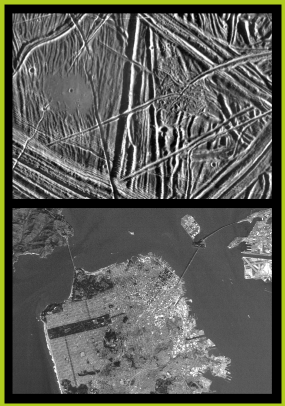
INVESTIGATING ICE WORLDS

LESSON DIRECTORY

PHOTO GALLERY



This lesson develops precursor understanding about investigating ice worlds in the outer planetary regions that can help us explain more about the Solar System.

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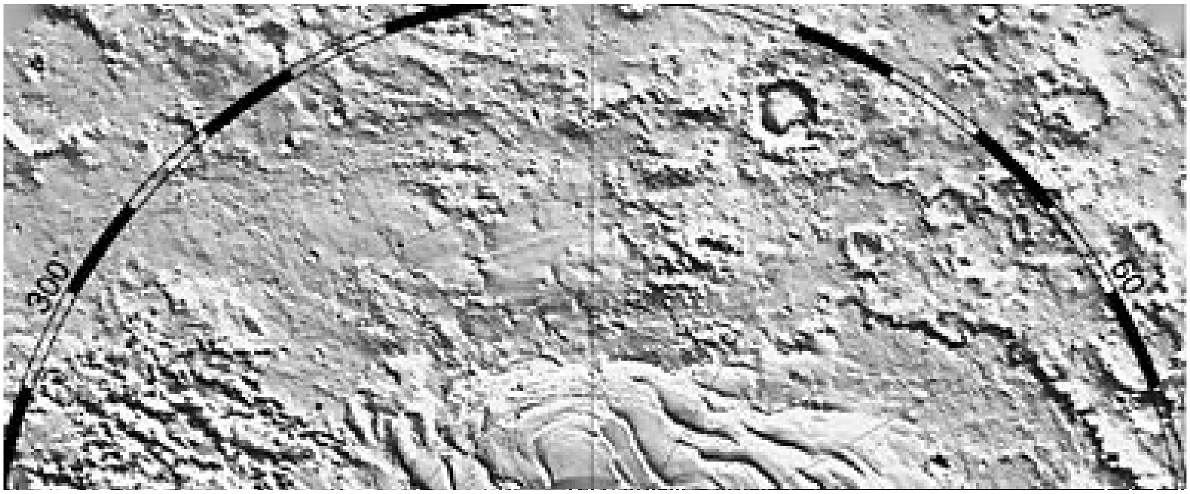
SCIENCE & LITERATURE



"Life beneath the ice-covered oceans of Jupiter's moon Europa will appear increasingly likely and before the century is half way through, large marine creatures will be discovered when the first robot probes drill through Europa's ice, revealing an entire new biota."

— Sir Arthur C. Clarke,
"2099…The Beginning of History" in Greetings, Carbon-Based Bipeds!

"All these worlds are yours—except EUROPA. Attempt no landings there."

— Sir Arthur C. Clarke,
2010: Odyssey Two

"Today, most of Pluto's long-held secrets remain secrets—guarded by the depths of distance between us and that ancient, icy little world. Hubble delivered a glimpse of the pinkish little ice-ball ornament to us, temptingly close now, but still too maddeningly far.

To see the Solar System's ninth sister as she really is, we must go to her. And amazingly, our species has developed the will, and the way, to do just that.

So guard your secrets while you can, Pluto! We are coming."

— Alan Stern, and Jacqueline Mitton,
Pluto and Charon: Ice Worlds on the Ragged Edge of the Solar System

CONCEPT OVERVIEW

This lesson develops precursor understanding about investigating ice worlds in the outer planetary regions that can help us explain more about the Solar System.

Concepts:

- Outer planets
- Ice worlds
- Photometry

This lesson provides concrete experiences of:

- Enacting stories that connects literature to science related to ice worlds.
- Viewing and interpreting space-based images of ice worlds.
- Investigating ice on outer planetary ice worlds.

PRE K–GRADE 2 CONCEPTS

- There are many small icy, rocky worlds in the outer Solar System, such as Pluto/Charon.
- Jupiter's moon Europa is covered with ice and is thought to have an ocean of water beneath its icy surface.

