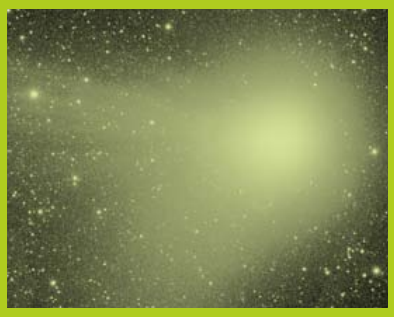
LESSON

COMETS, THE ICE WITNESSES

DIRECTORY

PHOTO GALLERY



This lesson develops precursor understanding about how comets are distant icy worlds, and when they come in close in their orbit around the sun they are often visible to observers on Earth.

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SCIENCE & LITERATURE

An eyewitness is a person who saw everything that happened at the scene. Comets are ice witnesses who were at the scene of the formation of the Solar System. Scientists would like to learn the stories the comets have to tell about the history of the early Solar System.

"A comet is a dirty snowball, typically about 5–8 miles in diameter. It is made of mostly organic molecules gathered over billions of years from all over the galaxy. Most comets were already formed when the Earth got going."

— Astronomer David Levy, interviewed by CNN

"Exploring the mostly frozen comets gives us a window into the past, provides clues regarding the origin of the Solar System and a means for testing our theories of Solar System evolution."

— Ray Brown, Science Writer/Reporter, University of Maryland

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CONCEPT OVERVIEW

This lesson develops precursor understanding about how comets are distant icy worlds, and when they come in close in their orbit around the sun they are often visible to observers on Earth.

Concepts:

- Comets
- Oort Cloud

This lesson provides a concrete experience of:

- Enacting a story of how comets travel through the Solar System.
- Examining images of comets and the current space missions exploring comets.

PRE K–GRADE 2 CONCEPTS

- Comets are ancient icy worlds.
- Comet tails are mostly dust and ice reflecting in the sunlight.
- Most comets originate in the Oort Cloud.

GRADE 3–5 CONCEPTS

- Comets are a mix of ice and other organic materials.
- There are two kinds of comet tails: the visible, reflected by sunlight, and the magnetic tail, caused by highly charged particles.
- Comets are ancient remnants from the formation of the Solar System.
- Most comets originate from the Oort Cloud, which extends from about 5,000 A.U. to 100,000 A.U. from the sun.

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LESSON SUMMARY & OBJECTIVES

The fascination with comets has a long history in art, literature, and mythology, but it is only in the present era of space exploration that we have been able to explore comets directly by sending spacecraft up close to examine these ancient icy worlds and learn from the stories they have to tell us about the history of the Solar System.

Objective 1: Notice that comets appear as they travel through the Solar System.
From time to time comets appear in the sky as they travel close to the Sun on their orbital path. As a comet approaches the Sun, it melts and outgasses, releasing particles that leave visible and invisible trails millions of miles long.

Objective 2: Notice that comets come from very far out in the Solar System.
Comets originate from an area at the outer fringes of the Solar System known as the Oort Cloud, the leftover debris from the formation of the Solar System.

Objective 3: Notice that we can send spacecraft to explore comets.
In 1995, the *Galileo* spacecraft was able to provide images of the breakup of the Shoemaker-Levy 9 comet as it struck Jupiter. Several current NASA and ESA missions are exploring comets up close: *Deep Space 1* flew by a comet; *Stardust* brought back samples of cometary particles; *Deep Impact* examined what's inside a comet; *Rosetta* will get the best close-up glimpse ever of a cometary nucleus, as both an orbiter and lander.

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STANDARDS

BENCHMARKS

4A The Physical Setting: The Universe

GRADES 9–12, PAGE 65

Mathematical models and computer simulations are used in studying evidence from many sources in order to form a scientific account of the universe.

4A The Physical Setting: The Universe

GRADES 6–8, PAGE 64

Large numbers of chunks of rock orbit the sun. Some of those that the Earth meets in its yearly orbit around the Sun glow and disintegrate from friction as they plunge through the atmosphere—and sometimes impact the ground. Other chunks of rocks mixed with ice have long, off-center orbits that carry them close to the Sun, where the radiation (of light and particles) boils off frozen material from their surface and pushes it into a long, illuminate tail.

4A The Physical Setting: The Universe

GRADES 9–12, PAGE 65

On the basis of scientific evidence, the universe is estimated to be over ten billion years old. The current theory is that its entire content expanded explosively from a hot, dense, chaotic mass. Stars condensed by gravity out of clouds of molecules of the lightest elements until nuclear fusion of the light elements into heavier ones began to occur. Fusion released giant amounts of energy over millions of years. Eventually, some stars exploded, producing clouds of heavy elements from which other stars and planets could later condense. The process of star formation and destruction continues.

1B—The Nature of Science: Scientific Inquiry

GRADES K–2, PAGE 10

People can often learn about things around them by just observing those things carefully, but sometimes they can learn more by doing something to the things and noting what happens.

GRADE 3–5 PAGE 11

Scientific investigations may take many different forms, including observing what things are like or what is happening somewhere, collecting specimens for analysis, and doing experiments. Investigations can focus on physical, biological, and social questions.

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NSES

Content Standard G History and Nature of Science: Nature of science

GRADES 5–8, PAGE 171

Scientists formulate and test their explanations of nature using observations, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.

Content Standard A Science as Inquiry: Understanding about scientific inquiry

GRADES 9–12, PAGE 175

Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.

Content Standard D Earth and Space Science: Earth in the Solar System

GRADES 5–8, PAGE 160

The Earth is the third planet from the Sun in a system that includes the Moon, the Sun, eight other planets, and their moons, and smaller objects, such as asteroids and comets. The Sun, an average star, is the central and largest body in the Solar System.

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Content Standard D Earth and Space Science: Origin and evolution of the universe.

GRADE 9–12, PAGE 190

The origin of the universe remains one of the greatest questions in science. The "big bang" theory places the origin between 10 and 20 billion years ago, when the universe began as a hot dense state; according to this theory, the universe has been expanding ever since.

