



Comparing Comets

COLLEGE GUIDE TO COMET ENCOUNTERS (FOR EDUCATORS)

Background Information:

Cometary scientists think that the surface layer of a nucleus is highly evolved. Meaning, in successive orbits that take it close to the Sun, the surface has been altered by exposure to sunlight—causing outgassing, and sublimation of volatile substances from the surface exposed to the Sun.

For this activity, your students will play the role of cometary scientists, using images to observe and compare the surfaces of two comet nuclei from close range. Comets are so small that, even when viewed through a large optical telescope, they are just points of light in the sky. These points of light are reflections of sunlight on the comet's coma, the gaseous cloud surrounding the nucleus, and the dust tails of the comet, not the nucleus itself.

So how did we obtain the images shown in the student activity sheet?

They were taken from two spacecraft in NASA's Discovery program as they penetrated the comets' comas.

- The image on the left is the surface of comet Wild 2 (pronounced Vilt Two), taken from the Stardust spacecraft in January 2004 at a distance of about 237 km.
- The image on the right is the surface of comet Tempel 1, taken from the Deep Impact Impactor spacecraft in July 2005 at a distance of about 1500 km.

Both images represent each comet at a scale of 15 m/pixel and are 4 km x 4 km. They are shown here displayed on the same intensity scale. However, because the images were taken with cameras from two different spacecraft with different resolutions, the image clarity differs. For a separate activity about the cameras of these two spacecraft see "Comparing Cosmic Cameras" from Stardust-NExT.

For information and activities surrounding the basics of comet science visit *Exploring Comets and Modeling Mission Success* at: <http://deepimpact.umd.edu/educ/ExploringComets.html>

Exploring similarities and differences, one of the nine strategies identified in *Classroom Instruction that Works*, has been shown to increase student achievement. This exercise allows students to compare and contrast the nucleus of two comets and listen to audio files of NASA scientists conducting the activity. The imagery and data are authentic and related to real-world science that is currently underway. By comparing their responses to those of NASA scientists, students realize that while their vocabulary may be different, their process parallels that of the scientists and the task of doing science is well within their reach.

Objectives:

- Compare surface features on the nuclei of two comets.
- Explain some possible causes for differences between the two nuclei.
- List questions that you have about the surface of comet nuclei.

Materials

- Student background information on comets
- Student activity and recording sheet
- Audio files of scientists comparing two comet nuclei.
- Access to computers with ImageJ software for quantitative analysis

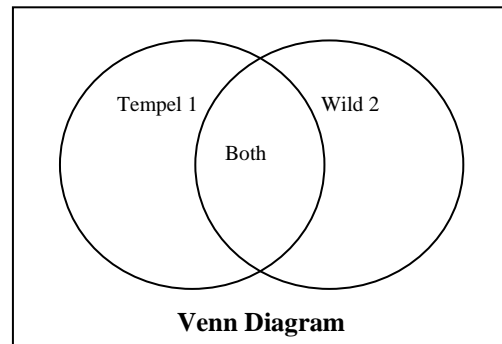
Procedure:

Part 1

1. Ask students what they know about comets. Elicit student responses without comment. You may want to list these initial ideas on the board.
2. Provide some background on comets using one or more comet resources such as materials from NASA:
 - Stardust-NEXT Comet Interactive:
<http://stardustnext.jpl.nasa.gov/multimedia/ci/index.html>
 - Deep Impact: 10 Important Comet Facts:
http://deepimpact.umd.edu/educ/mod_ExploringComets/10_CometFacts.pdf
 - Comet Fun Fact Sheet:
http://stardustnext.jpl.nasa.gov/mission/pdfs/comet_fun_sheet3.pdf

At a minimum, students should understand that comets are ancient members of the Solar System made of ice and rock; they travel in elliptical orbits around the Sun and consist of a coma (head), a small, dark nucleus beneath the coma, and sometimes two or more tails.

3. Explain to students that today they will work as scientists to compare the nucleus of two comets from two different NASA missions. The first is comet Wild 2, which was imaged by NASA's Stardust Spacecraft. The second is comet Tempel 1, imaged by NASA's Deep Impact spacecraft.
4. Assemble students into small groups of 2 to 4. Distribute the student activity sheets and ask students to record both qualitative and quantitative observations on the Venn diagram on their sheet. If students are not familiar with a Venn diagram, explain that the middle should include features that are found on both surfaces and that the space on either side of the diagram should include features that are unique to each one. If students are not familiar with the differences between observation and inference, refer to the box below and provide some examples.
5. Provide students with enough time to make several observations. Once they have had ample time to record observations, ask them to report out some of the similarities and differences they recorded. Possible responses are found at the end of this guide.



Note:

In comparing the comets, you may note some descriptions include only observations, while some include interpretation too.

- We suggest students start with including observations only, making interpretations a separate step.
- Once students are comfortable with making observations, the interpretation flows more easily, as they will hear is the case with many experienced astronomers.
- Have students justify any inferences.

Part 2

1. Explain that they will now listen to audio clips of NASA scientists who completed a similar exercise on these two surfaces.

As they listen, ask students to listen for similarities and differences in the descriptions.

Note: There are three audio files from scientists on the EPOXI website. The first audio file from the scientists should provide enough information for students to get the idea that scientists often observe the same features, but may use different vocabulary to describe what they see.

