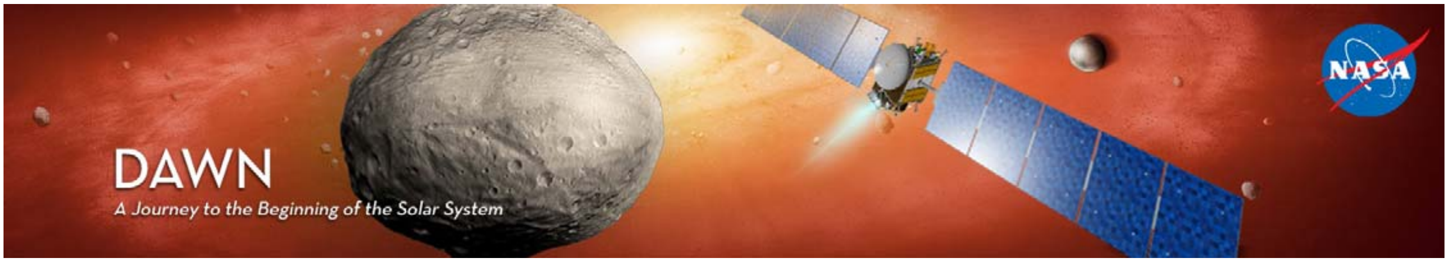


Interaction of Energy and Matter: Dawn Instrumentation

Framing Camera

TEACHER GUIDE

What will the Framing Camera "see" when we get to Vesta and Ceres?

EMR and the Dawn Mission
Electromagnetic radiation (EMR) will play a major role in accomplishing the goals of the Dawn Mission. The Dawn spacecraft instrumentation payload utilizes the interaction of specific ranges of electromagnetic radiation with the ***matter*** that comprises Ceres and Vesta. When EMR interacts with matter, ***radiation*** is absorbed or reflected only at wavelengths corresponding to the discrete amounts of ***energy*** that are related to the constituents of the matter. These wavelengths can then be used to identify the components of a given substance.

The scientific data that results from these interactions will enhance our knowledge of Vesta and Ceres by providing information about their surface composition and mineralogy, surface modification, and surface ages. When this information is incorporated with what is already known, either it will substantiate current scientific theories of asteroid origins and geologic processes or it will form the basis for new models.

Dawn Mission Objectives
The mission's science goals are to understand the conditions and processes in place at the beginning of solar system formation. Scientists also hope to gain a new understanding of the role of water in asteroid evolution.

Framing Cameras
Primary Objective
Return images that map the surfaces of Vesta and Ceres that will characterize their geologic history and evolution.

Most science curricula emphasize how we use electromagnetic radiation in our everyday lives, using illustrations such as radios, x-ray machines, microwaves, and ultraviolet and infrared lamps. The materials in this module will introduce students to the ways that scientists, engineers, and technologists in the real world design instrumentation that utilize the interactions between different frequencies/wavelengths of the EMR and matter to make scientific measurements and analyze data. This section of the *Interaction of Energy and Matter: Dawn Instrumentation* module is designed to help your students understand more about how the Framing Cameras aboard the Dawn Spacecraft operate and what they will help us "see" when the spacecraft reaches Ceres and Vesta.

For a more information on the Framing Cameras, see page 7 of this guide.

Options for using the Framing Cameras *Interaction of Energy and Matter materials*
The Framing Camera *Interaction of Energy and Matter* materials may be used in three ways:

1. Use the Framing Cameras PowerPoint presentation to engage the whole class in how this instrument in the Dawn Spacecraft payload utilizes the interaction of specific ranges of electromagnetic radiation with the matter to identify the composition of Ceres' and Vesta's surfaces. Have individual students complete the observation sheet handout as they watch the presentation. This option, designed to be incorporated into your study of electromagnetic radiation or your study of matter–energy interactions, can be completed in 30 minutes of class time.

