbit.

Mass—The measure of an object's inertia. Mass is not the same as weight, which measures the gravitational force on an object. Your mass is the same everywhere, whether you are at home, on the Moon, or floating in interplanetary space.

Nucleus—The solid part of a comet, made of ices and rock. As the nucleus approaches the inner solar system, its ices melt, creating a much larger coma of dust and gas that surrounds it. The nucleus of a comet (Halley) has only been seen once, by the spacecraft Giotto.

Oort Cloud—A huge spherical "cloud" of cometary particles that extends from beyond the orbit of Neptune and Pluto, half way out to the nearest star. It may contain a trillion comets orbiting the Sun. This is thought to be the source of long period comets.

Orbit—The path a planetary body makes as it revolves around the Sun. The orbit of a comet tends to be far more elliptical than planets.

Particle—A tiny quantity of a substance.

Perihelion—The point where an object orbiting the Sun is closest to the Sun.

Periodic comets (also short period comets)—A comet with an orbital period of less than 200 years. Short period comets fade over time as more and more of their ices melt with each passage of the Sun. Examples: Comet Halley, 76-year orbit; Comet Encke, 3.3-year orbit; Comet Wild 2, 6.2-year orbit.

Short period comets—See periodic comets.

Spectrometer—An instrument used to obtain and record a spectrum of an astronomical object. A spectrum is a series of colors that is produced when light is spread out in order of wavelength. Scientists use spectra to determine the chemical composition of an object.

Sublimation—The process of an ice turning from a solid state directly to a gas state, without changing to a liquid first.

Tail—A long trail of dust and gas that extends out from the coma of a comet when it is relatively close to the Sun. The tail of a comet always points away from the Sun. These appendages come in a variety of shapes and lengths that can cover a significant portion of the sky.

Resources

This is a selected list of web sites, organizations, and magazines that teachers can consult for more information about the STARDUST mission, comets, and other small bodies. We encourage you to visit them, and hope they will inspire you to keep exploring.

Web Resources

STARDUST Mission Homepage http://stardust.jpl.nasa.gov/
Includes information on the mission, spacecraft, and comets, and educational materials with terrific links to other sites. This collection of comet activities was made possible through the support of JPL's STARDUST Mission.

Asteroid and Comet Page, NASA and National Space Science Data Collection
http://nssdc.gsfc.nasa.gov/planetary/planets/asteroidpage.html
Contains fact sheets, FAQ's, photo galleries, and future mission information.

Comets and Meteor Showers http://medicine.wustl.edu/~kronkg/index.html
You've probably seen a "shooting star" flash briefly across the sky on a clear summer night. This site will help you learn about these and other cosmic interlopers. Plenty of pictures and hints for observing are among the highlights here.

Comet Observation Homepage http://encke.jpl.nasa.gov/
Check this site for the latest comet observations, finder charts, and background information on comets.

Comet Hale-Bopp Homepage http://www.halebopp.com
Be sure to visit the official Comet Hale-Bopp page and find out just how Dr. Alan Hale discovered this mysterious cosmic visitor! HINT: It wasn't from some huge observatory.

JPL Comet Hale-Bopp Page http://www.jpl.nasa.gov/comet/
Chronicles one of the brightest comets ever observed. Clear explanations and numerous pictures let you keep tabs on this visitor from deep space.

JPL's Shoemaker-Levy 9 Homepage http://www.jpl.nasa.gov/sl9/
Contains images of comet Shoemaker-Levy 9's impact with Jupiter, including many from spacecraft Galileo. This website was visited more during the week of the impact with Jupiter than any homepage to date.

NASA Spacelink http://spacelink.msfc.nasa.gov/home.index.html
Offers educational materials, software, and images on aerospace topics. Special features for teachers that sign up for accounts. Check for upcoming events for educators.

National Space Science Data Collection (NSSDC) Homepage http://nssdc.gsfc.nasa.gov/planetary/
Offers latest news in planetary science, CD-ROM collections, and information on all comets.