2. Have students make quantitative analyses of the comet images with image analysis software, by having them complete the procedure as directed at the end of this teacher guide.
3. Provide students with time to respond to the follow-up questions in small groups before reviewing the answers as a class.
 - How can you tell the Sun's position in relation to this image? Provide two reasons for your answer. For locating the Sun's position, look at the shadows and the location of the bright spots on each nucleus to determine the Sun's location.
 - Elicit student responses. Provide clues by asking the student to look at the shadows cast by objects on each of the surfaces. Also, call their attention to the symbols and arrows at the bottom of the image. The Θ symbol shown indicates the direction of the Sun.
 - Based on your comparisons and contrasts, why do you think the two surfaces are different? What factors may have caused these differences?
 - Accept student responses. Students might suggest that the two surfaces are located in different parts of the Solar System, or have different orbits around the Sun. Some might suggest that the age of the two comets might be different.
 - What questions do you have about these two bodies? How would you go about answering these questions? These are the types of questions scientists brainstorm when designing a mission concept.
 - Student answers will vary. For the second question, students might suggest sending a spacecraft to orbit the comet for an extended period of time.
 - Use the following links containing background for cratering/collisions after the students have given their answers:
<http://deepimpact.umd.edu/mission/updates/update-200512.html>
http://www.planetary.org/explore/topics/asteroids_and_comets/wild2.html
 - Optional: Read the surface revealed at:
<http://deepimpact.umd.edu/results/excavating.html>. Scroll down to the bottom of this page for a description of the surface of the nucleus of comet Tempel 1.
 - Student answers will vary.
4. "You have just compared two comets, (Tempel 1 and Wild 2). The Deep Impact spacecraft flew by comet Hartley 2 in November 2010 for a mission called EPOXI. For the assessment, we will now predict what the spacecraft saw. Have students predict size, features, etc., based on their knowledge of Wild 2 and Tempel 1."
5. Show an image of Hartley 2 taken by Deep Impact on November 4, 2010. Have students make careful observations of the nucleus of comet Hartley 2 and compare them to their predictions. Point out the rubric on the student sheet. Explain that it is provided to help them self assess the

type of observations they are making. You may use this rubric to assess students on making accurate observations and interpretations.

Scoring Rubric

Criteria	4	3	2	1
Makes accurate observations	Clearly describes almost all of the features of the image in detail. Includes great clarity of the entire nucleus as a whole.	Clearly describes the features of the image in detail.	Describes a few of the features of the image but doesn't provide many details.	Describes only one or two features in the image, but provides so few details that the reader has trouble distinguishing them
Interprets and synthesizes information	Explanations of observations about the features of the comet are reasonable and thorough.	Explains observations about the features of the comet in ways that are reasonable.	Provides explanations about observations of the features of the comet which may not be reasonable.	Explanations about the features of the comet do not match the observations.

- End the session by saying that “You have analyzed images of the nucleus of comets in much the same way as a NASA scientist. While the words that you used to make observations, interpretations, and predictions might be different, the process is very much the same.”

Digital Image Analysis Procedure:

Using ImageJ software, compare features on the two comets. Note the names of the comets for labeling. Follow this procedure to make some comparative measurements.

Obtain *ImageJ* found at: <http://rsb.info.nih.gov/ij/download/zips/ij134.zip> for free (after download, right click and extract all files).

- Launch the ImageJ program (ij.jar) and choose File > Open to find and open each comet image for comparison.
- Move the windows of each image so that they are side-by-side with the ImageJ dashboard at the top of your screen.
- Using the Oval Selection tool button, draw an oval around the largest crater on each of the two comets.
 - They should be whole craters
 - Look for clear rims with shadows characteristic of impact craters rather than smooth-looking surfaces
- Use Analyze > Set Measurements to choose area, perimeter, and anything else you choose to measure in pixels. Use Analyze > Measure to compare the areas. This will take some trial and error.
- Choose Edit > Draw or Control D to make the ovals permanent.
- Label your craters using the Text Tool button.
 - Include their area and perimeter
 - Choose Edit > Draw or Control D to make each label permanent. Use labels like W1, W2, T1, T2 for later comparison.
 - Figure out the area of each circular feature using the Oval or Polygon Selection tools. Remember to measure the area, draw a perimeter around the circular feature and use Analyze > Measure to find the area. Save the areas in a separate folder for each comet. They are text data files measured in pixels.
- Quantitative analysis:
 - Discuss accuracy vs. precision and have the students use an appropriate number of significant figures in their answers.
 - Figure out all of the areas of all of your craters.

- Use similar methods to determine the area or length of smooth flows or other irregular features. You may also want to use the Image menu to manipulate the appearance of the comets to better reveal other characteristics such as shadow length.
 - Use a calculator or spreadsheet to determine the average area and standard deviation of each type of feature.
8. Challenge:
- Estimate the percentage of the visible hemisphere that is covered by craters.
 - Compare the crater count on these two comets with that in the literature for an irregular satellite of Jupiter or Saturn.
 - Compare the average size of the craters with craters found on Earth.
 - Make measurements on Hartley 2 following similar methods.

Questions:

1. How did the use of the ImageJ software help you analyze the two comet images?
2. Compare the craters on Tempel 1 and Wild 2:
 - a. Average area
 - b. Frequency
 - c. Location
3. What other (non-circular) surface features were measured?
4. Compare these features on both Tempel 1 and Wild 2:
 - a. Average area
 - b. Frequency
 - c. Location
5. How do the orbital paths affect what we can deduce from the average crater areas and the number of impact craters about the age of the comets?

Possible Responses to Venn Diagram:

