Enceladus, I Barely Knew You

Middle School Grades

Lesson Summary

Students will establish whether Saturn's small moon, Enceladus, has an atmosphere, whether that atmosphere is over the entire planet, and what creates Saturn's E-ring.

Prior Knowledge & Skills

- Activities "A mixed up problem," and, "Starlight, starbright? Finding remote atmospheres."
- Introductory understanding of electromagnetic spectrum
- Graphs are used to represent physical data
- Occultation events can be used to determine whether a planet or body has an atmosphere

AAAS Science Benchmarks

- The Nature of Science
- The Scientific Worldview
- Scientific Inquiry
- The Nature of Technology
- Technology and Science
- The Mathematical World
- Shapes (9C/4M)
- Habits of Mind
- Communication Skills
- Critical Response Skills (12E/Mb5)

NSES Science Standards

- Science as Inquiry
- Abilities necessary to do scientific inquiry
- Physical Science
- Transfer of energy
- Science and Technology
- Understandings about science and technology

NCTM Mathematics Standards

Data Analysis and Probability: Develop and evaluate inferences and predictions that are based on data

Colorado State Standards

- Science: 1 (Physical Science), 3 (Earth Systems)

Teaching Time: 60 minutes

Materials

Each group of 4-5 needs:

- Copies of student pages

To Share with Class:

- Enceladus, I Barely Knew You PowerPoint

Preparation Time: 10 minutes

1. Make copies of student pages.
2. Prepare for viewing PowerPoint

Why Do We Care?

Enceladus is a small moon that orbits Saturn. We don't understand everything about Saturn, its moons, and its rings. For example, we are just beginning to understand how the rings formed. Studying the Saturn system gives us one more piece of the puzzle for determining how our solar system and the individual planets formed.

LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS
UNIVERSITY OF COLORADO AT BOULDER

Enceladus, I Barely Knew You

Group Size 1 or 2

Expendable Cost per Group $0.10

Engineering Connection

The Cassini Spacecraft has a variety of instruments onboard, built by engineers, which aided the exploration of Enceladus. The Composite Infrared Spectrometer (CIRS) took data that showed a hot spot near Enceladus' south pole. From that discovery, Enceladus became a "hot" target for scientists since they were not expecting a hot spot on a moon they assumed to be geologically dead. The instruments were engineered to look at the thermal properties of the moon. If they had not been, we may have never known anything unusual was happening on this tiny moon.

Learning Objectives

After this activity, students should be able to:

- Describe data collected from a remote solar system object
- Demonstrate how data can be used as evidence for geologic events occurring on a remote solar system object

Introduction / Motivation

Before students begin the activity, show the images: "Enceladus," "Enceladus in the E-ring," followed by "The Saturn Ring System," from the PowerPoint presentation. There's something funny going on in Saturn's E-ring and on the tiny moon, Enceladus (en-SELL-ah-dus), that orbits in the E-ring. The E-ring is Saturn's largest ring, is furthest from the planet and, according to scientists' calculations, it shouldn't last long! Basically, without a way of "refilling" the ring with material, the E-ring shouldn't last more than about 50 years. *Show the image, "Enceladus in the E-ring" again.*

Based upon spectroscopic measurements, we know the E-ring is largely made of water ice. Energetic charged particles that orbit around Saturn can impact the water ice particles in the E-ring, eventually eroding them away. Scientists calculate that the ring would not last very long unless some process added more material to the ring. Scientists know that micrometeorites (small meteorites) hit Enceladus and break off ice particles from the surface, sending them into space around Saturn--but this wouldn't provide enough material to keep the E ring around for very long. Something else must be happening, and it will be your job today to help scientists figure out what.

In 2005, the Cassini Mission found something unusual about Saturn's moon, Enceladus. Today, you will look closely at data obtained about Enceladus to help explain what is happening on the small moon. You will also read about what scientists think is replenishing the E-ring and determine if they are right.

Enceladus, I Barely Knew You

Vocabulary / Definitions

Word	Definition
Enceladus	A moon of Saturn that orbits in the E-ring
Ultraviolet	A part of the electromagnetic spectrum (light) with wavelengths shorter than violet that cannot be seen with the human eye.
Infrared	A part of the electromagnetic spectrum (light) that cannot be seen with the human eye and is often measured as a temperature.
Hypothesis	An educated guess, based on observation
Data	Facts collected for analysis

Procedure

Background

The E-ring is mostly made of water ice, but scientists have concluded that the water ice should not last very long in the ring. Plasma circling Saturn interacts with the water ice, rapidly eroding the ice particles that make up the E-ring, in a process called sputtering. They can then be transported away due to interactions with plasma (highly energetic charged particles). This means that something must be supplying water ice particles to the E-ring to keep it maintained. One alternative is that water ice is supplied by micrometeorites impacting the surfaces of the moons, but measurements indicate this is not the only source of material for the E-ring.

In 2005, the Composite Infrared Spectrometer (CIRS), onboard the Cassini Spacecraft, took measurements of the surface temperature of Enceladus. Enceladus has a hot spot at its south pole (see Image 1). Note that the hottest spot recorded is 85 Kelvin (-188 degrees Celsius), which is pretty chilly!