Night of the Comet
NASA, SOFIA, and Internet in the Classroom
http://www.comet.arc.nasa.gov/comet/
Chronicles amateur astronomers from around the world sharing information and photographs of Comet Hyakutake.

Welcome to the Planets http://pds.jpl.nasa.gov/planets/
This is a collection of the best images from NASA's planetary exploration program.

Sky On Line Homepage http://www.skypub.com/
This is the Sky & Telescope magazine homepage. Offers news bulletin, Sky Publication Catalogs, Comet Page, tips on backyard astronomy, star parties and events, links to Internet telescopes, clubs, and observatories.

Space Image Libraries
NASA Aerospace Education Specialists Site
http://www.okstate.edu/aesp/image.html
Offers latest pictures on rockets, probes, and spacecraft, and information about the Hubble Telescope, NASA-related sites, Space Agencies, Astrophotography, special missions, observatories, and events.

Non-Web Resources

Astronomical Society of the Pacific: ASP has a free quarterly educational newsletter and catalog full of great educational items. Project ASTRO's *Universe at Your Fingertips,* a comprehensive and ready-to-use collection of classroom activities, teaching ideas, and annotated resource lists, is a must-have resource for every school in the country! For around $30, it is a bargain that cannot be passed up. Call (800) 335-2624 or write to the Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112.

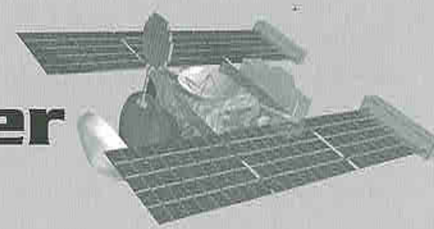
Lunar & Planetary Institute: This branch of the Center for Advanced Space Studies is part of the Universities Space Research Association (USRA) that offers specialized slide sets for educators on a variety of Solar System topics. Contact LPI, Order Dept., 3600 Bay Area Blvd., Houston, TX 77058. Call (281) 486-2172.

NASA CORE: The Central Operation of Resources for Educators for NASA generated materials. CORE, Lorain County JVS, 15181 Rt. 58 South, Oberlin, OH 44074. Call (216) 774-1051, ext. 293 or 294.

National Science Teachers' Association: In addition to hosting wonderful conferences and producing a variety of classroom resources, NSTA coordinates NASA's two primary teacher training programs for elementary and secondary teachers—known as NEWEST & NEWMAST—and the Space Science Student Involvement Program. NSTA, Space Science and Technology, 1840 Wilson Blvd., Arlington, VA 22201-3000. Call (703) 243-7100.

National Space Society: With membership comes a subscription to NSS' *Ad Astra* magazine, a great way to stay in touch with the current events and issues surrounding space exploration. NSS, 600 Pennsylvania Avenue, SE, Suite 201, Washington, DC 20003. Call (202) 543-1900.

Challenger Center Resources



Challenger Center for Space Science Education: Mixing a little adventure with education has proven to be a recipe for success, resulting in a vibrant, growing portfolio of Learning EdVentures™ programs. Classroom programs include *Cosmic EdVentures: Exploring Earth's Neighborhood* (grades 3-6); *Mars City Alpha (grades 5-8);* and *Marsville: A Cosmic Village* (grades 5-8). *EdVentures in Simulation: A Great START to the 21st Century* is a professional development workshop sharing the secrets behind Challenger Center's simulations based on more than 10 years of experience conducting successful simulation programs. The Challenger Learning Center network reaches more than a quarter million students and teachers each year with full immersion simulations at its 31 sites across North America. For more information contact your local Challenger Learning Center or write Challenger Center for Space Science Education, 1029 North Royal Street, Suite 300, Alexandria, VA, 22314. Call (703) 683-9740.

