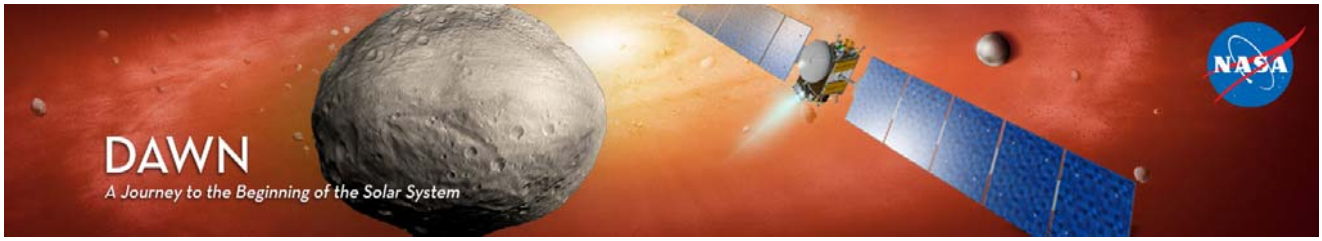


# Interaction of Energy and Matter: Dawn Instrumentation

# Mineral Identification

TEACHER GUIDE

## Introduction

In this activity, students are guided through the analytical process that Dawn scientists will use to determine the ***mineral*** content of the surfaces of Vesta and Ceres from the data collected by the instrument payload onboard the Dawn spacecraft. Although it is designed as a stand-alone activity, it is helpful if students have experienced the background information contained in the *Interaction of Energy and Matter* PowerPoints that focus on the functions of the instruments in the Dawn Spacecraft payload (Framing Camera, GRaND, and VIR).

In this activity, students are given a simulated surface of an astronomical body and some simulated data about that surface that could have been collected by the instruments aboard the Dawn spacecraft. They compare that data with the information in *Mineral Standards* reference sheets (see the Materials Section below) to determine possible mineral content at specific locations. For a detailed description of how these Dawn payload instruments will collect and analyze reflected ***electromagnetic radiation*** from the asteroids' surfaces, see the Exploration section of the *Interaction of Energy and Matter: Dawn Instrumentation* module.

In Card Number 1 in the *Instruments Data* packet, the Framing Camera Data Card, students are given a photograph of a simulated surface of an astronomical body that could have been obtained by Framing Cameras aboard a spacecraft in low orbit above the body. There are seven designated sites on that surface identified by specific ***latitude*** and ***longitude*** readings that can be assigned to individuals or small groups. If your students have completed the *Gravity Mapping: Measuring Mass Concentration* student activity in the Development section of the *Interaction of Energy and Matter: Dawn Instrumentation* module, they will have had experience using this method to locate sites on a surface. If not, you may have to demonstrate how to use the data to locate their assigned sites.

In addition, this card lists some general classifications of ***albedo***—light, medium, and dark— given for each site. You may want to review the definition of albedo and explain how the classifications relate to the amount of electromagnetic radiation reflected from the mineral content of the surface. You may also want to do the introductory "Albedo and Digital Imagery" activity with your students that is found in Appendix B of the *Framing Camera Teacher Guide* as an introduction to the concept.

The Gravity Measurement Data Card (Card Number 2 in the *Instruments Data* packet) includes some "Changes in Line-of-Sight velocity" data. If your students have completed the *Gravity Mapping Student Activity: Measuring Mass Concentration* in the Development section, they will understand the significance of changes in the ***line-of-sight velocities*** of the orbiting spacecraft. Note, however, that only the change in line-of-sight velocity is given in this table, rather than the actual ***velocities***, for each assigned location.

If they have not completed this gravity measurement activity, you will need to supply some background information to help them understand the relationship between the object's ***mass concentration***, ***mass distribution***, and the line-of-sight velocity of the orbiting spacecraft.

The following are excerpts from the *Gravity Mapping: Measuring Mass Concentration Teacher Guide* from the *Interaction of Energy and Matter: Dawn Instrumentation* module:

**Applying Newton's Second Law to Gravitational Forces**
If an object is moving in a circular path at a constant speed, its velocity is constantly changing direction. If that object is accelerating, there must be a net ***force*** acting on the object in the direction of the ***acceleration***, which in this case is towards the center of the circle—***centripetal acceleration***. For a ball on a string, the tension in the string supplies the centripetal force. For an orbiting spacecraft, ***gravity*** is the centripetal force.

