COMPARING COSMIC CAMERAS

Developed for Stardust-NExT mission

EDUCATOR GUIDE

ACTIVITY DESCRIPTION

Of all the sophisticated instruments carried by spacecraft, cameras are the most accessible to our students. With cell phones, social networking, and photo editing programs, kids are more empowered than ever to explore the medium and try their own imaging.

In *Comparing Cosmic Cameras,* students compare cameras from different spacecraft capturing the cool images illuminating comet science. At the same time, they expand their knowledge of the NASA Discovery Program missions that are helping scientists and engineers that take us—virtually—to comets so we can learn more about these members of our Solar System.

In *Comparing Cosmic Cameras,* students will take and then compare the images taken by a camera—to learn about focal length (and its effects on field of view), resolution, and ultimately how cameras take "close up" pictures of far away objects. Finally, they will apply this knowledge to the images of comet Tempel 1 taken by two different spacecraft with three different cameras, in this case Deep Impact and those obtained from Stardust- NExT. This lesson could easily be adapted for use with other missions.

Comparing Cosmic Cameras is written to be relevant and engaging for students in grades 6–12. It is estimated to take 90 minutes, which could be broken into two 45-minute sessions.

National Science Education Standards
Abilities of Technological Design
5–8
Understanding about science and technology
9–12
Understanding about science and technology

***National Educational Technology Standards (NETS•S) and Performance Indicators for Students*:**
1. Creativity and Innovation
Students demonstrate creative thinking, construct knowledge, and develop innovative products and processes using technology. Students:
c. use models and simulations to explore complex systems and issues.
2. Communication and Collaboration
Students use digital media and environments to communicate and work collaboratively, including at a distance, to support individual learning and contribute to the learning of others. Students:
b. communicate information and ideas effectively to multiple audiences using a variety of media and formats.
3. Research and Information Fluency
Students apply digital tools to gather, evaluate, and use information. Students:
b. locate, organize, analyze, evaluate, synthesize, and ethically use information from a variety of sources and media.
d. process data and report results.

4. Critical Thinking, Problem Solving, and Decision Making
Students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources. Students:

c. collect and analyze data to identify solutions and/or make informed decisions.

6. Technology Operations and Concepts
Students demonstrate a sound understanding of technology concepts, systems, and operations. Students:

a. understand and use technology systems.
c. troubleshoot systems and applications.

LESSON

Objectives

Students will

- describe how focal length affects the field of view of an image
- describe the relationship between focal length and distance
- describe the combined impact of focal length and resolution on image quality
- predict/verify ways in which the image quality will be different between the pictures taken by different cameras

Materials

A copy of the PowerPoint that accompanies this lesson
For all students:
Computer access
Per student or group of students:
Access to a computer with software that will allow them to manipulate the images (e.g., MS Word)
Digital copy of the Student Guide
1 camera with ability to manually focus and set differing resolutions

Advanced Preparation

Reserve computer lab and cameras
Review the accompanying PowerPoint

Background Information

Much of what we know about space comes through the images that missions send back to Earth. The nature of the image depends on the kind of camera in the spacecraft. Three aspects of the camera impact the image quality: the image detector or CCD (equivalent to film), the focal length, and the aperture. All of the spacecraft in this lesson have a similar image detector, but differ in focal length and aperture. Investigating the effects of aperture requires a solid understanding of mathematics and would be a good follow up activity for those students who are ready.

If you want to discuss other missions, the JPL website (http://photojournal.jpl.nasa.gov/) provides a wealth of high resolution images for your use and gives information about the cameras on its spacecraft with a simple search for the mission name and technology!

The websites for the cameras discussed in this lesson are:
Deep Impact: http://deepimpact.umd.edu/tech/instruments.html
Stardust-NExT: http://stardustnext.jpl.nasa.gov/technology/nav_cam.html

For images from other missions:
The European Space Agency's Rosetta mission to comet Churyumov-Gerasimenko: http://www.esa.int/export/SPECIALS/Rosetta/SEM44DZOFBG_0.html.
The EPOXI mission to image the nucleus of comet Hartley 2
http://www.nasa.gov/mission_pages/epoxi/index.html.

This activity addresses three key aspects of the images we get back from Stardust-NExT—camera focal length, distance between the camera and the comet, and final image resolution.

Let's begin with a little about cameras.