2. Divide the class into groups of two or three to view the Framing Cameras PowerPoint presentation with the Student Version of the script and, as a group, complete the observation sheet handout. If you select this option, you will probably wish to review the characteristics of electromagnetic radiation, using the information in *The Electromagnetic Spectrum* and in the *Characteristics of EMR* in Appendix A of this guide before dividing the class into groups. For more information on the electromagnetic spectrum, you can also use the interactive found here: http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html If you use the students' observations as the basis for a class discussion of the applications of electromagnetic radiation and/or matter-energy interactions, this option can be completed in one 50-minute class session.
3. Divide the class into groups of two or three. Assign each group to view one of the series of PowerPoint presentations that feature the instruments—GRaND, VIR, and the Framing Camera—in the Dawn Spacecraft payload. They should complete the observation handout as a group for the instrument they are assigned. If you select this option, you will probably wish to review the characteristics of electromagnetic radiation, using the information in the *Characteristics of EMR* in Appendix A of this guide, *The Electromagnetic Spectrum*, and the website mentioned above before dividing the class into groups. If you use the students' observations as the basis for a class discussion to compare the applications of electromagnetic radiation matter-energy interactions in the different payload instruments, this option may require more than one 50-minute class session.

Materials

All documents needed to complete this activity are located in the *Interaction of Energy and Matter: Dawn Instrumentation* module at http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/index.asp.

- Handout: Print PowerPoint slide four entitled *The Electromagnetic Spectrum*
- *Framing Camera PowerPoint* presentation from the *Interaction of Energy and Matter: Dawn Instrumentation* module
- *Student Report Sheet: Framing Camera* to record observed interactions of energy and matter from the *Framing Cameras PowerPoint* presentation
- Optional: *Student PowerPoint Script: Framing Camera*
- Optional: Interactive website on the electromagnetic spectrum found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html
- Optional: *Framing Camera Interactive* to reinforce the concepts introduced in the *Framing Camera PowerPoint*
- Optional: Activities for use with students with limited background in the concept of albedo can be found in Appendix B. The following are materials needed for Appendix B activities:
    - Copies of *Student Activity: Albedo and Digital Imagery Using Images of the Asteroid Vesta*
    - Graph paper copied onto transparency
    - Markers
    - A Dawn image from Vesta—use the one provided or find more at http://dawn.jpl.nasa.gov/multimedia/index.asp
    - Pastels (in shades from white to black, including various greys) or drawing pencils
    - Drawing paper (no lines)
    - Large chart paper
    - Glue sticks

Note**:** If you plan to use the assessment created for this module, please ask your students to keep all of their activities and handouts for use in completing the assessment entitled *Concept Maps: EMR Matter-Energy Interactions and Relationships.*

Procedure

Using the *Framing Cameras PowerPoint* presentation with the whole class

1. Start the *Interaction of Energy and Matter: Dawn Mission Instrumentation, Framing Camera PowerPoint* presentation. You will find a suggested script for each screen and cues for controlling the forward progress of the presentation below.

2. As students view the title page of the Framing Cameras PowerPoint presentation:
The Dawn spacecraft carries two identical framing cameras, whose primary science goal is to return images that map the surfaces of Vesta and Ceres. Only one framing camera will operate at any one time.

3. {click to Slide 2}
The Framing Cameras are the scientific imaging system of the Dawn mission.

4. {click to Slide 3}
The Framing Cameras are the "eyes" of the spacecraft. They contribute to the navigation system of the spacecraft.

   In this section, we will be learning more about the Framing Cameras, including what they do and how they work.

5. {click to Slide 4}
Have students examine Slide 4 and/or handout copies of the graph entitled *The Electromagnetic Spectrum.* You may also want students to review the interactive information found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html
If this is your first lesson in the Exploration phase of this module, introduce (or ask students to review) the characteristics of electromagnetic radiation using the information in the *Characteristics of EMR* in Appendix A of this guide and explore the interactive information presented at the website above.

   {The answers to the **bolded student questions** are not part of the Student Version of the script. Students are prompted to answer these questions on their *Framing Camera Student Report Sheet.*}

   What region of electromagnetic radiation (EMR) from Ceres and Vesta will the Framing Cameras measure?
   {Wait for student answers.}
   [The framing cameras on the Dawn spacecraft will focus EMR from the sun reflected from the asteroid's surface in the visible and near infrared range (from 430 to 1020 nm).]

   What frequency and wavelength regions of EMR are classified as visible radiation?
   {Wait for student answers.}
   [Wavelengths in the range of 10^{-6} m and frequencies in the range of 10^{15} hertz.]