The motion of a spacecraft is an excellent application of ***Newton's Second Law of Motion***. As it collects data, the spacecraft moves in a curved orbit around an astronomical body. To maintain that curved path, the spacecraft must use the mutual gravitational attraction between itself and the body it is orbiting to supply its centripetal acceleration.

The force of gravity ($F$) is equal to the ***mass*** ($m$) of an object times its acceleration ($a$), $F = ma$. Any increase in the mass concentration on or under the surface of an astronomical body will exert an extra gravitational force on the orbiting spacecraft, causing additional centripetal acceleration of the spacecraft. Conversely, a decrease in mass concentration will cause a decrease in gravitational force on the spacecraft, and, therefore, a decrease in the centripetal acceleration of the spacecraft.

**Doppler shifts and Line-of-Sight Velocity**
***Doppler shifts*** actually measure the component of velocity that is along the line-of-sight, that is, the component that is parallel to a line from that body to an "observer" or reference point. So we can use these changes in line-of-sight velocities to map the mass concentration and mass distribution of Vesta and Ceres. It is estimated that the line-of-sight velocities of the Dawn spacecraft will vary between a minimum of 182 m/s and a maximum of 207 m/s.

As the spacecraft encounters an increase in mass concentration, its increase in acceleration of the line-of-sight velocity causes a Doppler shift in the radio signals detected by the "observer." As the spacecraft accelerates or decelerates, scientists can plot these changes and use the plot to determine mass concentration and mass distribution.

There are seven individual *VIR Reflectance Spectra Data* cards (Card Number 3, Locations 1 through 7, in the *Instruments Data* packet) for each location. Each of the cards shows a specific reflectance spectrum in the same visible and near infrared region of electromagnetic radiation for the mineral at the identified location. Students will compare these reflectance ***spectra*** with those shown in the *Mineral Standards* reference sheets as part of the analysis activity.

There are also seven individual *Chemical Composition/Concentration Data* cards (Card Number 4 in the *Instrument Data* packet) for specific locations as determined by the GRaND (Gamma Radiation and Neutron Detector), another of the instruments on the Dawn spacecraft. In addition, there is a handout that explains how to use the spectroscopic data from the cards to provide further information about the mineral composition at each location.

## Materials

All documents and PowerPoint slides 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.

Copies of these handouts for each student:

- *Mineral Identification Student Activity* sheet
- *Mineral Standards reference sheets*
- *Framing Camera Data Card* from the *Instrument Data* packet
- *Gravity Measurement Data Card* from the *Instrument Data* packet
- *Using the GRaND Chemical Concentration Data* handout from the *Instrument Data* packet

Copies of these handouts for each student (or small group) assigned a specific location:

- *VIR Reflectance Spectra Data Cards* from the *Instrument Data* packet
- *GRaND Chemical Composition/Concentration Data* from the *Instrument Data* packet
- Slide 9 from the Dawn PowerPoint entitled *Interaction of Energy and Matter: Dawn Mission Instrumentation – VIR: Visible and Infrared Spectrometer*

***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**

1. Distribute copies of the *Mineral Identification Student Activity* sheet. Explain to students that the sheet contains procedures for completing each step of the mineral identification analysis.

   Explain to your students that in this activity, they will simulate the analytical process that Dawn scientists will use to determine the mineral content of the surfaces of Vesta and Ceres from the data collected by the instrument payload onboard the Dawn spacecraft. To do this, they will be given
   - a simulated surface of an astronomical body;
   - data that might have been collected from each of the instruments that are a part of the Dawn spacecraft payload—Framing Cameras, VIR, and GRaND—*if* the spacecraft had orbited this simulated astronomical body; and
   - gravity measurement information, measured by Doppler shifts in radio waves resulting from changes in line-of-sight velocity that the spacecraft would have experienced as it orbited different areas of the body.

   Tell students that the experimental data relating to different locations on the simulated surface will be in much the same format that the Dawn scientists will receive the data from Vesta and Ceres.

2. Distribute copies of the *Mineral Standards* reference sheets and *Framing Camera Data* card (Card Number 1 in the *Instrument Data* packet).