GRADE 3–5 CONCEPTS

- There are many small icy, rocky worlds in the outer Solar System, such as Pluto/Charon, Neptune's moon, Triton, and the Kuiper Belt Objects.
- Small icy worlds in the outer system are remnants of the formation of the Solar System.
- Scientists familiar with ice on Earth notice many similarities to the appearance of sea ice on Europa—suggesting that an ocean exists beneath its icy surface.
- The appearance of the surface of an icy world provides clues to interior processes.
- In addition to water ice (frozen H_2O), there are other ices on the surface of outer planetary worlds.

LESSON SUMMARY & OBJECTIVES

Once thought to be scarce, water ice appears in abundance as a constituent of ancient ice worlds that populate the outer region of the Solar System, the region of Pluto/Charon and the Kuiper Belt Objects orbiting at distances of 50 to 100 AU from the Sun. The large outer planets have captured ice worlds that may have formed early in the history of the Solar System, notably Neptune's Triton and Jupiter's Europa.

Objective 1: Notice that the outer Solar System is the home of many ice worlds.
Neptune's moon Triton, the planet Pluto and its moon Charon, and the Kuiper Belt objects beyond are small icy, rocky worlds and short-period comets.

Objective 2: Notice that the surface features of ice worlds are indicators of active processes, both on the surface and in the interior.
Scientists are alert to surface activity by examining reflected light at various wavelengths. Europa is especially interesting because of the very strong evidence for an ocean beneath the icy surface. Images of Europa's surface returned by the *Galileo* spacecraft have given clues to the interior workings of Europa.

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STANDARDS

BENCHMARKS:

4A The Physical Setting: The Universe

GRADES 3–5, PAGE 63

- Telescopes magnify the appearance of some distant objects in the sky, including the Moon and the planets. The number of stars that can be seen through telescopes is dramatically greater than can be seen by the unaided eye.

NSES:

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

GRADES K–4, PAGE 138

- Tools help scientist make better observations, measurements, and equipment for investigations. They help scientists see, measure, and do things that they could not otherwise see, measure, and do.

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ESSENTIAL QUESTION

What is the importance of outer planetary ice worlds?

How does the abundance of ice worlds affect scientist's view of the Solar System? How does the presence of ice and sub-surface oceans on a world like Europa affect our thinking about where to look for life in the Solar System?

ACTIVITY QUESTION

What do the surface features of ice worlds tell us about active processes?

What can we learn about the Solar System by considering the formation of ices on outer planetary worlds? What observations about water ice and other ices on ancient worlds in the outer Solar System can we record? What can we say, draw, or write about outer planetary ice worlds?

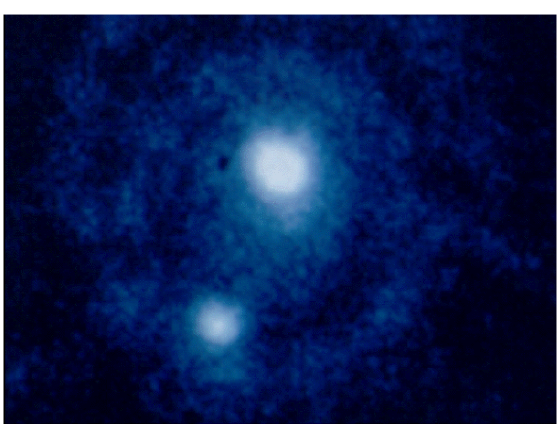
BACKGROUND

Our understanding of distant ice worlds in the outer Solar System is based on observation through ground-based and space-based telescopes as well as spacecraft. These objects are so distant that even the best images are still very dim, even when observed through the Hubble Space Telescope. Nevertheless, unlocking the mystery of these primeval icy worlds may tell us more about the story of how the Solar System formed.

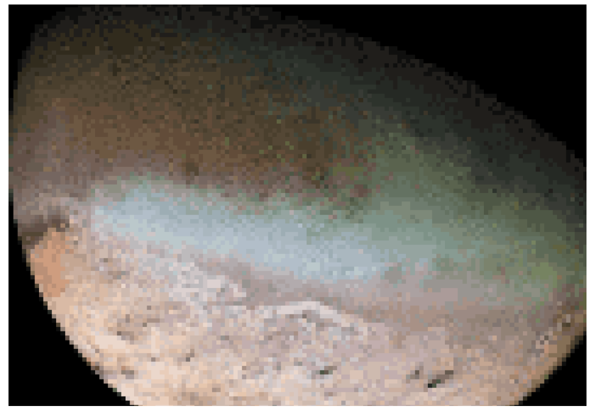
How do space scientists know the composition of dim and distant objects in the Solar System?