   What frequency and wavelength regions of EMR are classified as infrared radiation?
   {Wait for student answers.}
   [Wavelengths in the range of 10^{-5} m and frequencies in the range of 10^{12} hertz.]

   How does the energy of gamma rays compare with the energy of the rest of the EMR waves?
   {Wait for student answers.}
   [Gamma rays have the highest energy waves in the EMR.]

6. {click to Slide 5} [Also see optional hands-on activities in Appendix B.]
   What will the Framing Cameras do when Dawn gets to Vesta and Ceres?

   The Framing Cameras will return images that map the surfaces of Vesta and Ceres. These images will be used to:
   {click}
   create global ***topography***, ***albedo***, and color maps of Vesta and Ceres using clear and narrow band filters;
   {click}
   determine the shape, volume, and mass of Vesta and Ceres;
   {click}
   measure spin rates;
   {click}
   map the elemental and mineralogical composition of Vesta and Ceres;
   {click}
   study crater ***morphology*** and their distribution on Vesta and Ceres;
   {click}
   search for fractures and evidence of geologic processes on Vesta and Ceres; and
   {click}
   determine the reflectance characteristics of Vesta's and Ceres' surfaces.

7. {click to Slide 6}
   The Dawn spacecraft carries two framing cameras that are designed to operate in cold temperatures, as low as -60^{o} C, and the vacuum environment of space. Only one of them will be active at any one time.

   Their four-lens optical systems
   {click}
   will focus electromagnetic radiation from the sun that is reflected from Vesta and Ceres to form images of their surfaces.
   {click}
   This optical system is encased in a titanium tube, which also has
   {click}
   venting ports used to create a vacuum in the optical system that matches that of the environment in space.
   The framing camera is also the "eye" of the spacecraft.
   {click}
   A mirror cube, mounted on the titanium tube, is used for navigation. It measures the alignment of the camera with respect to the spacecraft coordinate frame.

8. {click to slide 7}
   Each of the framing cameras has a
   {click}
   cylindrical camera head capped by a
   {click}
   stray light ***baffle*** that shades the optics in the lens barrel from light reflected from the spacecraft.
   {click}
   When the cover door
   {click}
   is closed, it protects the hardened ***refractive*** radiation-proof glass lenses and filters in the lens barrel.

   When the cover door is open, reflected electromagnetic radiation from the surfaces of Vesta and Ceres can enter the camera.

{click}
The four-lens optical system focuses the incoming electromagnetic radiation that is ***reflected*** from the asteroid's surface and sends it through a filter wheel
{click}
which has eight positions—one with a clear filter from 450-950 nm and seven filters centered at 430, 540, 650, 750, 830, 920, and 980 nm. These wavelengths translate to 4.30×10^{-7} to 9.80×10^{-7} meters, which are within the visible and infrared ranges. These filters will be used for spectral analysis of Vesta's and Ceres' surfaces.

{Students are prompted to answer these questions on their *Framing Camera Student Report Sheet.*}

Compare how light interacts with the four lenses in the Optical System compared with how it interacts with the filter wheel.
{Wait for student responses.}
Light is refracted and focused as it passes through the four lenses. As the light passes through the filter wheel, the individual filters remove specific wavelengths from the image and allow only the specific wavelengths of the filters through to the CCD.

How is light reflected, transmitted, and refracted

a) **before it comes into the Framing Camera and**
   Light is transmitted from the Sun and reflected off the surface.
b) **as it moves through the Framing Camera?**
   Light is refracted by the lenses of the Framing Camera in order to focus the image.

9. {click to slide 8}
The framing cameras are equipped with a
{click}
1024 x 1024 frame transfer ***charge-coupled device*** (*CCD)* which converts electrical charge data into
{click}
surface images.
{click}
On the Dawn spacecraft, the Framing Camera shares the data processing unit box (DPU) with the VIR spectrometer. The DPU compresses and buffers the data from both the camera and spectrometer.

Each camera has independent readout electronics with data processing units that compress the images into desired formats.

{Students are prompted to answer these questions on their *Framing Camera Student Report Sheet*:}

What is the purpose of the Charge-Coupled Device (CCD)?
{Wait for student responses.}
The CCD converts electrical charge data into surface images.

