



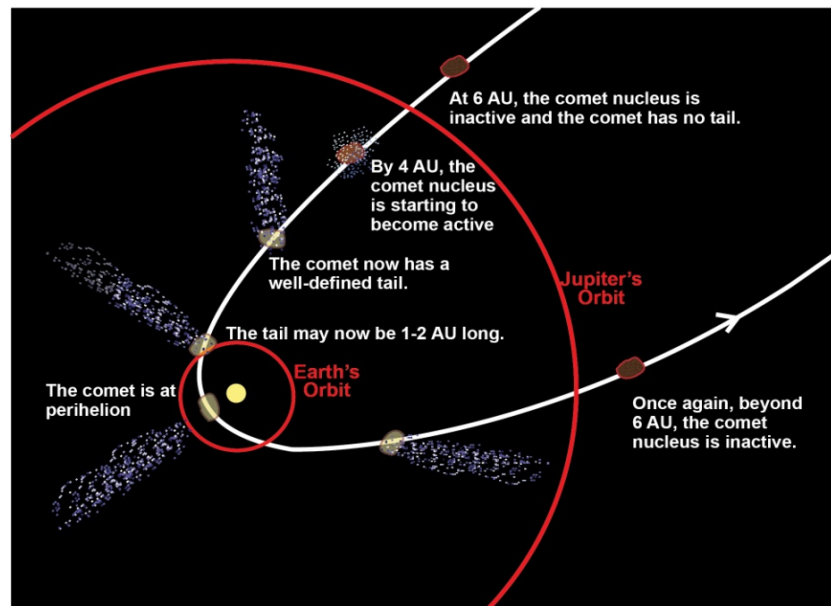
Comparing Comets

COLLEGE GUIDE TO COMET ENCOUNTERS (FOR STUDENTS)

Background Information:

Comets are made of **materials** such as rocks and ices. They usually have orbits that are long and elliptical. Comets come from the **cold** outer edges of the Solar System. When a comet is far away from the Sun (beyond the orbit of Jupiter), its nucleus (the solid part of the comet) remains **frozen** and changes very little. As it approaches the inner Solar System (closer than the orbit of Jupiter), the nucleus feels more of the Sun's radiation (warmth) and its ices begin to change directly from a solid to a gas (called sublimation). Some of the ices are on the surface while others are deeper into the nucleus. When the gas

sublimates, it escapes the nucleus and can drag dust off with it. The gases and dust released from the comet form a coma (head) around its nucleus, which can grow to become 100,000 kilometers in diameter and usually grows in size and brightness as the comet approaches the Sun. The charged particles that are given off by the Sun accelerate materials away from the coma at differing velocities according to the size and mass of the materials. Thus, two tails are formed—one of dust and one of gas. A tail may extend to millions of kilometers from the head and looks **fuzzy** from Earth. Each time a comet approaches the Sun, some of the mass of the nucleus is blown into space; eventually the nucleus contains no more ice and becomes just another rocky body in the Solar System.