The Ultraviolet Imaging Spectrograph (UVIS) took data from two occultation events with Enceladus in February and July of 2005. The first occultation with the star lambda Scorpii (aka Shaula) showed no atmosphere around Enceladus. The second event with the star gamma Orionis (aka Bellatrix) showed an atmosphere as it passed behind the moon but, oddly, no atmosphere on the other side as the star reemerged (Hansen, et al., 2006). Upon inspection of images, a geyser was detected near the south pole of Enceladus (Image 2). The occultation data differed because the stars followed different paths behind Enceladus (see Image 3). Since particles in the geyser have enough velocity to escape Enceladus, it has no true atmosphere.

A spectrum of the E-ring, taken with the Visual and Infrared Mapping Spectrometer (VIMS) instrument, shows that the spectrum of the ring closely matches the spectrum of the ice grains in the geyser, so the source of water in the E-ring is Enceladus itself! Enceladus seems to have a source of liquid water beneath its surface that emerges from cracks, called tiger stripes, at and around the south pole. More recent results suggest Enceladus has a salt-water ocean or reservoir under its icy exterior (Postberg, et al., 2011). The mechanism for the geyser is still being explored, but it's clear the water needs to be heated from below and suggests a complex geology on a seemingly unassuming small moon.

Project SPECTRA!

Enceladus, I Barely Knew You

Image 1

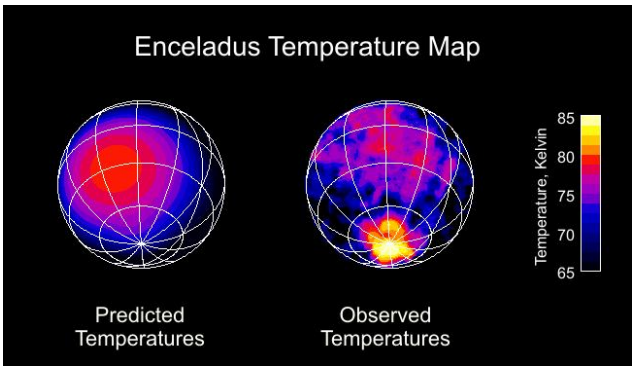

Image # 1

ADA Description: This image on the left shows the predicted surface temperatures of Enceladus and on the right, the measured temperatures. The measurements show a hot spot near Enceladus' south pole, which was not a predicted result. The Composite Infrared Spectrometer took the data.

Caption: This image shows the predicted temperatures (left) of Enceladus' surface and measured temperatures (right). The measurements show a hot spot on Enceladus' south pole, which was not a predicted result. The Composite Infrared Spectrometer (CIRS) took the data.

Source/Rights: Courtesy of NASA/JPL

Image 2

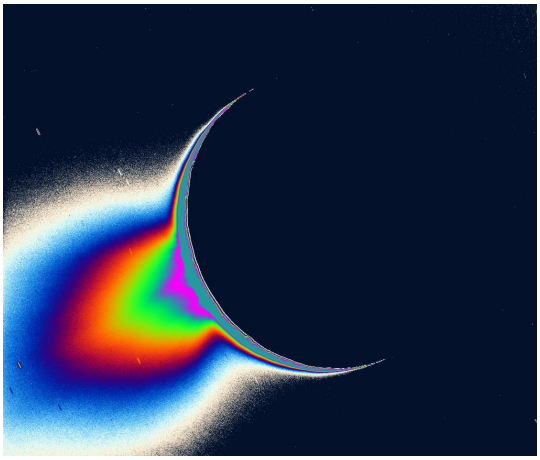

Image # 2

ADA Description: This ultraviolet image shows plumes rising from Enceladus' south pole.

Caption: This Cassini image shows discrete jets of a variety of apparent sizes above the limb of the moon. The greatly enhanced and colorized image shows the enormous extent of the fainter, larger-scale components of the plume.