Describe the output of the Framing Camera as shown on this slide.
{Wait for student responses.}
The Framing Camera produces black and white images of the surface.

10. {click to slide 9}
The Framing Cameras on the Dawn Spacecraft will utilize the interactions of energy and matter to collect scientific data about Vesta and Ceres.
{click}

{Students are prompted to answer this question on their *Framing Camera Student Report Sheet:}*

What energy and matter interactions are involved in the scientific measurements made by the Framing Cameras?

Possible answers include the following:

Energy interacting with Matter

The reflection of EMR from the surfaces of Vesta and Ceres.
The refraction of EMR to focus it on the filters of the Framing Cameras
The interaction of EMR with the filters in the filter wheel
The interaction of EMR with the CCD

Wrap-up Session

1. If you used this PowerPoint presentation either as a class or as groups studying the Framing Cameras, relate this information as an application to your study of electromagnetic radiation and matter-energy interactions.
2. If you used this PowerPoint presentation as one of three that explained the matter-energy interactions of instruments in the Dawn Spacecraft payload, have each group of students report their findings and make comparisons of the findings as they relate to the electromagnetic spectrum and matter-energy interactions.
3. Have students go to the *Framing Camera Interactive* from the *Interaction of Energy and Matter: Dawn Instrumentation* module at http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/index.asp. The first sequence shows the orbiter imaging the surface. The second animation demonstrates how light travels from the sun, reflects off the asteroid, and is captured by the Framing Camera. The third animation animates the process that occurs inside the Framing Camera as light passes through the telescope to a series of lenses and then filters, then onto the CCD chips finally creating an image. The fourth animation then demonstrates how the spacecraft transmits signals back to Earth that are detected by the Deep Space Network and finally made into a digital image for analysis. The fifth section of the interactive allows students to manipulate images of the Earth with red, green, and blue filters and discusses how those filters are used to create “color” images from the data transmitted from the Framing Cameras. Finally, the last section of the interactive allows students to analyze images that are familiar to our everyday lives using red, green, and blue filters. The interactive includes a comparison between what the Framing Camera would see and what the students would see with their eyes and demonstrates the many steps of analysis involved in creating usable images from data from the Framing Cameras.

More Framing Camera Information

The **Max Planck Institute for Solar System Research**, MPS, Katlenburg-Lindau, Germany, was responsible for the design, fabrication, and testing of the framing cameras, which they contributed to the Dawn Mission.

What scientists can learn by analyzing the information from the Framing Cameras

These images from the framing cameras and CCD will help scientists:

- characterize the geologic history and evolution of the asteroids;
- characterize the size and shape, surface texture, and regolith properties of the asteroids; and,
- determine the composition of the asteroids.

Additional technical details about the Framing Camera

- The field of view of the camera is 5.5 x 5.5 degrees with a resolution of 9.3 m/pixel at a distance of 100 km.
- All seven of the camera's filters have a ***FWHM*** of 40 nm except the 980 nm filter which has a FWHM of 80 nm. The sensitivity of each filter is sufficient to give a signal to noise ratio of 100 for exposures of 100 ms to 1 s of the asteroid surfaces.
- The camera readout rate is 1.6 s for a 1024 x 1024 frame, with an exposure time from 1 ms to 3.5 h.
- Each framing camera system has a mass of roughly 5 kg and consumes about 12 W.

What is a Charge-Coupled Device (CCD) and what does it do?

A charge-coupled device (CCD) is a light-sensitive integrated circuit that produces the data for an image in such a way that each pixel (or picture element) in the image is characterized by an electrical charge, the intensity of which is related to the amount of light reflected by the target.

The CCD functions in two phases—exposure and readout. During the exposure phase, tiny photosites with light-sensitive diodes convert photons of EMR into electrons, *i.e.,* electrical charge. After the exposure time is passed, the photosites are read out one line at a time.

A ***frame transfer CCD*** has a hidden, not normally used, area containing as many sites as the area exposed to light. In the Dawn version, it has a tungsten cover to protect it from protons and other high-energy cosmic particles. When the exposure time is up, the sites are transferred very rapidly to the hidden area. Here, safe from any incoming light, photosites can be read out at any speed necessary to correctly measure the site's charge. At the same time, the exposed part of the CCD is collecting light again, so no delay occurs between successive exposures.