Focal Length

Simply stated, the focal length of the camera is the distance between the lens and the image detector (imager). When this length is short, the amount of the world around it the camera can observe (called the field of view) is large. When the length is long, the field of view narrows. For example, the human eye has a focal length of 22 mm and a field of view of ~ 53 degrees (simulated as the big yellow box); the navigation camera on the Stardust spacecraft has a focal length of 200 mm and a field of view of ~ 3.5 degrees (simulated with the small blue box). To get a sense of how this would impact the field of view, look at Figure 1.

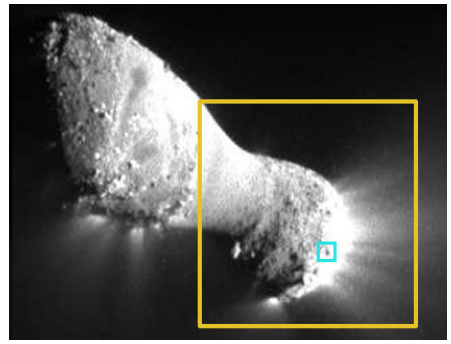


Figure 1

The larger yellow box shows simulated field of view of a human eye. The smaller blue box shows a simulated field of view of Stardust-NExT's Navigation Camera.

The Effect of Distance

Distance from the camera to the object of the image also affects the image. Obviously having the camera closer usually produces a more detailed image. In order to get its very detailed images of very distant objects, the Hubble telescope has a focal length of 58 meters! To get a sense of how cameras on spacecraft work, look at Figure 2.

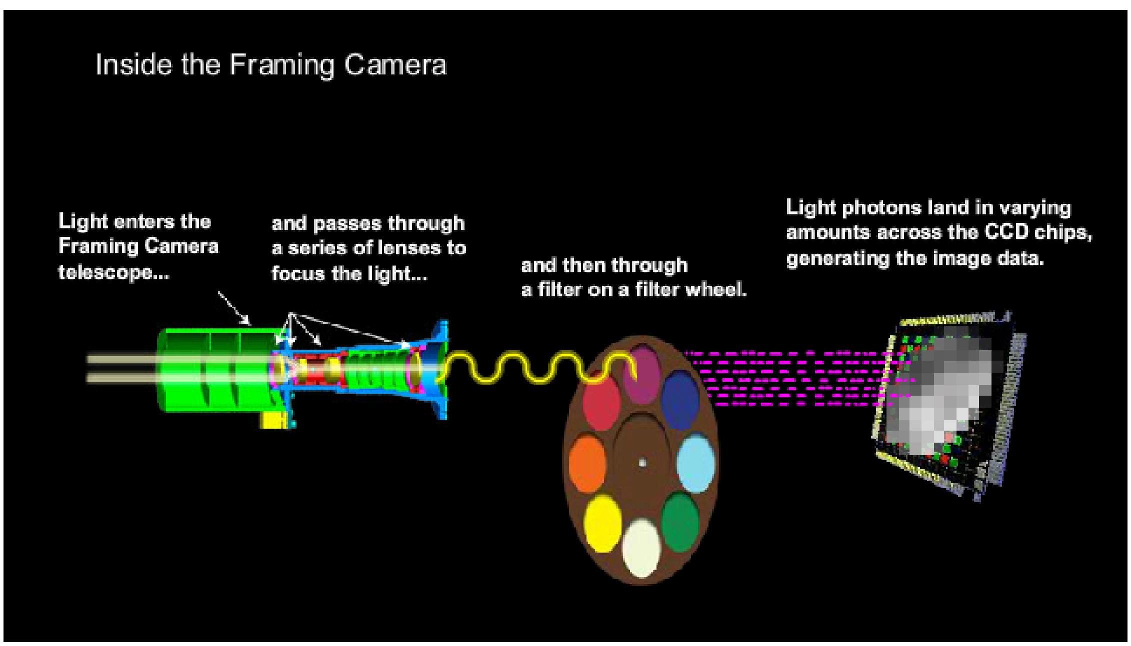


Figure 2 The schematic above shows the internal workings of a camera onboard a spacecraft. For more information about how images are captured in space, sent to Earth, and then interpreted visit the Framing Camera Interactive found on the Dawn Mission website: http://dawn.jpl.nasa.gov/technology/FC_inter.asp

Image credit: NASA/JPL/McREL

Final Image Resolution

When looking through a telescope the imager (your eye) stays the same, but because the telescope magnifies a distant object, it makes the object appear closer. In the case of cameras on spacecraft, the final image resolution is a combination of the magnification provided by the camera (like the telescope) and the resolution of the imager (like your eye).