GRADE 9–12, PAGE 189

The sun, the Earth, and the rest of the Solar System formed from a nebular cloud of dust and gas about 4.6 billion years ago. The early Earth was very different from the planet we live on today.

Content Standard A Science as Inquiry: Abilities necessary to do scientific inquiry.

GRADES K–4, PAGE 122

Plan and conduct a simple investigation. In the earliest years, investigations are largely based on systematic observations. As students develop, they may design and conduct simple experiments to answer questions. The idea of a fair test is possible for many students to consider by fourth grade.

Content Standard A Science as Inquiry: Understanding about scientific inquiry.

GRADES K–4, PAGE 123

Scientists use different kinds of investigation depending on the questions they are trying to answer. Types of investigations include describing objects, events, and organisms, classifying them and doing a fair test (experimenting).

Content Standard E Science and Technology: Understanding about science and technology.

GRADES K–4, PAGE 138

People have always had questions about their world. Science is one way of answering questions and explaining the natural world.

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ESSENTIAL QUESTION

What are comets?

What are comets made of? How do we know what comets are? When did comets form? Where in the Solar System are comets found? How do space scientists explore comets? What can we learn from comets about the Solar System?

ACTIVITY QUESTION

What do images and stories tell us about comets?

How do the perspectives of stories about comets help guide our understanding about comets today? What can we say, draw, write about comets that we look at, and read about in class?

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BACKGROUND

Comets once viewed as omens

Comets have been observed throughout history. Cometary events have been recorded as drawings, paintings, and petroglyphs. Many cultures have developed conceptions about comets, as omens, harbingers of good or bad luck. Comets have been viewed as dragons, fiery flames, but are understood today to be a mix of ice, gases, and particles.

Woodcut showing medieval view of destructive influence of a fourth century comet from Stanilaus Lubienietski's *Theatrum Cometicum* (Amsterdam, 1668) (Scan of original and caption from Don Yeomans' Comets: A Chronological History of Observation, Science, Myth and Folklore). Source: http://deepimpact.jpl.nasa.gov/science/comets-cultures.html

Cometary missions search for answers

We know generally that comets are made of ice and a mix of rocky, and loose material, but we need to learn much more. Currently NASA (National Aeronautics and Space Administration) and ESA (European Space Agency) are both in the midst of several missions that are exploring comets in different ways: as flybys, impactors, orbiters, and landers.

Comets are primeval remnants from the original formation of the planetary bodies, congealed out of interstellar gas in a process completed about 4 billion years ago. Planets and moons have changed a great deal over these past 4 billion years, due to impacts, weathering, and interior processes. The outer surfaces of comets have enclosed the original constituents of that time: ices, gases, rock, and dust—virtually unchanged. That means that the interior of a comet is a time capsule, an ice witness that holds clues for scientists to interpret.

One of the missions is named *Rosetta*, after the famed Rosetta stone that helped archaeologists interpret the meaning of Egyptian hieroglyphs. The spacecraft *Rosetta* lands a robotic explorer on the surface of a comet, to examine the mystery of the formation of the Solar System, and star systems in general. The Rosetta Mission is looking for evidence that might support one of three main possibilities about the origin of comets: 1) that comets are supernova remnants; 2) that comets condensed out of the interstellar medium; or 3) that comets formed as the Solar System emerged from a star-forming molecular cloud.

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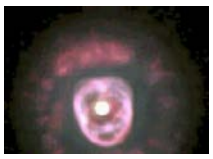
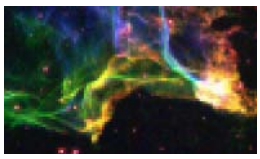
WHERE DID COMETS COME FROM?