Planetary objects such as Europa, Triton, Pluto, and the Kuiper Belt Objects are small, dim, and distant from the Earth. None of these objects are visible to the naked eye. Even through high-powered telescopes, these objects appear as tiny points of light, without features. So how do astronomers and planetary scientists figure out what these worlds look like and are made of? Basically, they look at these objects using ever more light-sensitive instruments to analyze the information contained in the reflected light.

Pluto and Charon can be considered as a binary system.



Scientists are studying the patterns of light reflected by Pluto/Charon to determine whether its tenuous atmosphere indicates active change processes. So far, data suggests minimal activity.



Neptune's moon Triton is another interesting ice world. Ground-based photometry data from Triton does indicate active processes, indicating changes in the atmosphere that suggest some kind of seasonal change.

Photometry and Spectroscopy: The Information in the Light

Photometry is the art and science of extracting information from light. All of these small outer planetary worlds receive the incident light of the Sun. Each object absorbs some of the light and reflects the rest. The measurement of the ratio of the amount of reflected light compared to the sunlight is called *albedo*. For example, Earth has an albedo of 0.38, which means that Earth reflects 38% of the sunlight back out into space.

Radar telescopes act like light flash attachments on a camera. Just as a flash illuminates the object to be imaged, a radio telescope beams radio waves that bounce off planetary objects and the reflected radar bounces back. *Radar albedo* is the ratio of the amount of reflected radar compared to the beamed radar.

Spectroscopy looks at patterns of emissivity and reflectivity of different elements and compounds. Stars emit light; planetary objects reflect light. By comparing patterns of reflected light with objects of known composition, scientists can infer what an object is made of, at least at the surface. Sensitive digital instruments called *charge-coupled devices* (CCD) can be used to observe objects in greater detail, limited by the resolution available, by changing the photon measurements into charged signals that read as *pixels*. These pixels are the photometric data that scientists examine to infer what the surface looks like and what the object is made of.

Occultations: Readings of Filtered Starlight

Occasionally, Pluto and Charon pass directly in front of a star. This is called an *occultation*, a hiding of the star behind the planetary object. By comparing the unobstructed starlight signal with the light that filters through the tenuous atmospheres of Pluto/Charon, we have learned that Pluto has water, ammonia and methane ices and that Charon is mostly water ice. Pluto is still an object for ground-based exploration: even students can observe Pluto/Charon and take photometric data. In early 2006, NASA launched a mission called New Horizons to explore Pluto/Charon and the Kuiper Belt objects beyond.

Europa

Europa is one of Jupiter’s four largest moons. The astronomer Galileo first saw Europa through his telescope back in 1610. At first the public was skeptical. They thought Galileo’s moons were mere bubbles in the flawed lenses. But as telescopes advanced in quality, the four Galilean moons were consistently observed, showing Jupiter and its moons to be a kind of miniature Solar System. In fact, Galileo’s discovery helped persuade the European public to accept that the Earth went around the Sun.

Back in the 1970s, Earth-based telescopic photometric data showed that Europa was covered with ice. Essentially, this was done with long-distance radar astronomy. By sending out a radio signal and letting it bounce back, investigators retrieved basic spectral signatures that identified the surface as composed of nearly pure frozen water: ice!

In 1979, NASA's *Voyager* spacecraft sent back the first views of surface features showing Europa's smooth icy surface, crisscrossed by fracture-like features hundreds of miles long.

From 1995 to 2003, the *Galileo* spacecraft sent back spectacular close-up images and other readings that gave us a detailed look at a surface that resembles ice-covered areas on Earth. Analysis has revealed evidence for movement of ice floes, absence of massive cratering (suggesting a relatively young surface no older that 30 million years), a tenuous oxygen atmosphere (perhaps a product of interaction with Jupiter's intense magnetosphere), and remnants of salts consistent with ocean-water evaporation (perhaps ice volcanoes, geysers, or cratering could explain such salt slicks).

The most exciting implication is the high probability that an ocean lies beneath the icy surface—surface features most resemble features of sea ice on Earth. Europa is a candidate for astrobiological exploration, exploring for the possibility of past or present life. Some scientists suggest that Europa's rosy glow might be explained by the presence of bacteria.

Eventually, planetary scientists would like to return to Europa for a closer look. The next step would be to send an orbiter back to Europa equipped with a radar sounder. Radar is electromagnetic energy that has long wavelengths that go through ice, but are reflected by water. The orbiter would identify locations where we might be able to melt through to explore beneath the ice. Then we could select places where we might send a Lander, perhaps a Cryobot to melt through the ice—or a Hydrobot, a submarine robotic explorer to see what the oceans of Europa might reveal.