Definition of Terms

Albedo—The ratio of the amount of light reflected from a surface to the amount of incident light
Baffle—A device used to control or impede the flow or emission of waves
Charged Coupled Device (CCD)—A light-sensitive integrated circuit for storing and displaying the data of an image
Electromagnetic Radiation (EMR)—"Waves" of electrical and magnetic "disturbance", radiated as visible light, radio waves, or any other manifestation of the electromagnetic spectrum
Electromagnetic Spectrum—The complete range of frequencies of electromagnetic waves from the lowest to the highest, including, in order, radio, infrared, visible light, ultraviolet, X-ray, and gamma rays
Energy—The capacity of a physical system to perform work. Energy exists in several forms such as heat, kinetic or mechanical energy, light, potential energy, electrical or other forms
Full Width at Half Maximum (FWHM)—In physics, the difference between the energies or frequencies on either side of a spectral line or resonance curve at which the line absorption or emission or the resonant quantity reaches half its maximum intensity (see figure to the right)
Matter—Any substance that has mass and occupies space
Morphology—The external structure and shape of rocks, formations, and surface units that can be used to understand how a feature has formed (*e.g.* surface features formed by erosion may have fan-shaped deposits)
Radiation—Energy that comes from a source and travels through some material or through space. Light, heat and sound are types of radiation
Refractive—Relating to, involving, or capable of refraction, which is the bending of light as it passes from one medium to another
Reflected—Thrown or folded back; the return of light or sound waves from a surface
Regolith—The layer of rocky or icy debris and dust that forms the uppermost surface of planets, moons, and asteroids
Topography—The heights of features on the surface

Appendix A
Characteristics of EMR

- Electromagnetic radiation is made of transverse waves (similar to water waves) that travel at the speed of light.
- Electromagnetic radiation is classified into types—radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays—according to the frequency (or wavelength) of the radiation. See the Electromagnetic Spectrum chart on the Dawn website and/or the interactive information found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html for more explanation.
- The frequency of electromagnetic radiation is inversely related to the wavelength of the radiation. See the Electromagnetic Spectrum chart on the Dawn website and/or the interactive information found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html for more explanation.
- The energy of electromagnetic radiation is directly proportional to the frequency of the wave.
- Electromagnetic radiation interacts with matter by transmission, absorption, or reflection.

Depending upon the age and background of your students, these characteristics should be forthcoming:

- Electromagnetic radiation consists of an electrical field that varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field oriented at right angles to the electrical field.
- Electromagnetic radiation has energy and momentum, which may be imparted when it interacts with matter.
- Electromagnetic waves can impact matter, causing atoms to vibrate, release heat, or cause electrons to oscillate, depending upon the wavelength of the radiation.

Appendix B: Albedo and Digital Imagery

Teacher Procedure:

1. Ask students to describe what they know about light:
   a. How is it we "see" things?
   b. List some things that reflect light.
   c. Explain how light interacts with white and black objects.

2. Explain that "***Albedo*** is the amount of whiteness of an object or the amount of light that is reflected from a surface. The term is used in astronomy to describe how much light is reflected from planets, moons, or asteroids." For a more in depth experience with albedo, use the activity "Seeing Circles" in the development section of the *History and Discovery of Asteroids* module at http://dawn.jpl.nasa.gov/DawnClassrooms/1_hist_dawn/.

3. Tell students that "images of large and small bodies in the solar system taken from spacecraft are often converted, or originally acquired, as a table of numbers, where each number represents the ***brightness*** of one pixel (dot) in the image. For example, 0 can represent black and 100 can represent white, with each number in between representing a different shade of gray. These numbers can be transmitted back to Earth and turned into ***digital images***. Although digital imaging was first developed and heavily used for spacecraft images, it is now common in our lives."

4. Part 1: Have students practice classifying enlarged pixels using the first set of squares on the next page. Suggested answers include a = 0, b = 20, c = 50, d = 60, e = 75, f = 100. Have students discuss their decisions with a partner.