Source/Rights: Image and caption text courtesy of NASA/JPL

Image 3

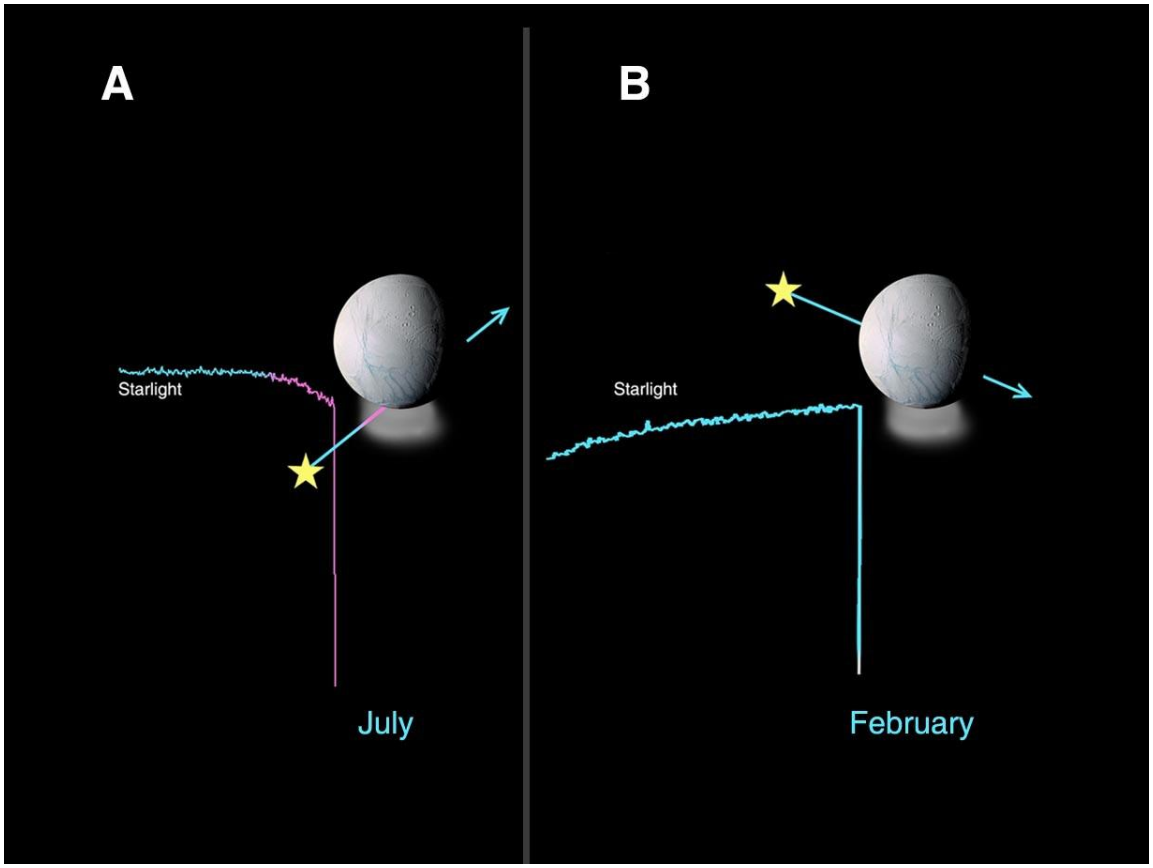

Image # 3

ADA Description: The image on the left shows the path of the star, Bellatrix, as it passed behind Enceladus in July of 2005 and the resulting plot showing that Enceladus' geyser blocked the light from the star. The image on the right shows the path of the star, Shaula, passing behind Enceladus in February of 2005 and a plot showing no atmosphere.

Caption: (A)The path of Bellatrix behind Enceladus (right) and the resulting plot showing the light attenuated behind the geyser, shown in pink. (B) The path of Shaula behind Enceladus and the plot demonstrating no evidence of an atmosphere. The path of Shaula did not cross the geyser at Enceladus' south pole.

Source/Rights: Courtesy of NASA/JPL

Enceladus, I Barely Knew You

With the Students

1. Hand out student activity, and instruct students to complete Part 1 and then stop.
2. Ask students to share the results from number 1.2 and 1.3 of the activity as a class. Write student's answers down on the board or have students share their drawings. Give students time to discuss why some answers might not be reasonable.
3. Show students the image, *"A Crescent Enceladus*" from the PowerPoint. Ask the class what they observe in the image.
4. Show students the image, *"Enceladus Illuminated"* from the PowerPoint. Ask students if/how their ideas about Enceladus have changed by viewing the image. Ask students to discuss with a peer what they think might be happening.
5. Show students the images, *"February 2005 Occultation"* and *"July 2005 Occultation."* Ask students what assumptions a person might make if they had only had the February data and why scientists take a lot of data.
6. Students should move on to Part 2 and then stop. Pass out and have students read the article, "NASA's Cassini Images Reveal Spectacular Evidence of an Active Moon." You may want to mention that the scientists think they need more data to better understand Enceladus, and that often a new finding requires more explanation.
7. When students have completed part 2, ask for students to share their answers to 2.3. Students should understand from the article that Enceladus is feeding the E-ring with water/ water ice with a jet (geyser, plume) or volcano. Ways to test this hypothesis will likely vary. Students may come to the conclusion that a spectrum of the jets of Enceladus will need to be collected to know if the material in the ring is identical.
8. Before students move on to Part 3, show the plots, *"Spectra for July 2005 Occultation," "Spectrum with Star's Light Removed," and "Water Discovered Around Enceladus,"* from the PowerPoint. Tell students: *First, the star's spectrum was measured before it got close to Enceladus, and then the star's spectrum was measured as it passed behind Enceladus. In order to get a spectrum for Enceladus alone, the spectrum of the star was removed from the combined spectrum. Dr. Candace Hansen identified water in the spectrum of Enceladus from the plots, but other methods of water identification were also used. More recently, data from Cassini helped identify salt water as well as some organic material in the plumes.*
9. The Extra Press Release for Differential Instruction may be used at the discretion of the teacher. This may stir discussion over what can still be learned about Enceladus in question 3.3.
10. Have students share the results from 3.3.

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Attachments

- Press Release: "NASA's Cassini Images Reveal Spectacular Evidence of an Active Moon."
- Extra Press Release for Differential Instruction
- Student Handout

Assessment

Pre-Activity Assessment

Class Discussion: Example questions/prompts with students: *What is geologic activity? What geologic activity occurs on Earth?* (Plate tectonics, volcanic eruptions) *What does it mean for a solar system body to have a young surface?* (The more craters a body has, the older the surface is, and geologic activity and weathering removes craters. Showing students an image of the Earth v. the Moon might help here) *How do we know a solar system object is geologically active*? (Direct observations of activity or inferences from observing the age of the surface using the number of craters) *Does Earth have a young or old surface?* (Young) *How about the moon?* (Old) *Do you think the moon is currently geologically active?* (Probably not, because most of the surface is heavily cratered, but it may have been in the past because some surfaces have fewer craters—it may be useful to show an image of the moon) Showing the image of Enceladus from the Power Point, ask: *Does Enceladus have an old or young surface?* (Some areas look somewhat cratered, but some do not, so some areas are young and some are older. Enceladus mostly looks like it has a younger surface than our moon.) *Do you think Enceladus could have geologic activity?* (Maybe)

Post-Activity Assessment

Poster Presentation: Have students create a poster and have a poster session based upon what they learned during the activity and what research question they would like answered. This may include a mission they would propose to Enceladus to gather more data.