ACT OUT THE SCIENCE STORY

Narration and mime activity: *Movement Integration Mediating Experience*
Based on accounts drawn from various versions of *Ovid's Metamorphoses*, this story of Europa moves from the Roman myth to the contemporary science. From classic Greek myth, the Roman poet Ovid retold how Jupiter appeared in the form of a bull to sweep Europa off her feet, then taking her to the island of Crete to found the Minoan dynasty.

The Story of Europa
Retold by Richard Shope

Narrative	Movement	Concept
From his balustrade on Mt. Olympus, Jupiter looked out over the world.	Leaning, looking out over the distance	Link the mythical power of the Roman God Jupiter, to the gravitational power of the planet Jupiter
He noticed a group of young people picking flowers and gathering wood in a pasture on a hillside near the shore, as they watched over their cattle that were grazing upon the green grass.	Select three or four girls and boys, as those who pick flowers and gather wood, and invite three or four boys and girls to become the cattle (humorously)	These characters will transform later to become Europa's ice surface, ocean and rocky mantle later on…
Jupiter noticed the beautiful Europa in their midst and he got an idea.	Invite an outgoing girl to play the part, invent gestures to convey her beauty (humor is fine)	
Jupiter sent his messenger, Mercury, to coax the cattle down from the hillside, closer to the shore, so that Europa and her friends would be sure to follow.	Fleet-footed messenger, running in slow motion, then gestures toward the cattle to move them toward the "sea," then stands to the side	Later becomes a Europa orbiter
Then mischievously, Jupiter transformed himself into a handsome bull, with magnificent horns and a gentle face.	The character of Jupiter transforms himself, taking on the movements of a handsome bull	
Europa and her friends noticed the bull and began to place garlands around his neck.	Garlands are crowns and necklaces of flowers strung together	
Soon Europa and the bull were walking hand in hoof along the shore.	The two mimewalk together	

Narrative	Movement	Concept
Europa decided to ride the bull. The bull waded out into the sea, then started to swim out far from the shore.	Europa stands a foot or so behind Jupiter the Bull as if to ride.	
Europa became alarmed. With one hand she grabbed a horn and with the other Europa waved back to her friends who were now clambering over the rocky shore calling out to her.	Europa grabs as if there were reins As Jupiter and Europa "swim" away from the shore, friends and cattle motion wildly	
Too late now to swim back, Europa was taken all the way to Crete, a rocky island surrounded by the sea. Transforming to reveal his true form, Jupiter then returned to Mt. Olympus. Though far from home, Europa became a greatly loved leader of the Minoan people who lived there.	Jupiter and Europa "swim" away out into the audience, and then return to where they began. Jupiter turns back into himself, returns to Mt. Olympus; Europa gestures like a queen of the people (in the audience)	
Just as the mythical Europa became the inner strength of the Minoan culture, on a rocky island surrounded by the sea, so Jupiter's moon Europa's rocky inner core is surrounded by a great ocean beneath it icy surface.	Around Europa, the cattle gather to become the rocky mantle surrounding her. Some of the friends become the ocean with arms moving like waves and others use the hands like a flat wall to show the icy surface. Jupiter stands away, but uses his arms to suggest a powerful gravity.	This image is to resemble a cutaway view of Europa the moon.

Narrative	Movement	Concept
And just as Europa's father Cadmus launched ships in search of her, so scientists urge NASA now to launch spacecraft to investigate the ice world, Europa.	"Mercury" becomes a spacecraft beaming radar, searching for Europa's ocean.	Projects an image of future exploration

Small Group Mime Activity: *Movement Integration Mediating Experience*
Invite students to form small groups (about three to five students), look at pictures of features on ice worlds and create their own mime and narrated story about how they formed. Encourage students to act out a sequence that results in drawing science questions from the story.

MATERIALS

For all activities, to record reflections, observations, calculations, etc.