5. Part 2: Point out that the enlarged area in *Figure 2* is within the full image of *Figure 1*. Explain that students are now going to put their digital imagery analysis skills to work by analyzing an image of Vesta. Tell students to estimate the albedo of each area by assigning radiance values to similarly colored gray regions. Have students complete the exercise using *Figure 3*. Suggested regions are outlined below, however it is important to recognize evidence versus interpretation—not everyone will interpret the images the same way even though they are looking at the same evidence. That is okay! Use the class discussion to highlight the importance of interpretation of evidence to the scientific process.

(Some possible regions)

6. Part 3 (Alternative 1): Have students complete this same exercise with an actual image from Vesta from the Dawn Framing Camera. One method would be to provide graph paper on a transparency to complete this. You may choose the image provided or another from the Dawn website (http://dawn.jpl.nasa.gov/multimedia/index.asp). When students have completed the exercise, have them answer the final question.

7. Part 3 (Alternative 2): Another way to have students recreate the photo of Caparronia Crater is to do it as an art activity using pencils or pastels. Students will "scale up" the image by rendering a portion of the image onto a larger piece of paper (i.e. they will "scale up" their smaller square). In Art, *value* is the measure of light and dark in an image. Value corresponds to the scientific concept of albedo. Through

this activity, students will be able to better understand albedo through carefully examining the light and dark areas of a small portion of an image.

a. Start with a copy of an image that is large enough for students to see some detail. Depending upon how many students you have, draw a grid onto the back of the image. You may need two or more images to accommodate all of your students. Number each square and indicate which direction is "up." If using multiple images, number accordingly (i.e. 1a, 1b, 2a, 2b…).

   For example, a 16-square grid might look something like this:

1 ↑	2 ↑	3 ↑	4 ↑
5 ↑	6 ↑	7 ↑	8 ↑
9 ↑	10 ↑	11 ↑	12 ↑
13 ↑	14 ↑	15 ↑	16 ↑

(back of the image)

b. Cut out the image squares and set them aside.
c. Decide how much larger you want the image to become. For example, an 8" by 8" image could be scaled up 2x's by making the drawing squares in the grid 4" by 4". This would result in a drawing that is 16" by 16".
d. Measure and cut out the appropriate number of drawing squares. (*Note*: If using a black and white image, using gray paper for the drawing squares makes the students pay closer attention to light and dark areas in the image square.)
   e. Draw a corresponding grid onto a larger piece of paper. This grid will "hold" the larger, rendered squares and be the conglomerated picture of student drawings. Put the grid up so that it hangs on a wall, whiteboard, etc. (*Note*: When numbering your grid, start in the upper right corner and move to the left, as shown below.)

4	3	2	1
8	7	6	5
12	11	10	9
16	15	14	13

(Number the grid on the wall opposite from your image.)

f. Using drawing pencils or pastels have each student render their image square onto their larger, drawing square. Their "pixels" will recreate the image.
g. As each student completes their image, have them affix it to their associated square on the wall.
h. Explain that these squares are like pixels used to comprise a digital image. Each one represents a small piece of data and together they create the whole picture.

8. For more information on digital imagery and Vesta, have students read "The Rest of the Story" in the flashback *More Discoveries...Better Descriptions* located at http://dawn.jpl.nasa.gov/DawnCommunity/flashbacks/fb_10.pdf. There are also helpful websites listed in the "Additional Resources" section.

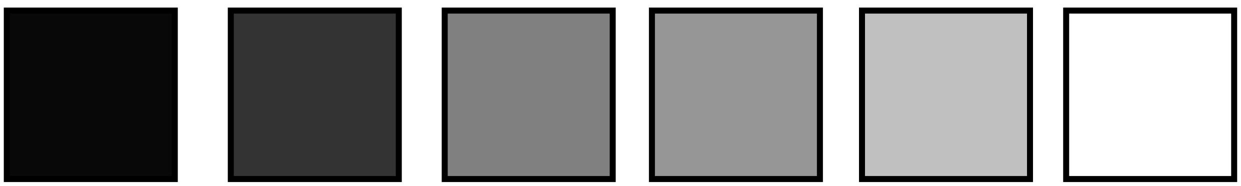
Student Activity: Albedo and Digital Imagery Using Images of the Asteroid Vesta

Part 1

Images of large and small bodies in the solar system taken from spacecraft are often converted into, or originally acquired, as a table of numbers. Each number represents the *brightness* of one pixel (picture element or square) in the image. For example, 0 can represent black and 100 can represent white, with each number in between representing a different shade of gray. These numbers are then transmitted back to Earth and turned into digital images. Although digital imaging was first developed and heavily used for spacecraft images, it is now common in our lives.