For the three cameras in question, the camera magnification changes, but the imager stays the same. The changes in the camera magnification (combined with distance) produce changes in the final image. To make the model images consistent and widely useable, we are modeling the changes in final image resolution by having the students modify the collector on their camera—by using different lenses—instead of changing the camera magnification. If you have the equipment—changing the camera magnification would be more representative of reality!

Pixels are the smallest unit of a given digital image. The more pixels you have in a picture, the higher the resolution of the image and the closer it looks to the real thing. The high-resolution camera on the flyby spacecraft for Deep Impact had a final image resolution of about 2 meters/pixel. This means that one pixel in the image would represent a region 2 meters by 2 meters at a distance of 700 kilometers (435 miles). This resolution would allow you to tell the difference between a car and a pickup truck from over 400 miles away!

The table below summarizes the information about these aspects of the navigation camera on Stardust-NExT and the medium- and high-resolution imagers on Deep Impact.

	Stardust Navigation Camera	**Deep Impact Medium-Resolution Imager**	**Deep Impact High-Resolution Imager**
Focal Length	0.200 m	2.1 m	10.5 m
Field of View	3.5 degrees	0.587 degrees	0.118 degrees
Distance*	200 km	700 km	700 km
Final Image Resolution*	12 m/pixel	10 m/pixel	2 m/pixel

* at closest approach

As you can see, the Stardust navigation camera does not produce the same quality images as either of the Deep Impact imagers. Why do we care? That calls for a little story about a crater . . .

About the crater . . .

Deep Impact
NASA's first encounter with comet Tempel 1 was through the Deep Impact Mission in July 2005. This mission was specifically designed to image the comet, which it did successfully. To do so, the Deep Impact spacecraft carried three different cameras. The flyby spacecraft had two cameras. One was a high-resolution imager, which produced images at a final resolution of about 2 m/pixel and another medium-resolution imager which produced images up to a final resolution of 10 m/pixel.

The mission also included releasing a probe, called an impactor, into the path of the comet to see what would result from the "deep impact." The impactor probe was equipped with an imager similar to the medium-resolution imager on the flyby spacecraft. But, because it would get closer, the images it obtained were at a final resolution of 0.5 m/pixel.

Though scientists wanted to be able to see the crater created by Deep Impact's impactor probe, the material thrown out from the comet nucleus when the impactor collided obscured the view. The images from Deep Impact revealed interesting facts that, when interpreted through the eyes and methods of science, lead to exciting and sometimes startling conclusions. For example, the nucleus of Tempel 1 is estimated to have a density of around 0.7 g/cm^3—it would float in water!

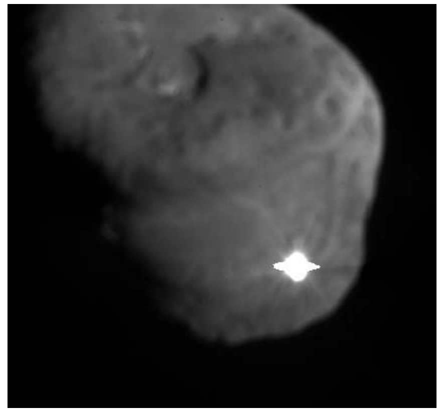


Figure 3

The image depicts the first moments after Deep Impact's probe interfaced with comet Tempel 1.

This image has a resolution of 88 m/pixel.

Image credit: NASA/JPL-Caltech/UMD
This image can be found at: http://www.nasa.gov/mission_pages/deepimpact/multimedia/pia02141.html

What next? Stardust-NExT
The Stardust spacecraft was originally launched in February of 1999 to collect coma dust from comet Wild 2. The Stardust spacecraft successfully completed that mission, returning the capsule containing particles from the comet and interstellar dust to Earth in 2006. NASA then repurposed the spacecraft with a new mission and name, calling it Stardust-NExT (New Exploration of Tempel 1). The mission: To visit comet Tempel 1 and gather new images of the dark side not previously seen by the Deep Impact mission. Because of differences in camera focal length and resolution, the navigation camera in Stardust-NExT sent back less detailed images than those we had already seen from Deep Impact.