- Science Notebooks: writing and drawing utensils

Occultation Demonstration

- Construction paper
- Colored transparencies
- Flat wooden sticks to be used as handles (for example, paint stirrers)

Photometry Activity

- Several shallow platters in which to freeze ice to model surfaces of an ice world (cookie sheets, cake pans, plastic platters)
- A selection of objects with varying degrees of reflectivity, such as:
- Ice cubes, loose
- Ice cubes, refrozen loosely in an ice platter
- Crushed ice, loose on a platter
- Crushed ice, refrozen on a platter
- Icy water
- Ice with dirt, flour, or cake mix sprinkled on top
- Ice with sand sprinkled on top
- Various light sources of different intensities (flashlights, bright lamp, sunlight)

Space phenomena

Gallery of images selected from NASA collections

- Ground-based and Hubble images of Pluto and Triton
- *Galileo* images of Europa
- Images of ice on Earth from space

DEMONSTRATION

This demonstration seeks to communicate one of the ways planetary scientists extract information from light about the appearance and composition of planetary objects. It introduces precursor understanding of photometry.

PRE K–2

Here is one way we get information about ice worlds from light:

Occultation Demonstration

1. Construct the occultation model out of circular cutouts of construction paper and sheets of colored transparencies. (Optional: fashion a handle for ease of holding.)

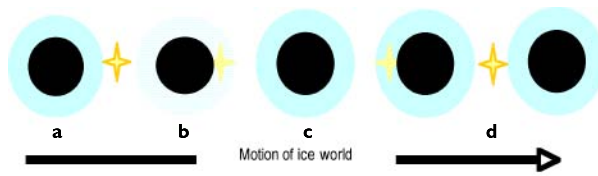
2. Have one student volunteer hold the "ice world" and be ready to move along an "orbital path."

3. Have another student volunteer hold a flashlight, in the role of the "star."

4. Use your own words to talk through the occultation sequence.

Explanation of occultation sequence

A circle of black construction paper represents an ice world. A surrounding circle of transparent colored plastic represents the tenuous planetary atmosphere, gases sublimating from the surface ices.



a. Ice world about to cross in front of star.
b. Starlight passes through atmosphere.
c. Star is hidden behind ice world.
d. Ice world reveals star; starlight passes through atmosphere again.

As the combined circles pass in front of a bright light source (a flashlight, for example), the "atmosphere" acts as a filter, so we see a difference between the "star" by itself and the starlight passing through the atmosphere. From that difference, scientists can use *spectroscopy* to tell what the atmosphere is made of, and infer what the surface is made of.

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3–5

This activity uses one of the most well-known passages of Dante's *Divine Comedy* (Canto V, Inferno) to build an understanding about how Pluto and Charon move through space and how scientists learn more about Pluto/Charon by observing during an occultation, the passing of a planetary object in front of a distant star.

> Adapt the telling to the audience. Parts this famous love story tend to produce some giggling among this age group. Have fun with it, keep it light, and use their fun with it to draw them toward the science point of the telling it.

In Dante's time in the 1300s, they did not know of the planet Pluto, which was discovered by Clyde Tombaugh in 1930. Had Dante known, he most probably would have seen the connection between his story of Paolo and Francesca and the science story of the occultation of Pluto and Charon.

As Dante was guided by the poet Virgil through the first realm of the underworld, he saw two spirits spinning slowly in space, with arms outstretched toward each other, but not quite touching. Dante was moved by their expressions, so seemingly in love. At last Dante spoke to his Guide: "Poet, I should be glad to speak a word with those two swept together so lightly on the wind and still be so sad." The two spirits, a young man and a young woman, approached to tell their story.

We are Paolo and Francesca, who once walked side by side into a beautiful garden. We sat down on a bench beneath a tree, where we read a story together. This was no ordinary story. It was the tale of Sir Lancelot in love with Queen Guinevere, who was married to Sir Lancelot's best friend, King Arthur, just as I, Francesca was married to Paolo's jealous brother.

Well, as we read on, we were drawn into the story. Just as Sir Lancelot looked into Queen Guinevere's eyes, just so our eyes lifted from the pages of the book, and the book seemed to float away. We looked into each other's eyes. We drew closer, and nearly kissed. But it was never to be. Just at that moment, Paolo's jealous brother came into the garden and saw us, thinking the worst. He raised his sword and slew the two of us.

Our spirits released, we floated toward the underworld. As we approached the River Styx, where the boatman Charon ferries spirits from the world of the living to the world of the dead, we entered Pluto's realm. Our fate is to swirl eternally in the darkened sky. We always face one another. We always circle about each other at an arm's length. Yet we are never able to give comfort to each other in the cold darkness so far from the Sun. And so we are very sad.

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But every once in a while, the light from a distant star passes through our outstretched arms, and in this occulted light we can see our icy breath, and sense the perfume of our radiant love.