Practice

Estimate a radiance (where 0= black and 100= white) for each pixel in these example pixels. Discuss with a partner how and why you decided on the values between 0 and 100.



a. 0 b. _____ c. _____ d. _____ e. _____ f. 100

Part 2

Figure 1 is the best image we had of Vesta before the Dawn mission. In Figure 2, we have magnified 97 pixels of varying brightness that represent a small sample of the larger area (640 by 480 = 307,200 pixels) in *Figure 1*. For planetary remote sensing, the numbers are first recorded on the spacecraft, then transmitted back to Earth where they can be reconstructed into images.

Figure 1: Image of Vesta from the Hubble Space Telescope

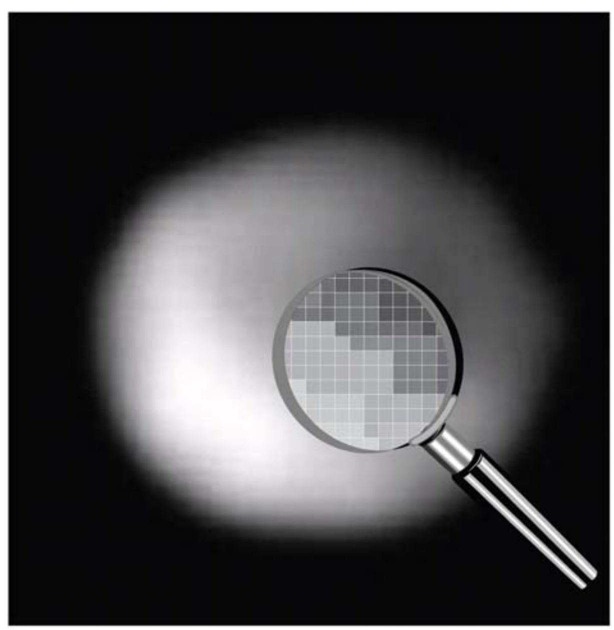


Figure 2: Enlarged area showing individual pixels

Figure 3: A larger image of the magnified area in Figure 2

1. Working with a partner, draw lines around each region of similarly colored pixels in Figure 3. Estimate a radiance value between 0 and 100 for each region of similar pixels, where 0 = black and 100 = white.

2. Compare your answers to the suggested answers in the *Teacher Guide* and to other groups working on the same image. What are some possible explanations for the differences in interpretation of the image?

Part 3 (Alternative 1)

Now try this same exercise with an actual image from the Dawn Framing Camera. Working with a partner, draw lines around each region of similarly colored pixels in Figure 4. Estimate a radiance value between 0 and 100 for each region of similar pixels, where 0 = black and 100 = white. You may use a transparency with a grid as an overlay and a marker to record your values.