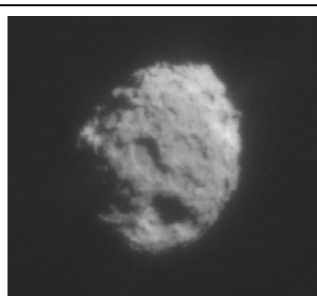
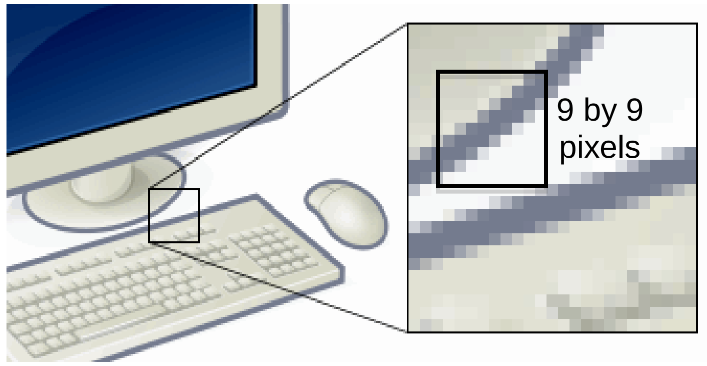


Figure 4

Comet Wild 2 is shown in this image taken by the Stardust navigation camera during the spacecraft's closest approach to the comet on January 2, 2004. The image was taken within a distance of 500 kilometers (about 311 miles) of the comet's nucleus.

Image credit: NASA/JPL-Caltech

This image can be found at:
http://stardust.jpl.nasa.gov/news/status/040102.html



Since the size and depth of the impact crater on the nucleus of comet Tempel 1 is unknown, it was hard to predict the quality of the image(s) and the kind of information that was collected by Stardust-NExT. At its closest approach (~ 200 km) the best final image resolution the Stardust-NExT navigation camera is capable of is 12 meters/pixel. This means that if the real crater is 100 meters in diameter, the image will show this in 8 or 9 pixels!

Introduction

1) Begin by giving students two different images and asking them to compare them.
2) Talk with students about one of the important aspects of comparisons—that they identify both the ways the images are similar and the ways they are different.
3) Use the PowerPoint (script in the notes section) to brief students on the missions to the nucleus of Tempel 1. Be sure to emphasize the differences in the cameras.

Data Management

Before students begin, delete all other images from the camera's memory card.

To keep each set of images separate: After they have transferred each set of images to the computer, have students delete the images from the camera.

Student Activity

1) Explain to students that they will be using digital cameras to show the differences between three cameras found on two different spacecraft. The goal of this first activity is to get students familiar with the cameras and investigate the effect of focal length.
2) Have students set up their photography space by:
   a) Selecting an object to image. This should be something that is interesting to look at and has some large and fairly small details. The sample images shown below use a ball of play dough to simulate a planet with a ring, polar cap, and some other smaller features.
   b) Set the object against a wall or other suitably drab backdrop.
3) Have students open an electronic copy of the Student Guide investigations section.
4) Investigating the effect of focal length.
   a) Explain the concept of focal length—the distance between the lens and the image detector.
      i) Show the PowerPoint slide that details the differences in focal lengths between the cameras. (slide 7)
      ii) Tell students what values on the camera's lens are the designated focal lengths.
   b) Have students take three images of their object using a short, medium, and long focal length.
   c) Have students connect their camera to the computer and:
      i) Download the images to a new folder—called focal length.
      ii) Use the images to fill in the comparison chart in the Student Guide. Example shown on the next page.
      iii) Compare the effects of focal length on the images they produced.

Sample Student data:

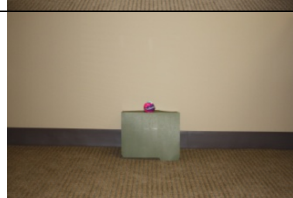
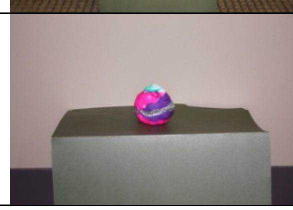
Focal Length	
Short	
Medium	
Long	
Comparison	
Ways the images are similar:	All show the same object
Ways the images are different:	The short focal length shows more of the surrounding area, and the long focal length shows a “closer” image of the object.
Conclusion	As the focal length gets longer, the object gets bigger.

iv) Ask students to identify which focal length represents which camera. Post the correct responses in a place for student reference.

Focal Length	Models
Short	Stardust Navigation Camera
Medium	Deep Impact Medium-Resolution Imager
Long	Deep Impact High-Resolution Imager

5) Investigating the effect of distance.

a) Use the PowerPoint (slide 7) to remind students that not all images were taken from the same distance.
b) Using masking tape, have students mark a short, medium, and long distance from the object.
c) Have students take three images of their object at each distance using a short, medium, and long focal length.
d) Have students connect their camera to the computer and:
   i) Download the images to a new folder—called Focal Length and Distance.
   ii) Use the images to fill in the comparison chart in the Student Guide. Example shown below.
   iii) Compare the effects of focal length and distance on the images they produced.