And just so, the Poet thought, the planet Pluto and its moon Charon circle about each other in their tilted orbit around the Sun. And just so, now one, then the other, occasionally passes before a star whose starlight filters through to reveal their frosty breath, the sublimation of ices from their surfaces: water, ammonia, and methane ices from Pluto, and water ice from Charon.

Dante writes: "Through a round aperture I saw appear some of the beautiful things that Heaven bears, where we came forth, and once more saw the stars."

(Closing lines of the Inferno, from Robert Pinsky's translation)

After telling the story, invite two volunteers (a boy and a girl as Pluto and Charon) to demonstrate the occultation sequence.

Instruct students as follows:
Reach out your arms toward each other without quite touching at the fingertips. Very slowly, still facing each other, move together so that you slowly whirl about each other. This is Pluto and Charon.

Invite another student to stand behind Pluto and Charon with a flashlight, ready to shine toward the line of sight of the rest of the class. Position them so that as Pluto and Charon whirl, they each occult, or hide, the "star" so that the light of the star appears and disappears. Talk through the occultation sequence (see page 15) in terms of the student volunteers.

MAIN ACTIVITY

This activity models photometric techniques and results that lead to understanding about outer planetary ice worlds.

PREPARATION

Devise several exploratory zones:

- Material for occultation sequence
- Set out a variety of examples of surface ice features along with a variety of light sources (for example, flashlights of various intensities)
- Select a gallery of dramatic Europa and outer planetary images.

TEACHING TIPS

Explore

Guide students to focus on the idea of how the way light reflects off icy surfaces provides useful information. Encourage students to notice how light strikes the ice at different angles and that each angle shows different features. Guide students toward making a connection between the light and ice exploration and the selection of images of ice worlds

Diagnose

In the midst of the exploration, listen to student ideas about light and what happens when it strikes the different samples of ice. How capable are students in connecting the classroom activity with the images of ice worlds? Ask questions that guide students toward recognizing connections.

Design

Invite students to devise ways to use the light sources to create different effects. If digital cameras or videos are available, have students imagine them as spacecraft obtaining images. Have students work in collaborative teams to devise ways to explore questions that arise from the exploratory zones.

Discuss

Lead a discussion guided by questions such as: How do scientists investigate outer planetary ice worlds? Observation of these dimly lit worlds is a challenge. What are the big science questions scientists are asking?

Use

Suggest that students apply new understandings about reflection of light to drawing, taking photos, and to better interpret space images.

WARM-UP AND PRE-ASSESSMENT

Assure that students have an understanding about light sources

Hold up one of the ice platters, tilted forward slightly so that everyone can see it. Ask that students imagine that the ice platter is the surface of an ice world in the viewfinder of a telescope. You might have students cup their hands together as if they were looking through a telescope. Ask students why the ice platter is visible: *Where is the light source? In the Solar System, where does the light come from?*

Demonstrate radar astronomy by using the analogy of a camera flash that illuminates the surface for a quick moment—use a flashlight to show the action. Remind students that there are wavelengths of light that our eyes cannot see, such as infrared, ultraviolet, x-rays, and radio waves, but that we can still take advantage of with special instruments. Some of the images in the exploratory zones use *false colors* to represent features revealed by those wavelengths.

PROCEDURES

PART 1.

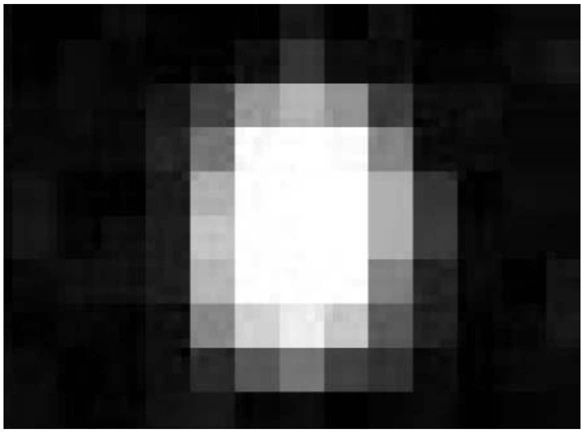
Three Ways to Obtain Photometric Data

1. Occultation Zone: Place the materials and explanation used for the occultation demonstration in an exploratory zone so the students can enact the occultation sequence for themselves, in small groups.
2. Sunlight Zone: Invite small groups of students to view the ice platters in the naturally available light. Have them generate and record drawings, observations, and questions about what they notice.
3. Flash Zone: Invite small groups of students to use light sources, such as flashlights of varying intensities to illuminate the ice platters. Have them generate and record drawings, observations, and questions about what they notice.
4. Lead a discussion about the different kinds of information each technique yields. Invite students to write/draw about their photometry and ice experience.