Possible Origin #1



Supernova Remnant

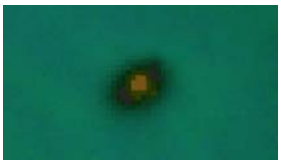
Possible Origin #2



Diffuse Interstellar Medium

Possible Origin #3

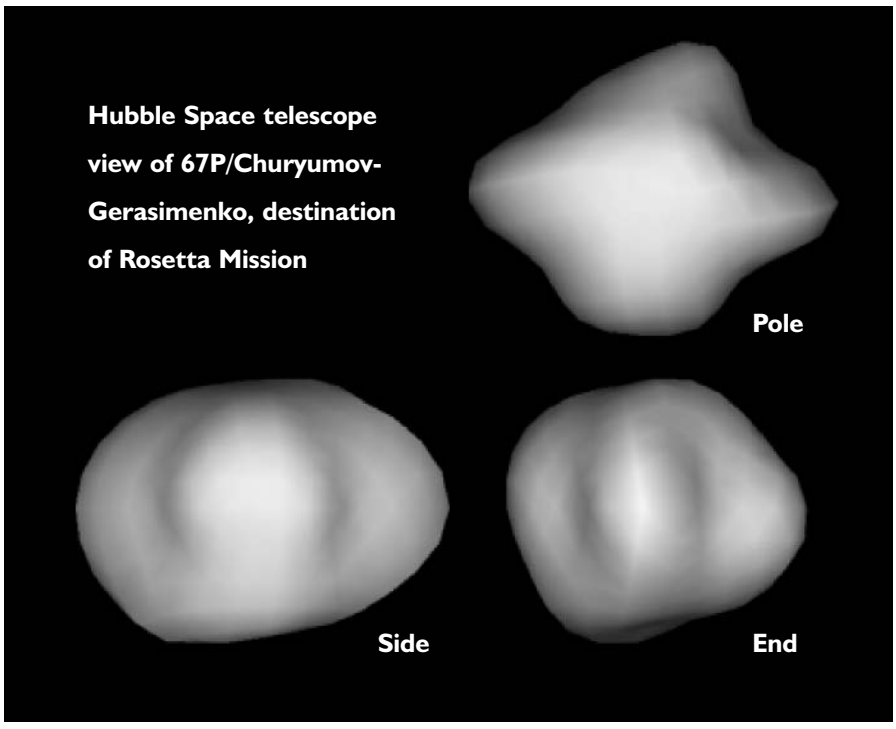
Natal Molecular Cloud



Forming Solar System

Comet Halley

Courtesy of Claudia Alexander,
JPL Scientist, Rosetta Mission



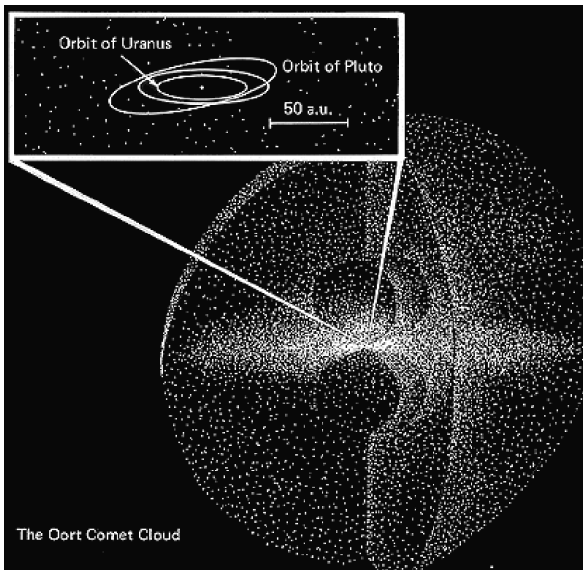
Where in the heliosphere is the Oort Cloud?

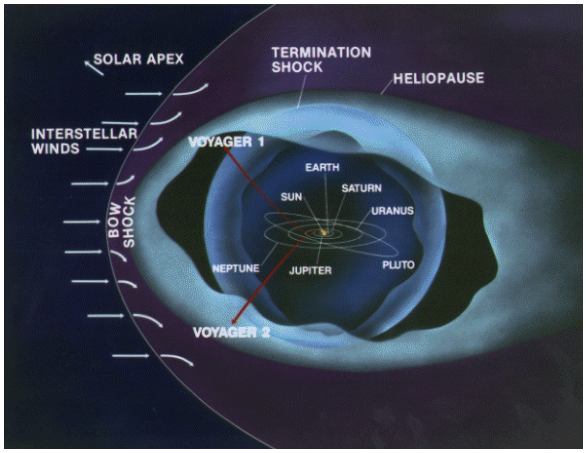
Comets are observed to come into the Solar System from all directions. In 1950, astronomer Jan Hendrik Oort suggested the existence of a cloud of icy worlds in the outer reaches of the Solar System.

Observations confirm that most comets come from the Oort cloud, out past 100 Astronomical Units from the Sun.

Here is a view of the Oort Cloud, as illustrated by JPL scientist Don Yeomans.

To put this into greater perspective, this is a view of the heliosphere, the volume of space influenced by the Sun, as it moves through the Milky Way. Voyager 1 and 2 are spacecraft traveling through the heliopause, a transitional region on their way to explore interstellar space. The spherical area around the planets represents the Oort Cloud.





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ACT OUT THE SCIENCE

Comet Story Example

Narration and mime activity: *Movement Integration Mediating Experience*

The Comet Sisters

Read the following story. Engage students in acting it out along the way. This story was written especially for the Deep Impact Mission by the Education and Public Outreach Coordinator, Maura Rountree-Brown. (Activity Adapted and Used with permission from Maura Rountree-Brown)

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Narrative	Movement	Concept
I'm going to tell you a story. Some of it has truth about comets. Some of it we think might be true about comets. And some of it—I just made up for the story. We have a wonderful Earth and some of it may be a result of comets. If they have contributed to what we have on Earth, have we used those gifts wisely and well?	This story can involve the whole class.	Comets have stimulated the imagination of humanity from the beginning.
Long, long ago, the people of the Earth had a close personal relationship with the planets and other bodies in the sky. None was sweeter than the relationship between the villagers of the Earth and the Comet Sisters. The Comet Sisters lived in the dark, cold outer regions of space and they waited there until it was time for one of them to come to Earth. For generations, the villagers had waited for the special time when one of the Comet Sisters would be chosen to come and visit them and when they came, there was great celebration. The villagers would make great preparation—special food and music.	Invite students to play any number of Comet Sisters, and have the rest of the class play as villagers. For growing hair, robe and capes—draw arms and hands back behind you to show the lengthening hair, robe and cape. For the Sun warming the comet's face—use hands to show the glow moving forward from the face and then swept back to the tail behind. Act out as much of the story in hand actions as possible. Comets showing gestures of being cold, sad.	Comets may be the source of water on Earth, the result of impacts early in geological history. Comets come from cold regions in the Kuiper Belt near Pluto and the Oort Cloud. Comets have different orbits that are either over 200 years long or under 200 years long and so they appear at different times.

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Narrative	Movement	Concept
And when at last it was time for one of the sisters to come, the villagers would gather their food and their instruments and make their way to the meadow where the meeting was to take place. Each family took with them a large basket for they knew that they would return from the celebration with special gifts from the comet. Meanwhile, the sister who had been chosen would begin her journey from the dark, cold region far away toward the planet Earth and her friends the villagers. As the families from the village approached the field, they looked into the sky and stopped dead still. Because they had to admit that it was the most beautiful sight they had ever seen. Coming toward them was the Comet Sister and as she approached, and her cold body was warmed by the Sun, her face began to glow with a beautiful radiance, and her hair began to reflect the Sun's light and grow in long streaming strands behind her. Her robes would begin to glow and (continued)	Motions for the celebration: Gathering their food Gathering musical instruments Moving in groups, like families Bringing baskets for gifts received from the comet sisters One comet sister comes toward the villagers… Face glowing, smiling Hair tossed about, reflecting the sunlight	Comets have a nucleus as a body. They are made of ice and dust and as their orbit brings them close to the Sun, their surface warms and ice and dust erupt from the comet pushing forward and then flowing back behind the nucleus in a long tail. This outgassed material is called coma. Comets have three tails, the main dust tail, the ion tail and the neutral sodium tail. We only see the coma around the nucleus and in the tail because of the reflection of the Sun on the dust and ice.