	Distance		
Focal Length	Far	Medium	Close
Short			
Medium			
Long			

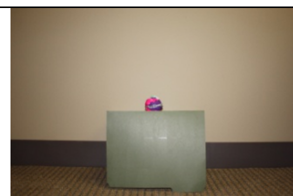
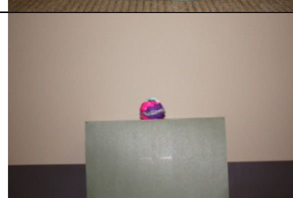
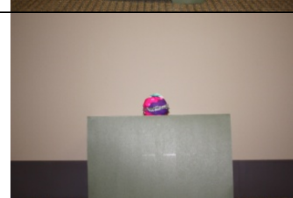
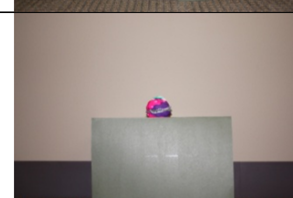
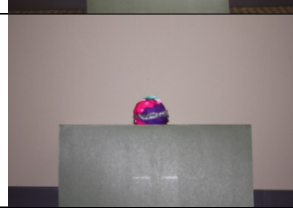
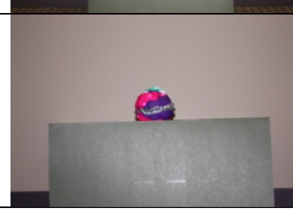
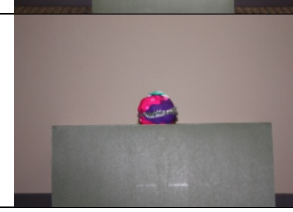
Comparison	
Ways the images are similar:	All show the same object
Ways the images are different:	The short focal length at a far distance shows much more of the surrounding area, and the long focal length at a close distance shows a "bigger" image of the object.
Conclusion	As the focal length gets longer and the camera gets closer, the image of the object gets bigger.

   iv) Ask students to pair with a partner and identify any combinations of focal length and distance that produce similar images.

v) Ask students to identify which combinations of focal length and distance represents which camera. Post the correct responses in a place for student reference.

	Distance		
Focal Length	Far	Medium	Close
Short			Stardust Navigation Camera
Medium	Deep Impact Medium-Resolution Imager		
Long	Deep Impact High-Resolution Imager		

6) Investigating the effect of resolution.
   a) Explain the concept of resolution.
   b) Use the PowerPoint (slide 7) to remind students that not all images had the same final resolution.
   c) Show the students how to change the resolution on their cameras and designate the resolutions you will be using to model low-, medium-, and high-resolution cameras (e.g., 2 megapixel; 6 megapixel; 12 megapixel).
   d) Have students pick one distance to take the next set of images at. The medium distance is recommended.
   e) Have students take nine images of their object: one at each resolution (low, medium, high) and with a short, medium, and long focal length.
   f) Have students connect their camera to the computer and:
      i) Download the images to a new folder—called Focal length and Resolution.
      ii) Use the images to fill in the comparison chart in the Student Guide. Example shown below.
      iii) Compare the effects of focal length and resolution on the final images.

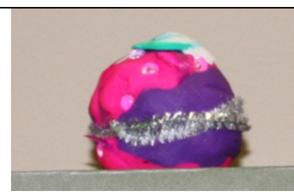
	Resolution		
Focal Length	Low	Medium	High
Short			
Medium			
Long			

Comparison	
Ways the images are similar:	All show the same object. None show much of the surrounding area (field of view).
Ways the images are different:	The short focal length and low resolution is the hardest to see the object. The long focal length at a close distance shows a “bigger” image of the object.
Conclusion	As the focal length gets longer, the image of the object gets bigger.

iv) Ask students to identify which combinations of focal length and resolution represents which camera. Post the correct responses in a place for student reference.

	Resolution		
Focal Length	Low	Medium	High
Short	Stardust Navigation Camera		
Medium		Deep Impact Medium-Resolution Imager	
Long			Deep Impact High-Resolution Imager

7) Investigating the properties of final image resolution.
   a) Explain that one of the benefits of high-resolution images is that they can be enlarged.
   b) Have students copy the pictures and crop each of them so it shows only the object they picked.
   c) Have students enlarge the cropped images to the same size. You may need to walk them through a few of these.
   d) Use the images to fill in the comparison chart in the Student Guide. Example shown below.
   e) Compare the effects of enlarging images of differing resolution.