PART 2.

View images and photometry data of outer planetary ice worlds.

1. Triton, Pluto and the Kuiper Belt Objects (KBOs) such as Quaoar.



Hubble Telescope photometric view alongside Artist's View of Quaoar, newly discovered icy world in the Kuiper Belt.

- Explore online about NASA's exploration of Quaoar and other icy worlds in the Kuiper Belt: http://hubblesite.org/newscenter/newsdesk/archive/releases/category/solar%20system/minor%20body/kuiper%20belt%20object/

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This table guides understanding of gallery images of Triton, Pluto, and KBOs.

Photometrics Observations/Questions	Possible Explanations
■ Ground-based observations through powerful telescopes show active changes in albedo on Saturn's moon Triton.	■ Active seasonal processes, in cycles of sublimation, cloud-forming, and snowing of its ammonia, methane, and water ices
■ Occultation data indicates that Pluto has a very thin atmosphere of ammonia, methane, and water	■ When Pluto is in closer (35-40 AU) to the Sun, ices sublimate to form its tenuous atmosphere
■ Occultation and radar data indicate Charon is composed of water ice: What does this tell us?	■ Pluto and Charon have different origins; perhaps the two are together as a result of an impact or close call; or that Charon is a captured comet
■ Telescopic photometry of Kuiper Belt Objects has revealed a variety of ices. What are they?	■ As a group Kuiper Belt Objects are small comets and icy rocky worlds
■ These objects probably formed at the beginning of the history of the Solar System. What can we learn from exploring them?	■ Debris from formation of the Solar System informs us of early Solar System conditions
■ Scientists speculate that short-period comets might reside in the Kuiper Belt. Why?	■ Jupiter perturbations cannot explain all the short-period comets ■ Observations tend to confirm the presence of water ice ■ Ice detected on Europa.

Europa

This table guides viewing of historical Europa images .

Europa Phenomenon	Photometric Measurements
■ Features on Europa: Europa explored by Galileo Mission,	■ Originally detected through ground-based radar telescopes ■ Confirmed by Voyager
■ Comparison to Sea Ice on Earth, similarities led to conclusion that a liquid ocean exists beneath Europa's icy surface	Optical data reveal: ■ Ridges ■ Fractures: linear, arcuate, wavy, cycloidal ■ Craters ■ Ice volcanism ■ Chaotic areas
	■ Earth-observing spacecraft reveal large-scale structure

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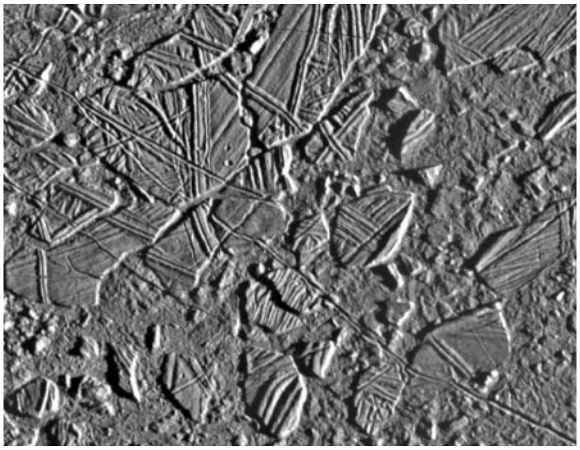
Explore online about NASA's exploration of Europa with the Galileo spacecraft at the Galileo web site: http://www.jpl.nasa.gov/galileo/



PART 3.

Optional Follow-Up: Investigate Ice Worlds with Planetary Scientists

Invite students to work in small groups to view the collection of materials and to generate questions to guide their investigation of ice worlds in greater detail. Have students utilize the Planetary Photojournal: http://photojournal.jpl.nasa.gov

Encourage students to prepare a focused interview, based on specific questions, that they would ask a planetary scientist working in the field.

Contact an expert in the field (start with Science or Education teams associated with NASA missions exploring ice worlds) to create access for students in a collaborative science learning relationship, via email or live speakerphone hook-up for class participation.

DISCUSSION & REFLECTION

How much of our knowledge of space relates to our understanding of light?