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Narrative	Movement	Concept
grow behind her and even her cape would flow to a long bright light behind her.	Streaming strands: consider props such as ribbons…and a cape…	Comets get their name from the Greek word *kometes*, which means hair.
As she landed in the meadow, they all greeted each other warmly and there was dancing and celebration and music throughout the night as they renewed their friendship with the Comet Sister. The most important part of the evening was when the Comet Sister would gather the villagers together to tell them secret stories from many years before. Only the Comet Sisters held the secrets of a time when the world was a whirling pool and the planets formed and swam in the skies. The villagers sat breathless listening to these stories trying to imagine what it must have been like. It was this way until morning and when the first dawn light was about to appear, the Comet Sister gathered the villagers with their baskets. She took long strands from her hair, gifts of reflected light from the Sun and put them into each family's basket. (continued)	Improvise dancing and music Pose as listening to Solar System stories	Clues in their stories. Comets are sometimes called dirty snowballs because they have in them debris from the early formation of the Solar System. We aren't sure how much rock and dirt there is compared to the amount of ice, gas and dust. Comets that still exist escaped being pulled into the formation of planets but they carry within them the last remaining clues from that period of formation 4.5 to 4.0 billion years ago. It would be difficult to explore the core of a planet the way we plan to explore beneath the surface of a comet to find those remaining clues.

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Narrative	Movement	Concept
She also took pieces of her robe with water for their fields and parts of her cape with life for their harvests. When each family's basket was full the Comet Sister bade them farewell and took to the sky. The villagers returned to their homes with their gifts and cherished them and used them wisely and they used them well. The Comet continued her journey to the Sun. She greeted the Sun who gave her so much and then began her journey back to her sisters. It was this way for generations and it was a relationship of light and love and loyalty.	A farewell scene Suggested Actions: For light, love and loyalty—use light (open arms wide in a circle), love (cross arms over your heart) loyalty (clasp hands together).	There are different theories about comets, two of which are that they may at one time have impacted the Earth to bring water (water for their fields) or perhaps the early organisms for life (life for their harvests). As a comet draws closer to the Sun, there is more coma and a longer tail and as the comet continues its orbit away from the Sun, the warming of the nucleus surface lessens and so does the comet's tail.
But it came to pass that the next generations did not have the same love in their hearts for the Comet Sisters and not, as it turned out, the same loyalty. They began to complain each time a Comet Sister would come and felt it unimportant to go to the meadows to celebrate and renew their relationship and eventually, they were bored and wanted something new and more exciting to treasure. Eventually they (continued)	Part 2: change in demeanor of villagers, less interested in the sky Shrugging, not paying attention	The Comet sister can be set up as a possible giver of water and life elements—one who cares for the environment. This raises questions such as: Do we use the gifts we have been given on Earth wisely and well? Have we moved beyond them to things we abuse and when

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Narrative	Movement	Concept
used up all the precious gifts the Comet Sister had given them. Some of them went out into the world and hunted and one day, one of them returned. "Look" he said, "I have found something new called fire." This will be our new treasure. The villagers gathered around fire and took it into their homes and formed a relationship with it for what it could give them and what they did not have to give in return and it was a relationship of light and love. The Comet Sisters were saddened that the villagers no longer came to the meadow or kept their relationship and so they did not come to Earth. Instead, they floated through the sky glancing down to Earth to watch their former friends and even though the comets were still a beautiful sight, the villagers ignored them. So the chosen sister journeyed to the Sun and greeted the Sun as before and then returned to the cold outer regions to report the sad news to her family. Finally, the villagers forgot the Comet (continued)	Use hands to hold an imaginary torch on fire, or various ways to start a fire (flint and rock) Comet sisters show expressions of sadness Villagers ignore comet sisters	those things are gone, what will our options be for getting more? As often today, with so much information overload, we take such things for granted; we do not pay attention to events such as comets, meteor showers, spacecraft launches, scientific discoveries

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Narrative	Movement	Concept
Sisters altogether and the secret stories of the beginning of the world faded from their memories. It was this way for generations more until a newer generation became even colder in their hearts and as they had become bored with the Comet Sisters, so they became bored with their friend, fire. Some of the villagers went out into the world to look for a newer treasure and one day, one of them returned and said, "Look–I have found Electricity. We can use electricity and we don't need to work at forming a relationship with it. It is ours to use." And so, rather than form a relationship with electricity, they enslaved it and used it for what it could give them. And it was a relationship of light.	Make the motion of orbit around the Sun and out again. Show fascination with electricity and electronic devices (video games, computers, TVs) Show actions of using electrical labor-saving devices	Comets orbit around the sun, coming into view occasionally.
Well, what is not nurtured or cherished, eventually dies, and so it was that electricity finally died because the villagers had used it neither wisely–nor well. The villagers were left in great darkness both on the Earth and in their hearts. Being cunning by nature, they gathered (continued)	Actions of peering through the darkness	This raises questions about humanity's relationship with the powers of nature.

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Narrative	Movement	Concept
together to discuss their plight and one of them reminded the others of the relationship their relatives had once had with the Comet Sisters. "We should ask the Comet Sisters to come again and bring us their gifts," said one. But the others complained that it would be too much work to go to the meadows or to make the food and plan the celebration.	A mix of emotions, those who want to appeal to ask the Comet sisters to return	Do we, as a society, have a responsibility to care for the Earth, or can we use resources freely, knowing that science and technology will save the day from environmental disaster?
Finally, one of them had a plan. "If we invite one of the Comet Sisters to come to Earth, we won't have to form a relationship but we can capture her and cut off all her hair and take her robe and cape and we will have plenty of light and water and life to last for the rest of our lives." All the villagers thought it was a fine idea and so they called to the Comet Sisters and begged them to return and promised them the same friendship their relatives had once had.	Movements of trickiness, greediness, cunning	
Well, the Comet Sisters were wise and they were not fooled by the (continued)	Comet Sisters show gestures of making a plan	