	Resolution		
Focal Length	Low	Medium	High
Short			
Medium			
Long			

Comparison	
Ways the images are similar:	All show the same object. None show much of the surrouding area (field of view).
Ways the images are different:	Even at a high resolution, the short focal length produces a fuzzy image when enlarged. A long focal length always produces a sharper image than either of the other focal lenghts.
Conclusion	A long focal length and high resolution produce a crisp image when enlarged.

   f) Ask students to pair with a partner and discuss how the modeled images from Stardust-NExT appear different than those from Deep Impact in terms of resolution.
   g) Listen for differences in the features they will see and how crisp/clear (or fuzzy) the image is.

8) Engage the students in sense-making. Ask them to pair and answer the following two questions. After the pair has an answer to the questions, ask them to share with the larger group.

i) Do any of the images show the differences in the image resolutions of Tempel 1 as captured by Deep Impact and Stardust-NExT? Why or why not? (No, none of the images show *all* of the differences between the cameras.)

ii) What would you predict are some ways in which the image quality will be different between the pictures taken by two different cameras, for example the pictures of Tempel 1 by Deep Impact's medium-resolution camera and Stardust-NExT's navigation camera?

9) Share with students:

a) Slide 8 of the PowerPoint:

i) This set of images is to model the differences in final image resolution between the Deep Impact medium-resolution imager and the images from Stardust-NExT. The actual image does not have the bright flash from impact and may be slightly better or worse based on a number of factors. These images also do not take into account that:

(1) The Stardust navigation camera does not have as many color levels as the Deep Impact imagers and images from Deep Impact's medium-resolution imager can be stretched in many different ways to show different contrasts and the images from Stardust-NExT cannot be.

(2) The nucleus was in almost full sunlight when Stardust encountered it, so the shadowing was dramatically reduced which may make the stretching problem more of an issue.

b) This thought:

The camera on Stardust-NExT took pictures as it flew-by comet Tempel 1 and was only able to take pictures of Tempel 1 for about 70 seconds. Tempel 1 is rotating (unevenly) and different regions of the comet are illuminated by the Sun at different times making them visible to Stardust's camera when it passes by. Stardust-NExT was able to image the same areas of interest previously imaged by NASA's Deep Impact mission in 2005 and see things we had never seen before! All of the images give us valuable information.

c) Slide 9 of the PowerPoint:

i) This pair of images shows the before-and-after comparison of the part of comet Tempel 1 that was hit by the impactor from NASA's Deep Impact spacecraft.

(1) The left-hand image is a composite made from images obtained by Deep Impact in July 2005.

(2) The right-hand image shows the same region as viewed by NASA's Stardust spacecraft six years later, on Feb. 14, 2011.

ii) Stardust-NExT was able to image both the area we had seen before—and new areas of the comet!

Extensions to take it further

- Create a series of images that model the kinds of differences in images we saw from 700 km with Deep Impact and the ones we see from 200 km in Stardust-NExT. This can be enhanced by using ratios of the actual distance of the spacecraft camera to the comet nucleus and approximating the differences in camera resolution and then enlarging the images.
- Have students view images from Stardust-NExT and verify their predictions about the differences between the images from Deep Impact and Stardust-NExT.
- Conduct further investigations about the effect of the speed of imaging and/or movement of camera or subject when it comes to comet imaging, both spacecraft and comet are very much on the move!
- Ask the students to work under constraints, such as
    - Imaging the object under a time limit (allow them to set the camera up ahead of time!).
    - Imaging in a dark room with a strong flashlight—and no flash from the camera.
- Have students select the camera settings that will give the best image for a specific task.
- Investigate the math behind focal length.
- Investigate the actual configuration of lenses in a telescope camera (similar to a spacecraft camera).
- Investigate the kinds of image distortion that occur when taking images (e.g., chromatic aberration)
- Investigate the way that f-stop or aperture impacts the field of view and image resolution.

For more fun with Comets visit:
Stardust-NExT education page:
http://stardustnext.jpl.nasa.gov/education/index.html
Deep Impact education page:
http://deepimpact.umd.edu/educ/index.html

And
EPOXI education page:
http://epoxi.umd.edu/4education/index.shtml
Where you can find a lesson to continue student's comparisons of comets: Comparing Comet (http://**epoxi**.umd.edu/pdfs/**Comparing_Comets**_SA.pdf)