Perhaps *all of it!* Through telescopes, ground-based as well as space-based, we view the electromagnetic signals emitted directly by stars and starlight reflected off interstellar clouds of dust and gas and off planetary objects. We have learned to correlate emission, absorption, and reflection wavelengths of electromagnetic radiation with specific elements and compounds. Science instruments on spacecraft provide information about planets and other planetary objects in the form of electromagnetic waves communicated back to Earth via radio waves. The spacecraft carries sensors that are like nerve endings; the radio waves are like the central nervous systems with its the multiple pathways; the complex of receivers are like the synapses that activate awareness once the signal arrives. Then it is the human mind that interprets what it all means. To the extent that we each piece together for ourselves the information gained through astronomy and space exploration, we participate in the construction of new knowledge of the universe around us. We each create our own vision of space and our own feelings about it. Through this encounter with light, and the information it contains, space exploration extends humanity's senses into the vast distances of the Solar System and beyond.

CURRICULUM CONNECTIONS

This lesson connects to the visual arts. Awareness of the effects of lighting enhances our capabilities to draw, take photographs, and interpret images. The activities can be springboards to observing the play of light in terms of: lightness and darkness, brightness and dullness, color, contours, shadows, relief, and intensity.

Compare and contrast how we think about the effects of lighting in art, when the purpose is aesthetic to how think about the effects of electromagnetic radiation when the purpose is scientific inquiry

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ASSESSMENT CRITERIA

Exemplary

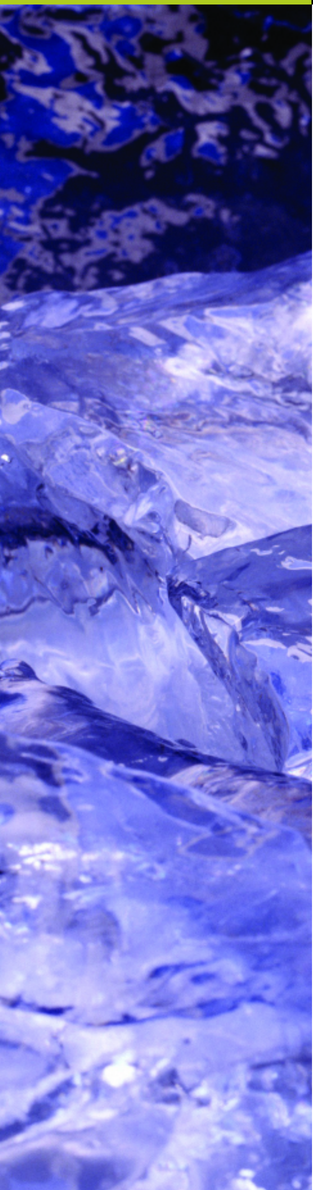
- Students write and illustrate a photometry and ice experience and share it dynamically with both a small group and the whole group.
- Students display drawings, constructions, and dynamic kinesthetic models drawn from their science notebooks and web-based research.
- Students identify and extend science questions drawn from research about the outer planets.
- Students explore a rich range of observations about outer planetary icy objects and relate it to prior shared experiences.
- Students ask a rich and extensive range of questions about outer planetary objects: composition, formation, orbits, and history of observation.
- Students extend learning by considering implications of the view that these icy, rocky outer planetary worlds may be the remnants of the formation of the Solar System.
- Students relate ideas to the whole context of exploring ice in the Solar System.

Emerging

- Students write and illustrate a description of outer planetary worlds sharing it with both a small group and the whole group.
- Students pose basic science questions drawn from their observations and research of Pluto/Charon, Europa, and other outer planetary worlds.
- Students observe examples of icy outer planetary objects.
- Students display results using a variety of ways to represent examples of Pluto/Charon and Europa.
- Students ask a rich range of questions about the origin, structure and composition of outer planetary worlds.
- Students make speculations about possible explanations for how they formed.

Formative

- Students recognize features of icy, rocky, outer planetary worlds and describe where they come from.
- Students identify characteristics of the structure of an icy, rocky outer planetary world.
- Students pose science questions drawn out of the context of observing and researching icy rocky, outer planetary worlds.



RESOURCES

Pluto

Pluto: Ninth Planet or Not! Nine Models of Teaching! Nine Lessons!
By Richard Shope

http://pluto.jhuapl.edu
The mission to Pluto/Charon and the Kuiper Belt

http://www.plutoportal.net

Alan Stern and Jacqueline Mitton
Pluto and Charon: Ice Worlds on the Ragged Edge of the Solar System

Europa

http://www.jpl.nasa.gov/galileo
The Galileo web site

Charles White comparing ice on Earth and Europa

Frank Carsey discussing the inferences about Europa from the point of view of knowing about sea ice

Images

Link to image gallery