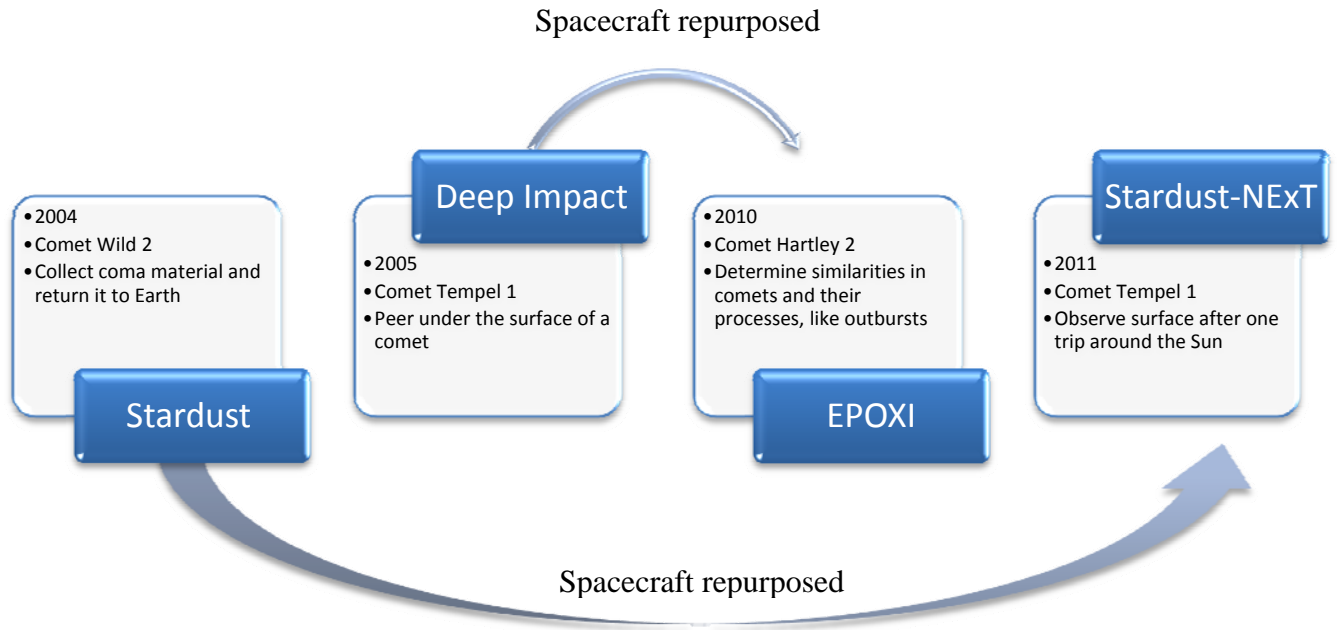
Scientists are interested in studying comets because they are some of the oldest bodies in our Solar System. They contain a record of the conditions in the disk when the planets formed. When comets impacted the Earth they may have brought resources important to life, such as water and carbon based molecules, but they may have also caused the extinction of life, such as the mass extinction of the dinosaurs 65 million years ago, by changing the climate conditions.

The interactions of comets with the Sun are some of the most spectacular events that humans can witness. If you ever have seen a comet in the nighttime sky, it is a memory you will treasure forever. When viewed in the sky, people can see the reflections of sunlight on the comet's coma (the gas and dust cloud surrounding the nucleus) and sometimes one or more of the tails of the comet, but the nucleus is hidden underneath the coma and is therefore veiled in mystery.

Cometary scientists think that the surface layer of a nucleus can tell us a lot about them and shed light on the processes that formed the planets. Comet surfaces are highly evolved, after all, they have been around a long time and each time their orbit takes them close to the Sun, the surface of the nucleus is

altered because of its exposure to sunlight. The changes that occur on the surface are capable of uncovering fresh layers of material, preserved inside the comet since the formation of our Solar System.

Spacecraft are required to penetrate the coma and see the nucleus in order to study the primitive body. NASA's Discovery Program launched several missions to help us better understand comets and to help answer big questions like "Where did we come from?" See the graphic below for more information.



Keep up-to-date with mission results by visiting the mission Web pages:

<http://stardust.jpl.nasa.gov>

<http://deepimpact.umd.edu>

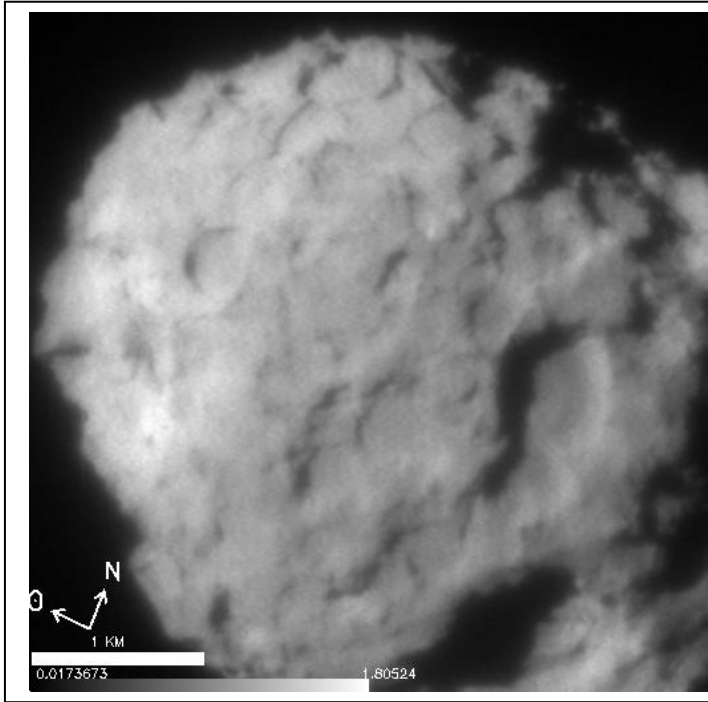
<http://epoxi.umd.edu>

<http://stardustnext.jpl.nasa.gov>

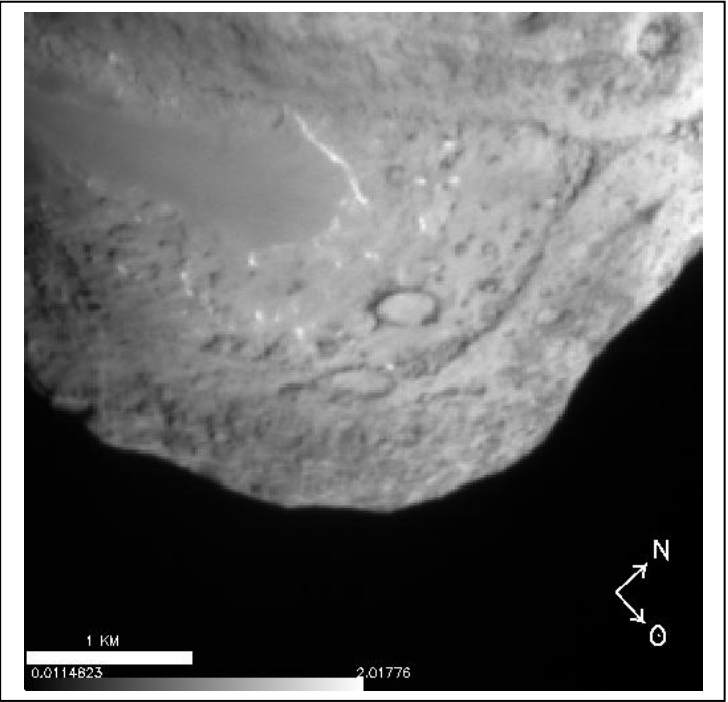
For this activity, you will observe and compare the surfaces of two comet nuclei. The images on the activity sheet were taken from two spacecraft in NASA's Discovery program. The image on the left is the surface of comet Wild 2 (pronounced "Vilt" because the discoverer is Swiss), taken from the Stardust 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. They are shown here displayed on the same intensity scale.

Objectives:

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

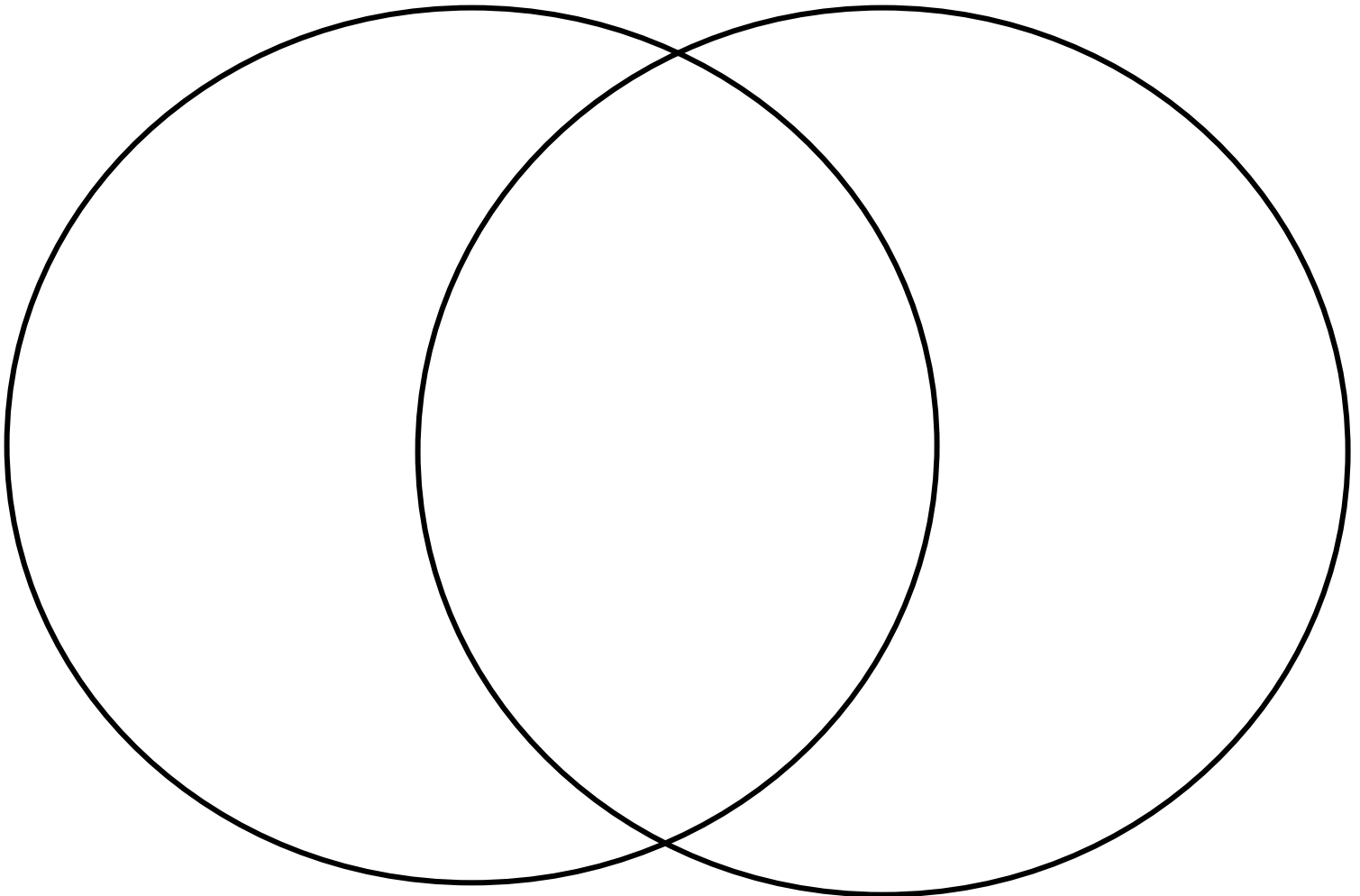


Comet Wild 2 taken by the Stardust spacecraft on January 2004 during its encounter. Scale is 15 meters per pixel and 4 km by 4 km.



Comet Tempel 1 taken by the Deep Impact's probe on July 4, 2005, just before the comet smashed into it. Scale 15 meters per pixel and 4 km by 4 km.

Based on your observations of these images, how are the nuclei of the two comets similar? How are they different? Use the Venn Diagram below to help organize your descriptions. Write your descriptions that are unique to comet Wild 2 on the left. Write your descriptions that are unique to comet Tempel 1 on the right. For those features that are common to both comets, write the descriptions in the middle, where the two circles intersect. Observations can be qualitative (using word descriptions) or quantitative (using numbers and measurements).