Enceladus in the News: Have students research new findings on Enceladus and present the findings to the class. Whenever possible, encourage students to locate plots and images that explain the findings.

Activity Scaling

For upper grades, include the Extra Student Handout for Differential Instruction as required reading. Have students research current findings on Enceladus in the news prior to answering question 3.3. A useful resource is the website: http://saturn.jpl.nasa.gov/news/topheadlines/

References

Hansen, C.J., Shemansky, D.E., Esposito, L.W., Stewart, A.I.F., Lewis, B.R., Colwell, J.E., Hendrix, A.R., West, R.A., Waite, J.H. Jr., Teolis, B., Magee, B.A. 2011. The composition and structure of the Enceladus plume. Geophysical Research Letters 38:L11202

Hansen, C.J., Esposito, L., Colwell, J., Hendrix, A., Meinke, B., Stewart, A. 2008. New occultation observation of Enceladus' plume. Lunar and Planetary Science XXXIX

Hansen, C.J., Esposito, L., Stewart, A.I.F., Colwell, J., Hendrix, A., Pryor, W., Shemansky, D., West, R. 2006. Enceladus' water vapor plume. Science 311:1422-1425

Postberg, F., Schmidet, J., Hillier, J., Kempf, S., Srama, R. 2011. A salt-water reservoir as the source of a compositionally stratified plume on Enceladus. Nature 474:620-622

Sodium salts point to subsurface ocean on Enceladus. European Space Agency science & technology news. 2009. News, 25 July.

Images and information were obtained from http://saturn.jpl.nasa.gov/

Owner

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Contributors

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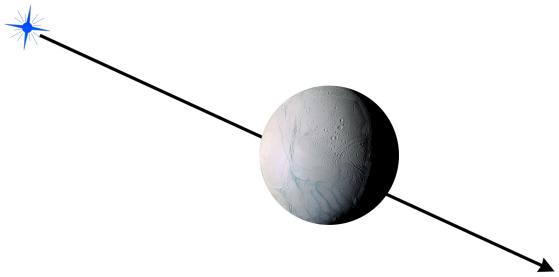
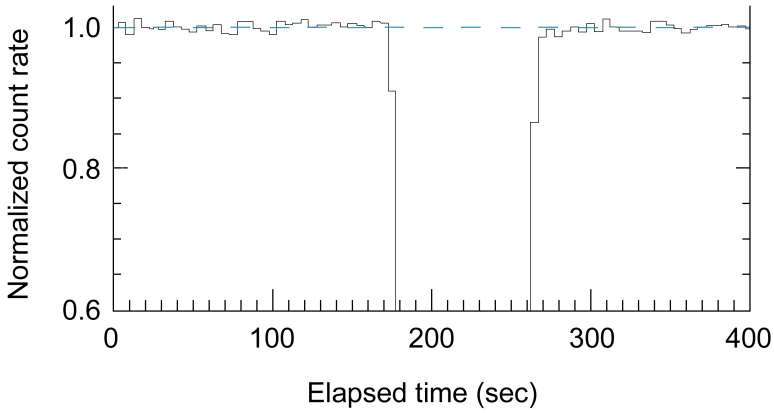
Enceladus, I Barely Knew You

Teacher Key

Part 1

In February of 2005, the Cassini spacecraft, that is orbiting Saturn, observed an occultation of the star, Shaula, by the moon, Enceladus (en-SELL-ah-dus). The Ultraviolet Imaging Spectrograph (UVIS) onboard Cassini made observations of the light from the star and moon while the occultation event took place. The plot below shows the light from Shaula during the event as it passed behind the moon. The count rate is a measurement of the amount of light collected.





1.1) Based on the plot above, do you notice an atmosphere around the moon, Enceladus? How did you come to that conclusion?

No atmosphere appears here. The plot descends straight down right before 180 seconds and straight up again at just after 260 seconds, indicating that there is no atmosphere. If the line curved down and up more gradually, it would indicate Enceladus has an atmosphere. Accept reasonable responses.