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Narrative	Movement	Concept
villagers' plan. "This foolish generation has no love or loyalty in their hearts and we will visit them but we will teach them a lesson."		
A date was set for the coming celebration and both the villagers and the Comet Sisters carefully planned what they must do.		
When the day arrived, the villagers put together some leftovers and someone sort of knew how to play a guitar and someone else thought they might remember a dance that would do and they started out to the field with their music and their food.	Movements of preparing a feast	
Each family carried a large basket for the gifts they knew they would receive. One of the Comet Sisters was chosen to visit Earth and so she departed from her family. As the villagers arrived in the meadow, they looked up into the sky and were stunned by what they saw.	Small groups bringing baskets Seeing the comet	
For they had to admit it was the most beautiful sight they had ever seen. Something inside them that had been long lost (continued)		

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Narrative	Movement	Concept
awakened and they wanted to grow close to this amazing comet. As the Comet Sister approached them, the Sun warmed her face and it glowed with a great light. And her long hair reflected the Sun and grew as did her robe and her cape and they trailed in a long stream behind her. As she grew closer, the villagers ran toward her with their baskets. But she did not come to the meadow. Instead, she flew through the sky and as she did, she took strands from her hair and from her robe and cape and flung them toward the Earth. In great excitement, the villagers ran toward the shining strand but as it came closer to the Earth, its light burned out and disappeared before they could catch it. And so it was throughout the night. The Comet Sister threw a shining strand toward the Earth and the villagers would run toward it only to have it vanish from its trail. The villagers ran back and forth (continued)	Actions of running toward the strands, but not finding anything	When we see a meteor shower…Meteor showers are really debris from comets falling into the Earth's atmosphere. Once inside the atmosphere they shoot across the sky and then burn up. We have 40,000 tons of debris from comets falling to Earth every year.

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Narrative	Movement	Concept
throughout the meadow until dawn and could not catch one strand of the comet's hair or robe or cape and finally, as the first light of day appeared, she vanished on her journey to greet the Sun before she returned again to her sisters. Sadly, the comet sisters met and knew that they must make a decision. They decided that only villagers who could love them and search for them in the skies could renew the friendship. This is the way it is to this day. And it may be that you will go out into the night to look at a meteor shower and realize that it is really the Comet Sisters, traveling through the sky and tossing strands of their beautiful hair and clothing toward the Earth—looking once more for those who can offer them a relationship of light and love and loyalty.	Form a closing tableau that finishes the story, with everyone in the picture, and everyone showing the gestures created for light, love, and loyalty.	The Comet Sisters are waiting for us to search them out again. We plan space missions to comets so we can find out more about them than we can find out from Earth. We will in a way begin a wonderful relationship with them and once again learn the secret stories from the beginning of time.

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FOLLOW-UP THE STORY WITH A DISCUSSION

Grades K–2

Ask students to tell what they remember about the story and use the background information to give them facts about comets. Return to the question of what is true, what is still to be learned, and what is made up for the telling of the story.

Follow the students' interests in discussing the story. A guiding question might be: *How wisely do we use the gifts we have on Earth?*

Grades 3–5

Make a class list asking the students to guess which parts of the story are:

1. What scientists believe to be true about comets
2. What scientists wonder about comets
3. What is made up for the story

Lead a discussion with guiding questions such as:

- How wisely do we use the gifts we have on Earth?
- How does scientific knowledge help us make decisions?

Small Group Mime Activity: *Movement Integration Mediating Experience*

Invite students to:

- Write and act out their own comet story.
- Write an adventure story about what will happen when NASA missions go visit the "Comet Sisters" in space. Encourage students to knowingly mix fact, theory, and fiction.

Invite anyone who has seen a comet to tell the class their own story and their feelings about the experience.

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MATERIALS

In this activity, students will experience stories and images of cometary phenomena.

For All Lessons, to Record Reflections, Observations, Calculations, etc.

- Science Notebooks: writing and drawing utensils

Warm-Up Activity: Time Capsule

- A container to place students' time capsules (such as a shoeboxes, cereal boxes, cereal box, small treasure chest)
- Arts and crafts materials for students to make objects for the time capsule
- Artistic representations of cometary phenomena
- Images selected from NASA and ESA web sites
- Videos and images depicting comets
- Illustration of the heliosphere, locating the Oort Cloud

DEMONSTRATION

This demonstration invites students to look at comets through the eyes of those who have experienced viewing them. Throughout history, the appearance of comets has affected people's lives. As marvels, mysteries, or monsters, comets have captivated the imagination and stimulated fears. Most of these reactions occurred in times and places that did not have full understanding of comets. The tools of scientific inquiry and the technologies of space exploration have transformed our view toward a scientific explanation of comets, no less amazing.

PRE K–2

Read a story about comets. There are many choices.

Recommended selection: *Halley Came to Jackson* By Mary Chapin Carpenter, Dan Andreasen (Illustrator)

Inspired by a family story told by Eudora Welty, the story focuses on Halley's Comet and the awe it evokes in the people of Jackson, Mississippi, as they view it in 1910. We meet a baby whose father holds her in his arms to see the great comet's tail "stretched out like a stardust streak." Then it fast-forwards to 1986, when the baby is now a white-haired woman, watching for the comet "from her daddy's porch" once again.

Invite students to ask questions upon hearing the story. Lead students in a discussion about comets and their attitudes toward comets. If anyone has personally viewed a comet, have them describe the event.

3–5

Read a story about comets. There are many choices.

Recommended selection: *Mr. Halley and His Comet*
By Teresa Dahlquist, Ralf Dahlquist

The book is written in whimsical rhyming prose. It places the story of Halley's Comet in the context of the life work of Edmund Halley, his colleagues, and the scientific adventures of his times.

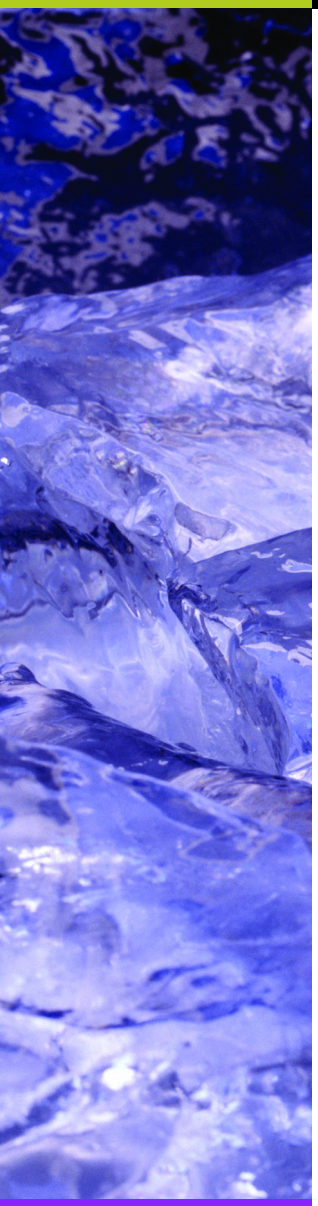
Invite students to ask questions upon hearing the story. Lead students in a discussion about comets and their attitudes toward comets. Have anyone who has personally viewed a comet share the story of the event.