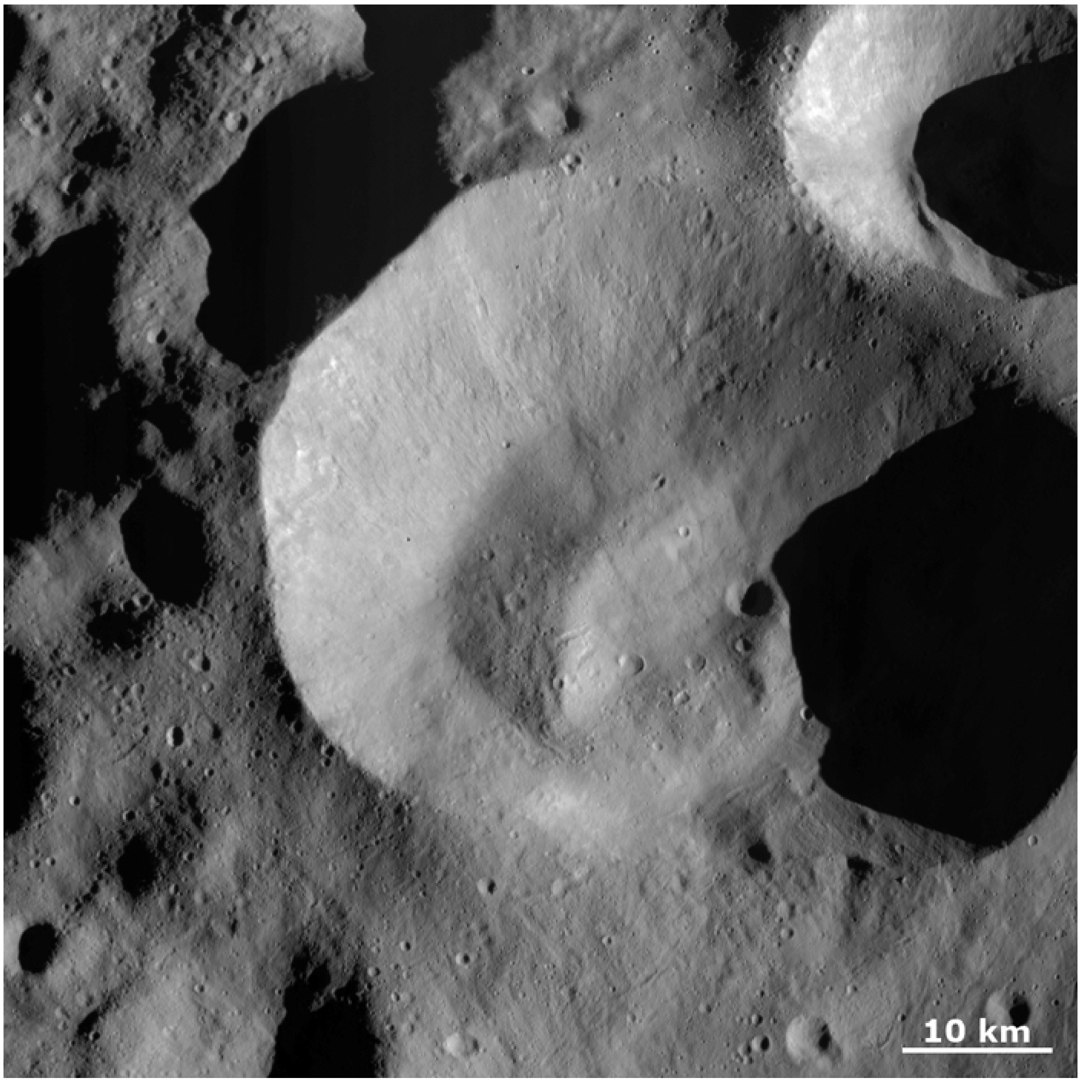


Figure 4*:* This Dawn FC (framing camera) image is dominated by Caparronia impact crater. Caparronia crater is approximately 55 km in diameter and has a mostly fresh, irregularly shaped rim. It also has a curved, linear mound running across most of its base.

Answer the following questions. Use the back of this sheet, if necessary.

1. What challenges, if any, did you and your partner face in outlining similar regions?

2. Compare your outlined areas to another group's outlines. Are they the same? If not, why do you think that you outlined different areas? How are these challenges similar to the ones faces by scientists studying Vesta today?

Part 3 (Alternative 2)
Science and Art have a lot in common. For example, in Art, ***value*** is the term used to describe light and dark in an image. This light and dark is similar to the "brightness" (or ***albedo***) of a pixel in a digital image from space.

You will be given a small portion of an image. Draw that image, paying close attention to the lights and darks. Once you have finished drawing your small portion, or pixel, look on the back of your image. There is a number and an arrow. Use that number and arrow to orient your square on the large grid on the wall. The arrow points to the top of the image. Be sure to affix your drawing in the correct orientation (i.e. make sure "up" is "up").

Below is an example of a collection of drawings ("pixels") that came together to create the larger image.

Answer the following questions. Use the back of this sheet, if necessary.

1. Look closely at the larger image. Describe the physical features that are light. Describe what you see that is dark.

2. What challenges, if any, did you face in drawing your small image?

3. Looking at the larger image created by the whole group, compare how this process is similar and/or different from the creation of digital images from the Framing Camera data.