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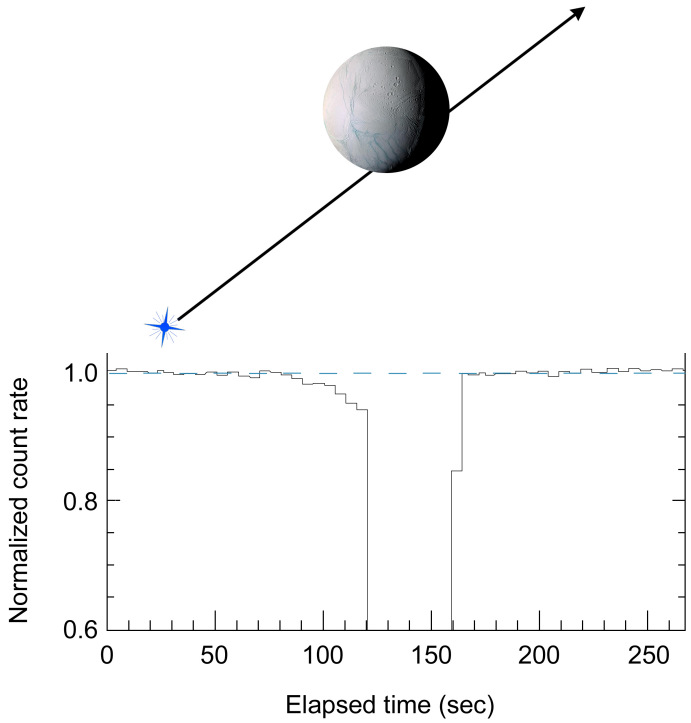
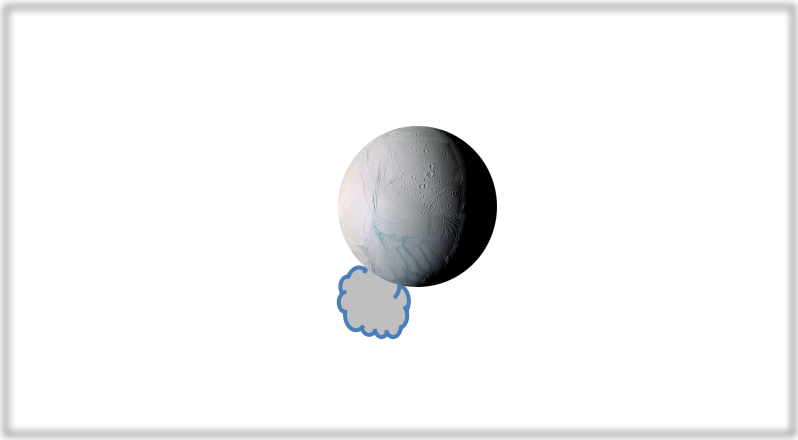
In July of 2005, another occultation occurred behind Enceladus with the star, Bellatrix. The UVIS took data on this event as well. The plot below shows the light from Bellatrix during the event as it passed behind the moon.



1.2) Write a *hypothesis* about what is happening at Enceladus.

I hypothesize that Enceladus has a cloud (jet, partial atmosphere, geyser etc.) of material on part of the south pole, but it doesn't appear to be on the other side of the moon. Note: Hypothesis does not have to be "correct" but the image below should support the hypothesis.

1.3) Draw a picture that shows your hypothesis, below:



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Part 2

Your teacher will display the images, “A Crescent Enceladus,” “Enceladus Illuminated,” “February 2005 Occultation,” and “July 2005 Occultation.” After discussing the images as a class, answer the following questions.

2.1) Was your hypothesis about what is happening on Enceladus correct? Why/ why not? Explain.

2.2) Read the article, “NASA's Cassini Images Reveal Spectacular Evidence of an Active Moon” and answer the questions below:

a) After initial observations were made of the jets, how did scientists determine what the jets were made from?

Cassini flew through the plume. During that flyby, Cassini's instruments measured the plume's water vapor and icy particles.

b) What evidence was examined to confirm that the jets exist?

Images taken earlier that year were analyzed to confirm the presence of the jets. More images were taken to further confirm their presence and examine them in finer detail.

c) What hypothesis is made about the E-ring?

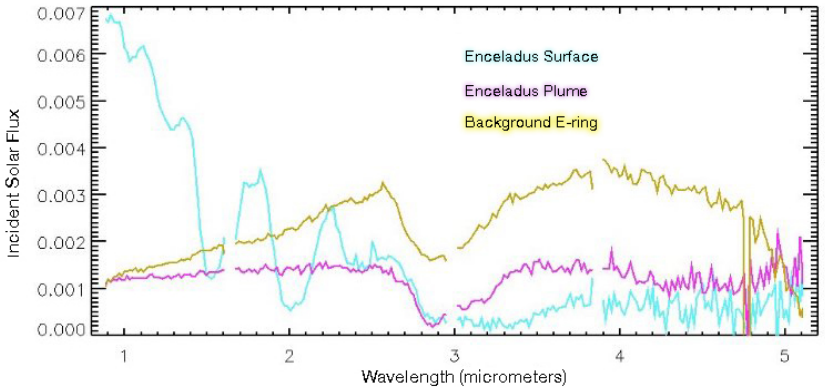
Enceladus’ jets supply material to the E-ring.

2.3) What *data* do you think could be taken by Cassini to support the hypothesis about the E-ring?

If Cassini took a spectrum of the jets and also a spectrum of the E-ring, we could compare them. If they were the same/similar, that would support the hypothesis.

Part 3

In November of 2005, Cassini flew by Enceladus again. This time, the Visual and Infrared Mapping Spectrometer (VIMS) took data on the surface of the Enceladus, the jets of material coming from the south pole of the moon, and also of the E-ring. The plot below shows the spectra recorded during this flyby:



3.1) Based on the plot above, could the majority of the material in the E-ring be from scattered ice from micrometeorites impacting the surface of Enceladus? Explain.

The spectrum of the E-ring closely matches the spectrum of the plume. Based on this plot, the material in the ring seems to be coming mostly from the plume. Since the surface spectrum does not match, the supposition is that the majority of the material is not from micrometeorite impacts. Note: This is a simplification of the actual processes. Micrometeorite impacts do contribute a percentage of material to the ring and scientists are in the process of establishing the amount. It's clear; however, that the plume makes significant contributions to the ring.

3.2) Explain in your own words how the E-ring is maintained.

The E-ring is maintained by a jet of water ice that comes from Enceladus' south pole along cracks in the surface called Tiger Stripes. Accept all reasonable responses.

3.3) If you could send a mission to Enceladus, what would you have it study, and why? Share your answer with the class.

Press Release:
NASA's Cassini Images Reveal Spectacular Evidence of an Active Moon
December 6, 2005 (Excerpts from source: NASA/JPL/Space Science Institute)

Jets of fine, icy particles streaming from Saturn's moon Enceladus were captured in recent images from NASA's Cassini spacecraft. The images provide unambiguous visual evidence the moon is geologically active.

"For planetary explorers like us, there is little that can compare to the sighting of activity on another solar system body," said Dr. Carolyn Porco, Cassini imaging team leader at the Space Science Institute in Boulder, Colo. "This has been a heart-stopper, and surely one of our most thrilling results."

The Cassini images clearly show multiple jets emanating from the moon's south polar region. Based on earlier data, scientists strongly suspected these jets arise from warm fractures in the region. The fractures, informally dubbed "tiger stripes," are viewed essentially broadside in the new images.

The fainter, extended plume stretches at least 300 miles above the surface of Enceladus, which is only 300 miles wide. Cassini flew through the plume in July, when it passed a few hundred kilometers above the moon. During that flyby, Cassini's instruments measured the plume's constituent water vapor and icy particles.

Imaging team members analyzed images of Enceladus taken earlier this year at similar viewing angles. It was a rigorous effort to demonstrate earlier apparitions of the plumes, seen as far back as January, were in fact real and not due to imperfections in the camera.

The recent images were part of a sequence planned to confirm the presence of the plumes and examine them in finer detail. Imaging team member Dr. Andrew Ingersoll from the California Institute of Technology in Pasadena, said, "I think what we're seeing are ice particles in jets of water vapor that emanate from pressurized vents. To form the particles and carry them aloft, the vapor must have a certain density, and that implies surprisingly warm temperatures for a cold body like Enceladus."

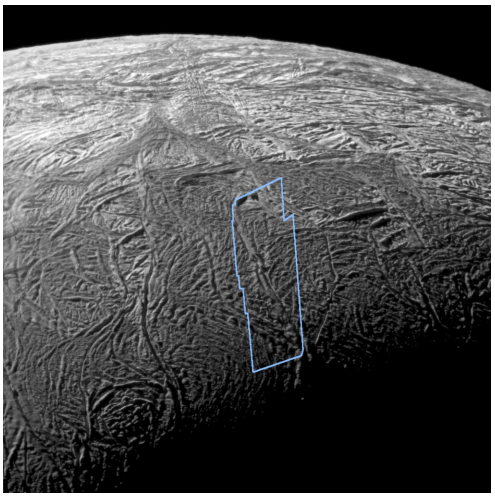
Imaging scientists are comparing the new images to earlier Cassini data in hopes of arriving at a more detailed, three-dimensional picture of the plumes and understanding how activity has come about on such a small moon. They are not sure about the precise cause of the moon’s unexpected geologic vitality. The new data also give yet another indication of how Enceladus keeps supplying material to Saturn’s gossamer E ring.

Extra Press Release for Differential Instruction

Cassini Finds Plethora of Plumes, Hotspots at Enceladus
Feb. 23, 2010 (Source: NASA/JPL/Space Science Institute)

Newly released images from last November's swoop over Saturn's icy moon Enceladus by NASA's Cassini spacecraft reveal a forest of new jets spraying from prominent fractures crossing the south polar region and yield the most detailed temperature map to date of one fracture.

The new images from the imaging science subsystem and the composite infrared spectrometer teams also include the best 3-D image ever obtained of a "tiger stripe," a fissure that sprays icy particles, water vapor and organic compounds. There are also views of regions not well-mapped previously on Enceladus, including a southern area with crudely circular tectonic patterns.



Close up image of a "tiger stripe."

"Enceladus continues to astound," said Bob Pappalardo, Cassini project scientist at NASA's Jet Propulsion Laboratory in Pasadena, Calif. "With each Cassini flyby, we learn more about its extreme activity and what makes this strange moon tick."

For Cassini's visible-light cameras, the Nov. 21, 2009 flyby provided the last look at Enceladus' south polar surface before that region of the moon goes into 15 years of darkness, and includes the most detailed look yet at the jets.

Scientists planned to use this flyby to look for new or smaller jets not visible in previous images. In one mosaic, scientists count more than 30 individual geysers, including more than 20 that had not been seen before. At least one jet spouting prominently in previous images now appears less powerful.

"This last flyby confirms what we suspected," said Carolyn Porco, imaging team lead based at the Space Science Institute in Boulder, Colo. "The vigor of individual jets can vary with time, and many jets, large and small, erupt all along the tiger stripes."

Project SPECTRA!