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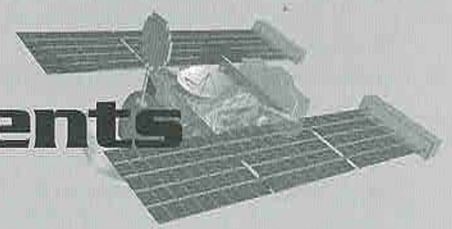

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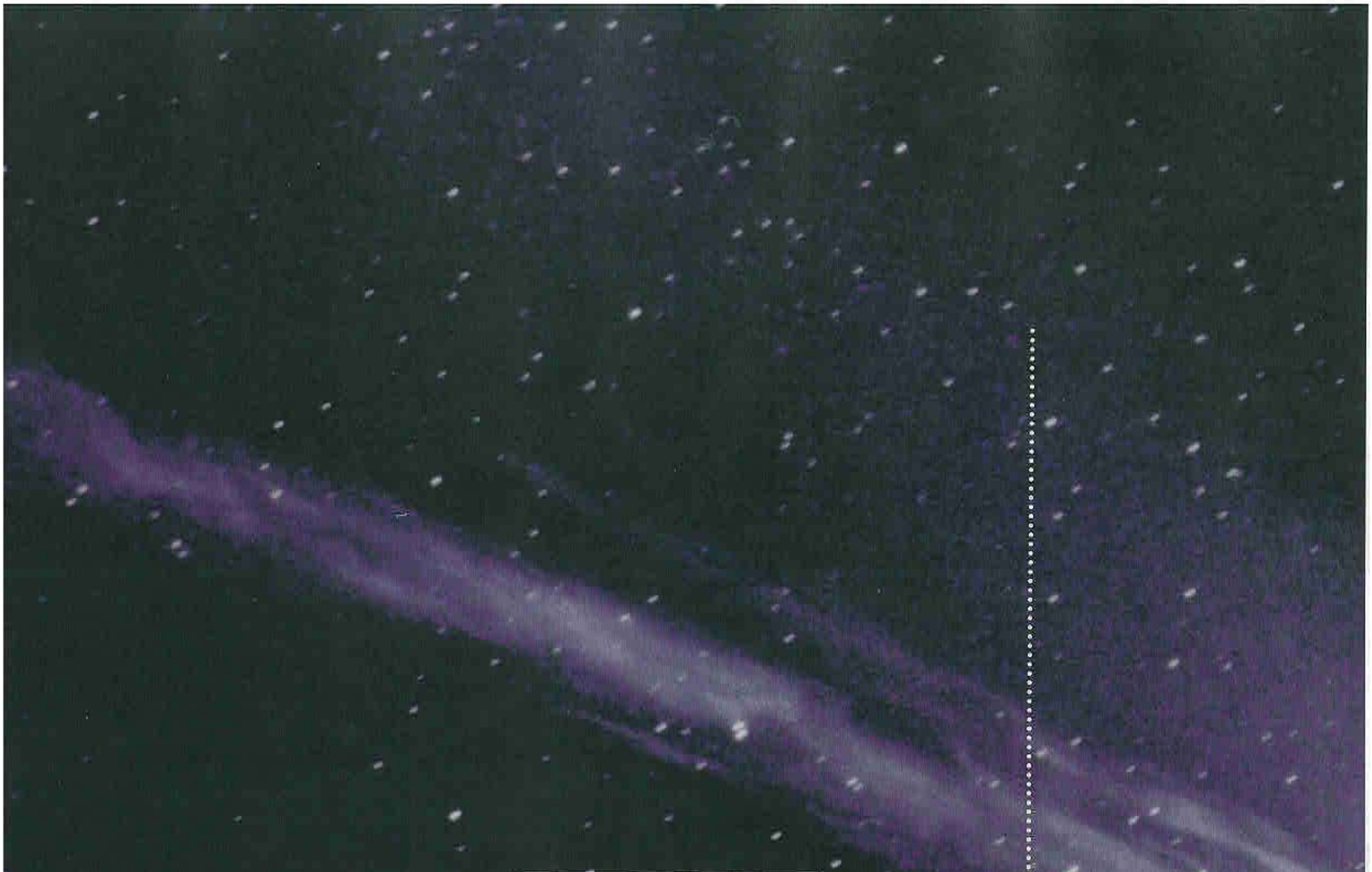
Inside Cover Image: Artist rendering of the STARDUST spacecraft's encounter with comet Wild-2 is the work of artist B. E. Johnson



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