Comet Wild 2

Comet Tempel 1

Note:

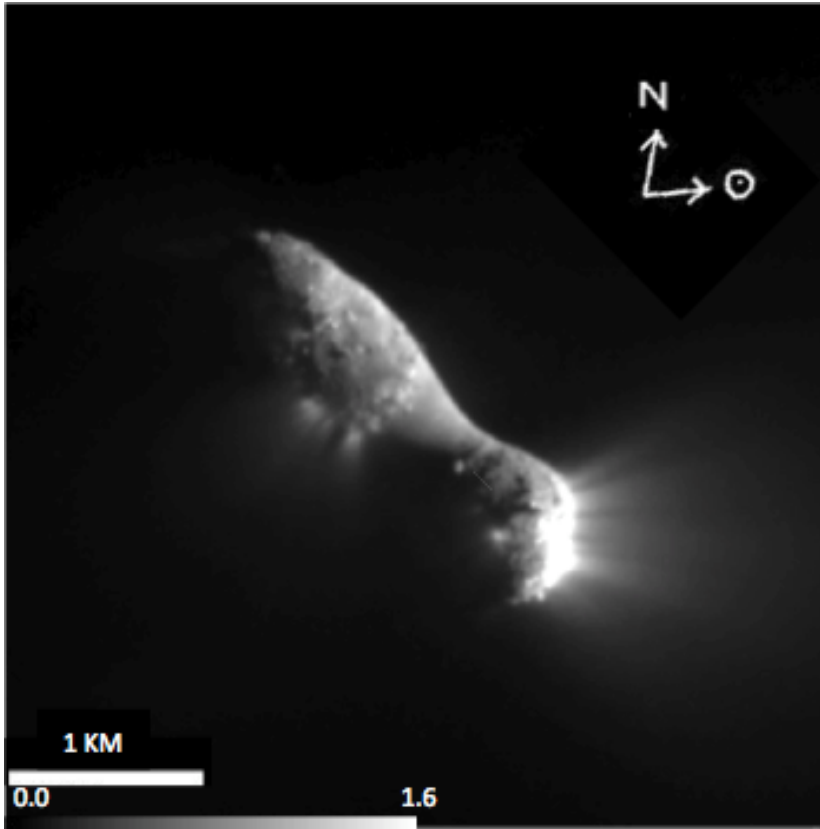
In comparing the comets, you may note the following.

- Some descriptions include only observations, while some include interpretation too.
- We suggest including observations only to start, then adding interpretation afterward.
- When you are comfortable with the observations and have experience, the interpretation flows as in the case with some experienced astronomers.

1. How can you tell the Sun's position in relation to this image? Provide two reasons for your answer.
2. Based on your comparisons and contrasts, why do you think the two surfaces are different? What factors may have caused these differences?
3. What questions do you have about these two bodies? How would you go about answering these questions? Refer to the following link containing background for cratering/collisions for comparing comet surfaces:
<http://deepimpact.umd.edu/mission/updates/update-200512.html>
4. Listen to the audio clip of scientists comparing the surfaces of these to comet nuclei. How did your description compare with the description on this page? 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.
5. You have just compared the nuclei of two comets, (Tempel 1 and Wild 2). The Deep Impact spacecraft flew by comet Hartley 2 on November 4, 2010 for a NASA mission called EPOXI. In the assessment that follows you will make predictions of what the spacecraft saw when it arrived. You will then make careful observations and interpretations of Hartley 2 using the same skills you practiced above.

Assessment

Make observations and interpretations of the image of comet Hartley 2 below. Use the rubric provided on the next page as a guide.



This 15 m/pix image of Hartley 2 was taken 108 seconds after closest approach by the Deep Impact spacecraft on November 4, 2010. The spacecraft was 1500 km away from the target. The square image is 4 km across.

Observations:

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.

Digital Image Analysis Procedure:

Using ImageJ, 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)

1. Launch the ImageJ program (ij.jar) and choose File > Open to find and open each comet image for comparison.
2. Move the windows of each image so that they are side-by-side with the ImageJ dashboard at the top of your screen.
3. Using the Oval Selection tool button, draw an oval around the largest crater on each of the two comets.
 - a. They should be whole craters
 - b. Look for clear rims with shadows characteristic of impact craters rather than smooth-looking surfaces
4. 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.
5. Choose Edit > Draw or Control D to make the ovals permanent.
6. 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.
7. Quantitative analysis:
 - Discuss accuracy vs. precision and use an appropriate number of significant figures in your 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 assist you in making analyses of 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?