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A new map that combines heat data with visible-light images shows a 40-kilometer (25-mile) segment of the longest tiger stripe, known as Baghdad Sulcus. The map illustrates the correlation, at the highest resolution yet seen, between the geologically youthful surface fractures and the anomalously warm temperatures that have been recorded in the south polar region. The broad swaths of heat previously detected by the infrared spectrometer appear to be confined to a narrow, intense region no more than a kilometer (half a mile) wide along the fracture.

In these measurements, peak temperatures along Baghdad Sulcus exceed 180 Kelvin (minus 135 degrees Fahrenheit), and may be higher than 200 Kelvin (minus 100 degrees Fahrenheit). These warm temperatures probably result from heating of the fracture flanks by the warm, upwelling water vapor that propels the ice-particle jets seen by Cassini's cameras. Cassini scientists will be testing this idea by investigating how well the hot spots correspond with the jet sources.

“The fractures are chilly by Earth standards, but they’re a cozy oasis compared to the numbing 50 Kelvin (-370 Fahrenheit) of their surroundings,” said John Spencer, a composite infrared spectrometer team member based at Southwest Research Institute in Boulder, Colo. “The huge amount of heat pouring out of the tiger stripe fractures may be enough to melt the ice underground. Results like this make Enceladus one of the most exciting places we’ve found in the solar system.”

Some of Cassini’s scientists infer that the warmer the temperatures are at the surface, the greater the likelihood that jets erupt from liquid. “And if true, this makes Enceladus’ organic-rich, liquid sub-surface environment the most accessible extraterrestrial watery zone known in the solar system,” Porco said.
The Nov. 21 flyby was the eighth targeted encounter with Enceladus. It took the spacecraft to within about 1,600 kilometers (1,000 miles) of the moon's surface, at around 82 degrees south latitude.

More details are also available at the imaging team’s website http://ciclops.org and the composite infrared spectrometer team’s website http://cirs.gsfc.nasa.gov.

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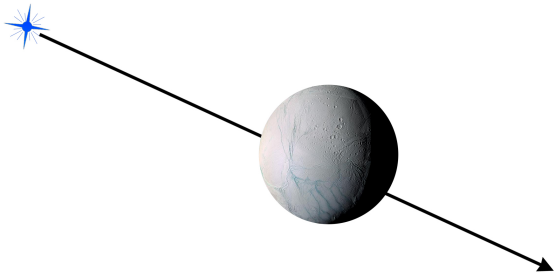
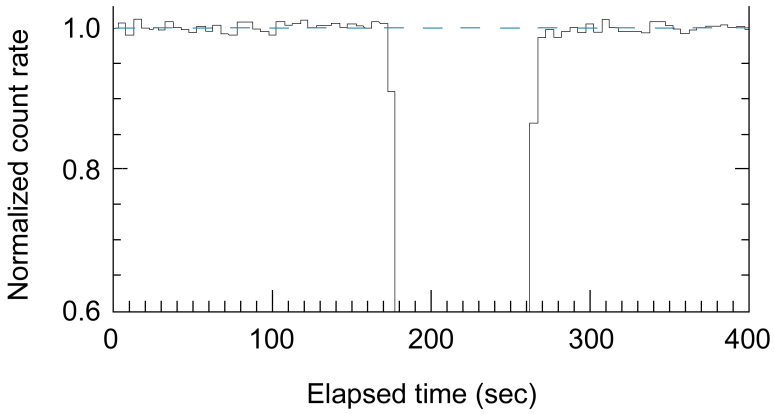
Student Handout

Part 1

In February of 2005, the Cassini spacecraft, that is orbiting Saturn, observed an occultation of the star, Shaula, by the moon, Enceladus (en-SELL-ah-dus). The Ultraviolet Imaging Spectrograph (UVIS) onboard Cassini made observations of the light from the star and moon while the occultation event took place. The plot below shows the light from Shaula during the event as it passed behind the moon. The count rate is a measurement of the amount of light collected.





1.1) Based on the plot above, do you notice an atmosphere around the moon, Enceladus? How did you come to that conclusion?