MAIN ACTIVITY

This activity involves understanding what comets are, what comets are made of, and how comets are ice witnesses to the formation of the Solar System.

PREPARATION

For the warm-up activity, prepare a container for a class time capsule that will be stored for a week or so. Around the room, display several comet-themed exploratory zones consisting of images, videos and artistic representations of cometary phenomena.



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TEACHING TIPS

Explore

As students explore the phenomenon of comets, they are likely to have already formed conceptions about comets that correspond to historical misconceptions. As a strategy to move students toward new understanding, be prepared to help students understand the cultural context of stories about comets, by examining the lore that developed over many centuries of oral traditions, as well as more recent scientific investigations about comets.

Diagnose

Listen to student ideas about comets. Guide students to consider the new knowledge about comets emerging from space exploration. Listen to their thoughts about such questions as: Where do comets originate? What are comets made of? What can we learn about the Solar System by studying comets? What can we learn by placing the cultural story traditions side by side with what we are learning about comets through space science?

Design

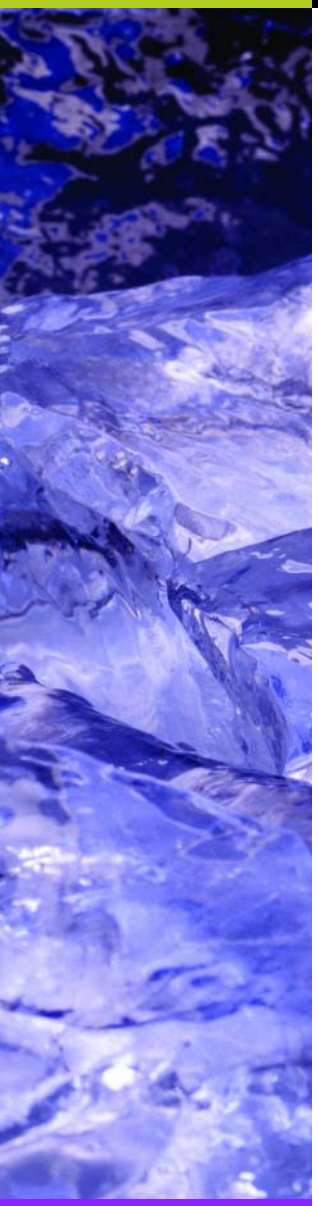
Have students work in teams to generate questions that arise from the visits to the exploratory zones about comets. Invite students to devise ways to get answers to their questions through data from the current missions or by imagining a cometary mission they might design

Discuss

Ask questions such as: How do scientists learn about comets? What is the relationship between the knowledge of comets from earlier historical times and today? What are the big questions scientists are asking about comets through the current and future missions?

Use

This activity connects concepts about comets to an understanding about what the early Solar System might have been like and how the Solar System formed.



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WARM-UP AND PRE-ASSESSMENT

Invite students to contribute a drawing, a piece of writing, or a small object of their own making to place into a time capsule. Ask them to consider that the item they select is a clue about themselves. Invite discussion about why they made their choice and what it means about themselves. Place the items in a specially prepared container (for example, a shoebox, a cereal box, a small treasure chest). Let them know that in a week or so, after some passage of time, they will open the time capsule and take a look at it and talk again about what it means.

Lead a discussion that connects this time capsule activity to the notion of a comet as a time capsule that was packed 4 billion years ago and that the cometary spacecraft are going to explore over the next few years.

PROCEDURES

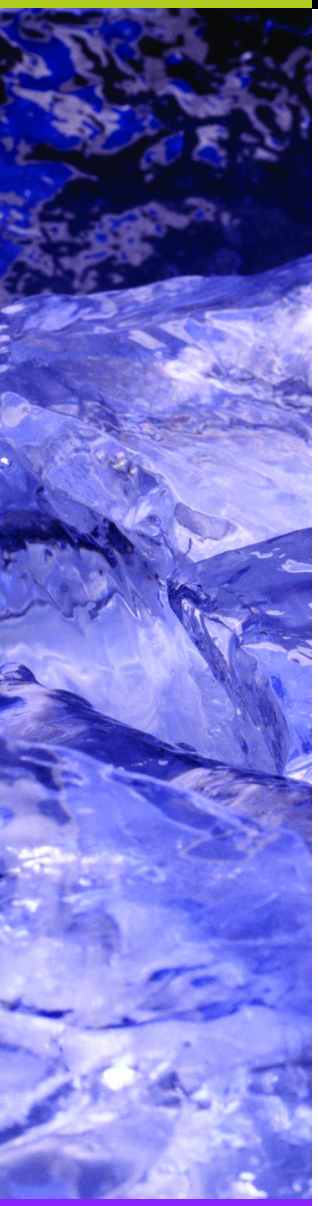
Devise exploratory zones using gallery images of comets as observed from Earth and space:

- Halley's Comet
- Hale-Bopp
- Kohoutek
- Shoemaker-Levy 9
- Evidence of the comet that struck Earth 65 million years ago, coinciding with a massive dinosaur extinction event
- Map of the Oort Cloud

Invite small groups of students to visit each exploratory zone, make observations and generate questions.

Select images and information from NASA and ESA exploration of comets: *Deep Space1, Stardust, Deep Impact, Rosetta,* indicating the different ways each mission examines comets.

COMETS, THE ICE WITNESSES



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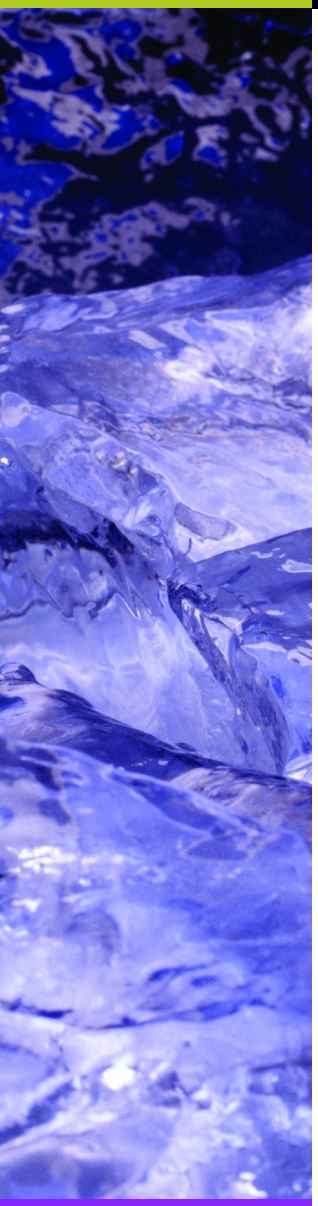
This table can be used to guide discussion of common conceptions and misconceptions about comets.

Conceptions/Questions	Explanations
■ Comets look icy: What are they made of?	• Comets are primitive icy worlds • A mix of ice, gases, particles
■ Comets have tails: What are they made of?	• Ice and dust • Charged particles (ions)
■ Comets look fiery: How does fire burn in space?	• Sometimes people have imagined that comets are like fireballs or fiery dragons • This is sometimes how it appears in the sky
■ Comets have elongated orbits from the Oort Cloud to the Sun: How far away is the Oort Cloud? What triggers the inward journey of a comet?	• Debris from formation of the Solar System • Orbital perturbation may send comets inward to the Sun
■ Comets impact planets and moons: What results from cometary impacts?	• Brings water to planetary object • Makes impact craters • Creates enormous impact effects
■ How did comets form? (Reference: Claudia Alexander, *Rosetta* mission)	• Supernova remnant? • Diffuse Interstellar Medium condensate? • Formed out of the natal molecular cloud (solar nebular theory)?
■ How can we observe comets directly?	• With the naked eye • Through telescopes • Spacecraft flybys • (*Deep Space 1*) • Return sample gathered from the debris escaping from a comet (*Stardust*) • We can poke a hole in a comet and look at what comes out (*Deep Impact*) • Analysis of gases coming off a comet (*Rosetta*) • A lander (future mission?)



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DISCUSSION & REFLECTION

What's in a Name?

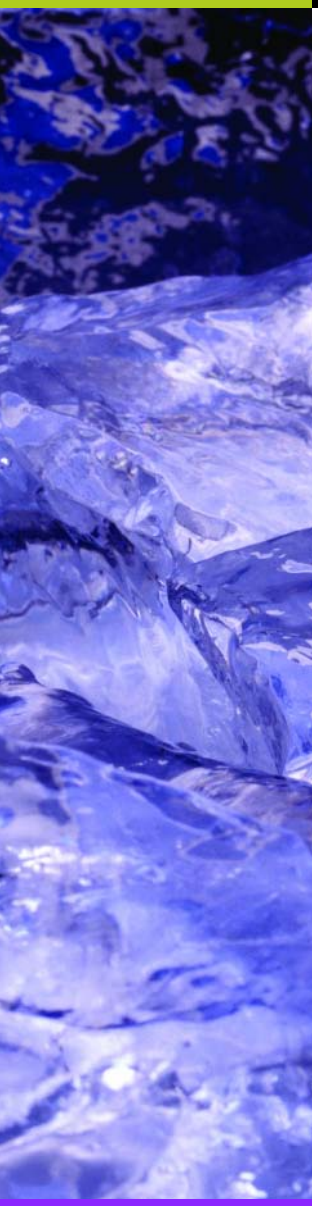
How does the language we use to describe spacecraft affect our understanding of the purpose of the spacecraft's mission? How does the language we use to describe the mission affect our understanding of the science objectives?

Lead a discussion that reflects on the language used to name spacecraft and describe their mission science. For example, here are some thoughts that might arise upon reflecting on the names of three of the comet missions.

The spacecraft called *Stardust* collected dust coming off a comet and returned the sample to Earth for scientists to examine in the laboratory. The name evoked the idea that comets, as well as the entire Solar System, originated as stardust. Perhaps *Comet Dust* would have been a more accurate description of what it actually did.

The spacecraft *Deep Impact* used the dramatic method of placing an object in the path of the comet, causing the comet to strike the object, making a hole, which resulted in ejecta strewn out that the spacecraft then observed as data. Another name might have made us think differently about the mission. What if it were called *Ice Fisher*, as if to go to a frozen lake up north, poke a hole, let out a line, and fish for data?

Rosetta evokes the history of the *Rosetta* stone which had the same message carved in known and unknown languages, allowing linguists to translate and break the code. This gets us thinking about the constituents of the comet as an ice witness telling the story of what happened 4 billion years ago in an unknown language that we might come to understand.



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CURRICULUM CONNECTIONS

Social Studies

The cultural history of human thought about comets offer rich connections to social studies, for example, one famous appearance of Halley's Comet occurred in April 1066 in the midst of the crucial Battle of Hastings during the Norman invasion of Anglo-Saxon England.

Below is the scene as depicted in the 14th Century Bayeaux Tapestry.

At the left, several people point in the sky toward what was described as "a great ball of fire with a flaming tail (top center). At the top, in Latin it reads, "*Isti mirant stella*" which means, "they wondered at a star." A man runs to warn King Harold of this very bad omen. Overtaken by anguish he has a foreboding, a vision of a ghostly Norman fleet (seen at the bottom), about to invade.

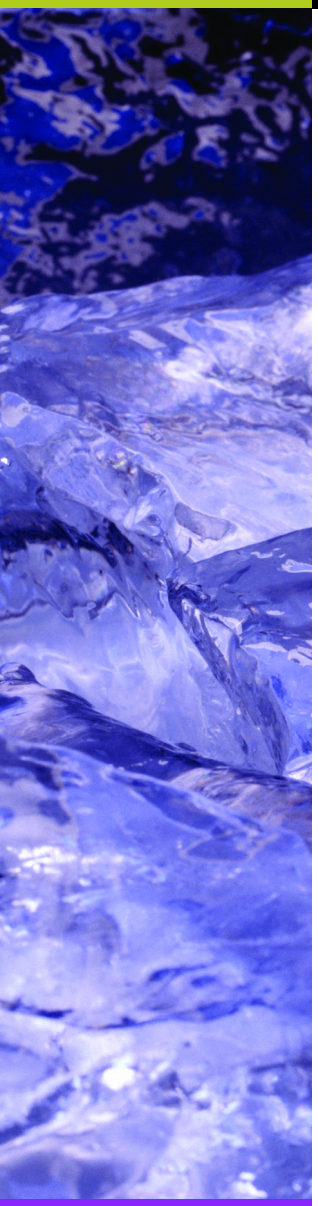
Source: http://www.bayeuxtapestry.org.uk/bayeux14.htm

In this event, the appearance of the comet was seen as a bad omen. Might the outcome have been different if Harold had viewed the comet as a good omen? The same comet must have appeared to the Normans on the other side of the English Channel? What was their view of the meaning of the comet?

Going Deeper: Astronomy and Social Studies

Archaeoastronomy brings together the natural science of astronomy and the social science of anthropology, studying how different peoples in different times and places conceived of the universe, the stars, the planets, the Moon, and comets.

By piecing together depictions of comets in art and oral traditions that record eyewitness accounts of the appearances of comets, archaeoastronomers have described how attitudes about space phenomena have affected the direction of civilization and key moments in history. In some cases, historians have been able to match timelines of cometary events recorded in different ancient cultures.



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ASSESSMENT CRITERIA

Exemplary

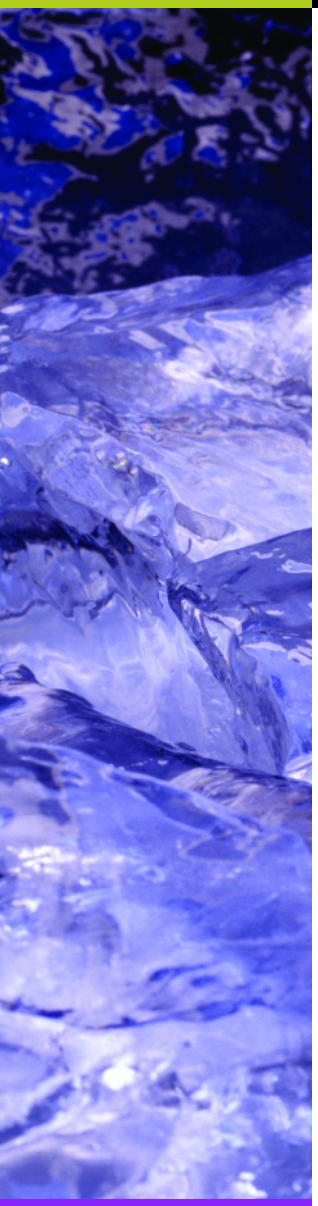
- Students write and illustrate a comet story and share it dynamically with both a small group and the whole group.
- Students display drawings, constructions, and dynamic models drawn from their science notebooks and web-based research about comets and how they may be ice witnesses to the formation of the Solar System.
- Students identify and extend science questions drawn from direct observation and extended research about comets.
- Students explore a rich range of observations about comets and relate it to prior shared experiences.
- Students succeed in asking a rich and extensive range of questions about the origin, structure and composition of comets.
- Students relate ideas about comets to the whole context of exploring ice in the Solar System.

Emerging

- Students write and illustrate a description of comets and share it with both a small group and the whole group.
- Students make their own time capsule and connect how a comet is like a time capsule.
- Students pose basic science questions drawn from their observations and research of comets.
- Students observe examples of comets.
- Student use a variety of ways to represent examples of comets.
- Students ask a rich range of questions about the origin, structure and composition of comets.
- Students make speculations about possible explanations for comets

Formative

- Students recognize comets and describe the basic features of comets and where they come from.
- Students identify characteristics of the structure of a comet (the nucleus, the coma, the tails).
- Students pose science questions drawn out of the context of observing and researching comets.



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RESOURCES

NASA Cometary Exploration Resources

http://nmp.jpl.nasa.gov/ds1
Deep Space 1 Mission

http://deepimpact.jpl.nasa.gov/educ/index.html
Deep Impact Mission, many hands-on K–12 activities, such as Make a Comet and Eat it!; Deep Impact Comet on a Stick!; Exploring Comets and Modeling for Mission Success

http://stardust.jpl.nasa.gov/classroom
Stardust Mission

http://sci.esa.int/science-e/www/area/index.cfm?fareaid=13
Rosetta Mission

Articles

http://www.planetary.org/html/news/articlearchive/headlines/2001/Oort1.htm
Oort Cloud Article:

http://www.cnn.com/books/dialogue/9805/levy.chat
CNN interview with David Levy about comets

Children's Books

Davy Crockett Saves the World by Rosalyn Schanzer.

Halley's Comet Pop-Up Book by Patrick Moore and Heather Cooper.
Paper Engineering By Vic Duppa-Whyte, Illustrated by Paul Doherty. London, United Kingdom: Deans International Publishing, 1985.

Why Did Halley's Comet Cross the Universe? and other spaced-out riddles, jokes, and knock-knock. Written and illustrated by Mort Gerberg (Scholastic, 1985).

Edmond Halley: The Man and His Comet
by Barbara Hooper Heckart
Presents the life of the seventeenth-century scientist who made predictions about the comet that bears his name and discusses many other important scientific contributions he made.

Work by JPL Scientist Don Yeomans

Yeomans, Donald K. Comets: A Chronological History of Observation, Science, Myth and Folklore. John Wiley & Sons, Inc. New York. 1991.

Images

Link to image gallery