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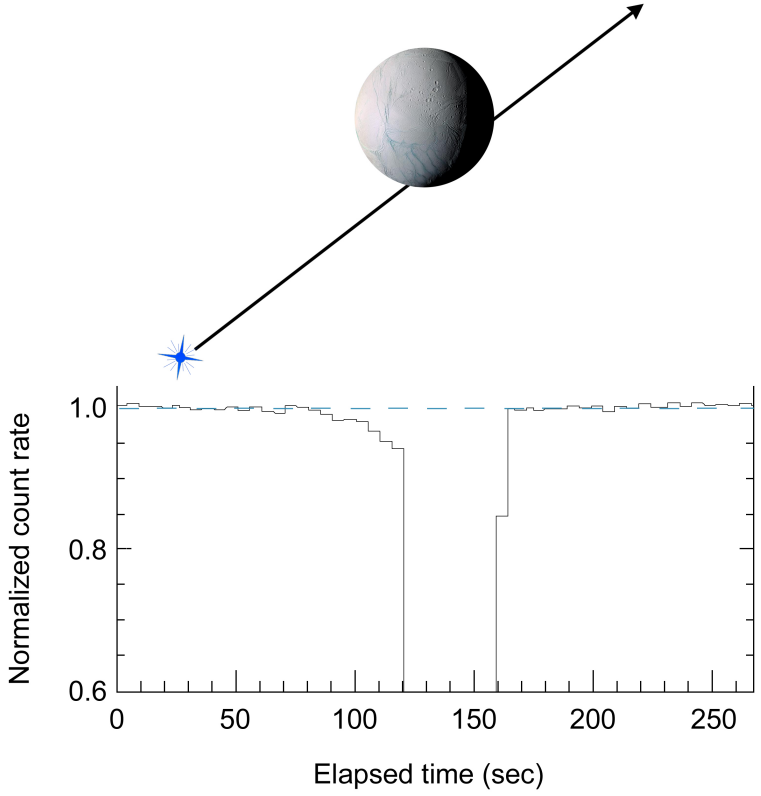
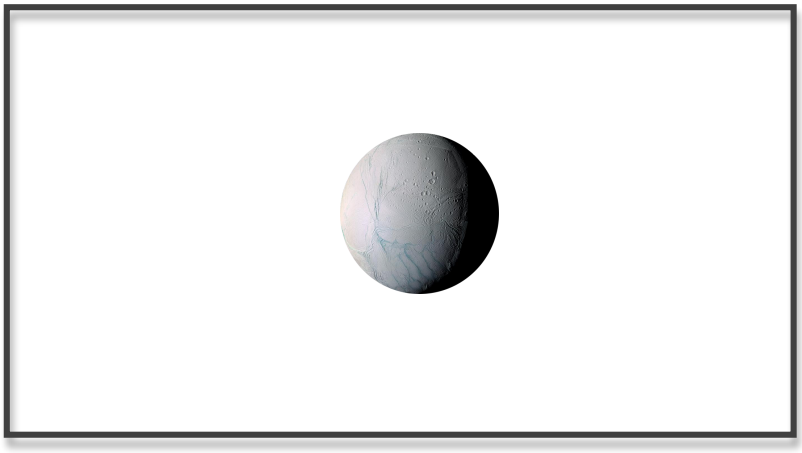
In July of 2005, another occultation occurred behind Enceladus with the star, Bellatrix. The UVIS took data on this event as well. The plot below shows the light from Bellatrix during the event as it passed behind the moon.



1.2) Write a *hypothesis* about what is happening at Enceladus.

1.3) Draw a picture that shows your hypothesis, below:



Enceladus, I Barely Knew You

Part 2

Your teacher will display the images, “A Crescent Enceladus,” “Enceladus Illuminated,” “February 2005 Occultation,” and “July 2005 Occultation.” After discussing the images as a class, answer the following questions.

2.1) Was your hypothesis about what is happening on Enceladus correct? Why/ why not? Explain.

2.2) Read the article, “NASA's Cassini Images Reveal Spectacular Evidence of an Active Moon” and answer the questions below:

a) After initial observations were made of the jets, how did scientists determine what the jets were made from?

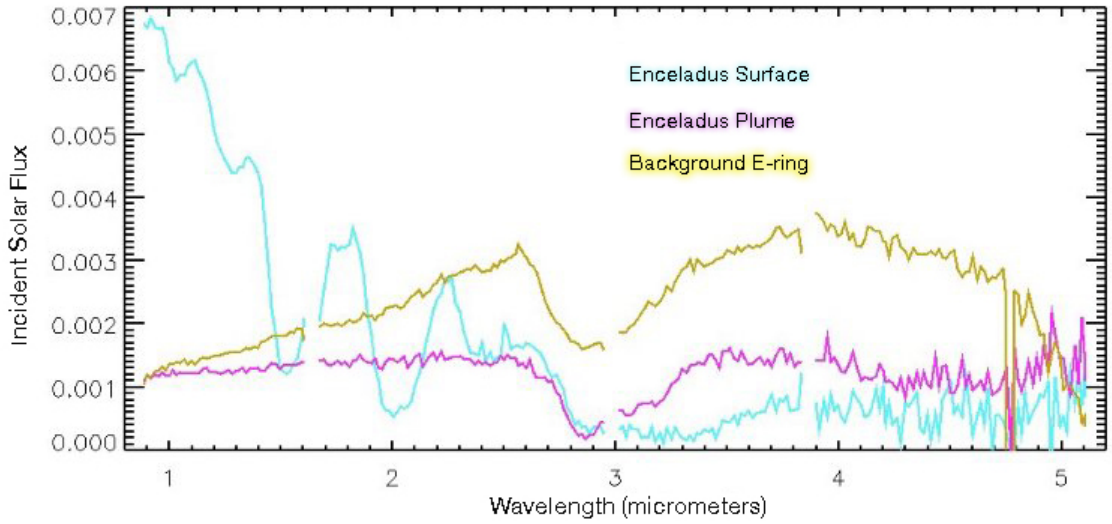
b) What evidence was examined to confirm that the jets exist?

c) What hypothesis is made about the E-ring?

2.3) What *data* do you think could be taken by Cassini to support the hypothesis about the E-ring?

Part 3

In November of 2005, Cassini flew by Enceladus again. This time, the Visual and Infrared Mapping Spectrometer (VIMS) took data on the surface of the Enceladus, the jets of material coming from the south pole of the moon, and also of the E-ring. The plot below shows the spectra recorded during this flyby:



3.1) Based on the plot above, could the majority of the material in the E-ring be from scattered ice from micrometeorites impacting the surface of Enceladus? Explain.

3.2) Explain in your own words how the E-ring is maintained.

3.3) If you could send a mission to Enceladus, what would you have it study, and why? Share your answer with the class.