   The *Framing Camera Data* card contains a photograph of a "simulated" surface of a astronomical body that could have been taken by a Framing Camera onboard the Dawn spacecraft. The latitude and longitude data for seven different locations are listed in the table. If your students do not have experience using latitude and longitude data to identify specific locations, work with them to identify Location 1 on the photograph.

   Explain to your students that scientists have established databases of information that relate specifically to the types of minerals that we might expect to find on the surface of the simulated astronomical body that they will be analyzing.

   Ask: What data do you see in the *Mineral Standards* reference sheets that could help you identify the minerals at the seven locations specified in the *Framing Camera Data* card.
   [*Answers should include the color and density of the mineral; the chemical composition of the mineral; and the reflectance spectrum of the mineral.*]

3. Assign specific locations shown in the *Framing Camera Data* card to individual or small groups of students. Allow time for students to locate and mark their assigned locations on the photograph of the surface.

   The *Framing Camera Data* card also lists some relative albedo classifications from Framing Camera data for the locations being studied. You may need to review or introduce the meaning of albedo, which refers to the amount of electromagnetic radiation reflected from a surface, before they continue

Procedure 1. You may also need to explain that any location that is classified as “light” means that it reflects lots of radiation, whereas a location classified as “dark” indicates that very little radiation is reflected from that surface. If you feel your students would benefit from more exposure to the concept of albedo, there is an introductory albedo activity at the end of the *Framing Camera Teacher Guide* in Appendix B.

Ask: Is there any information in the *Mineral Standards* reference sheets that could be useful in identifying specific types of minerals related to the information given in the *Framing Camera Data* card?

[*Answers should include the color of the mineral and may include the reflectance spectrum of the mineral*]

Have students complete Procedure 1 on the *Mineral Identification Student Activity* sheet.

During the mineral identification activity, assist any students who are having difficulty eliminating minerals as possible matches for their assigned locations.

Distribute copies of the *Gravity Measurement Data* card (Card Number 2 in the *Instrument Data* packet). This card includes “Changes in Line of Sight Velocity of the Orbiting Spacecraft.” If your students have not completed the *Gravity Mapping Student Activity: Measuring Mass Concentration* from the Development section of the *Interactions of Energy and Matter: Dawn Instrumentation* module, you will need to supply some background information included in the Introduction to this guide to help them understand the relationship between the ***density*** of the surface material and the line-of-sight velocity of the orbiting spacecraft. Call your students’ attention to the fact that this table shows the change in line-of-sight velocities. Help them interpret the data by saying:

> The “0” for Location 2 indicates that there was no change in the spacecraft’s line-of-sight velocity as it flew above that site. The sites with “+” changes indicate that the spacecraft’s velocity increased as it moved over those sites; the sites with “–” changes indicate that the spacecraft’s velocity decrease as it moved over those sites.

Allow time for students to complete Step 2 of the Student Activity Procedure Sheet.

Mineral Identification Activity: Help any students who are having difficulty eliminating minerals as possible matches for their assigned locations. Students can record the minerals that might be eliminated in the data table on page three of the student activity.

5. Distribute individual copies of the *VIR Reflectance Spectra Data*, Card Number 3, to those students assigned the specific locations. Show slide 9 from the *Interaction of Energy and Matter: Dawn Mission Instrumentation, VIR: Visible and Infrared Spectrometer* PowerPoint.

Use wording similar to the following to help students recall the wavelength range of the electromagnetic spectrum that they will be considering as they use the spectral data in their *VIR Reflectance Spectra Data* cards and compare them to the *Mineral Standards* reference sheets.

> This slide shows the reflectance spectra of four different minerals in the visible light range (0.4 to 0.8 microns or micrometers) and in the near infrared region (from 0.8 to 2.2 microns or micrometer).
>
> If a mineral is colored, like the red sandstone, it reflects more red light than blue light. Note the low reflectance of blue light (at about .05 microns) and the high reflectance of red light (just below 0.8 microns).
>
> Limestone is light colored, usually rather cream-colored, so it reflects in all ranges of visible light.

Andesite and basalt don't reflect any one color light much more than any other color so they appear dark gray of black to our eyes.

The color of rocks in visible light is not a unique indicator of what kinds of minerals are present in the rock. For this reason, VIR will also measure reflected radiation in the infrared region of the electromagnetic radiation spectrum.

The "dips" or "troughs" at specific wavelengths in the infrared spectrum can help us identify the minerals that are present in the rock. For example, the dips in red sandstone's reflectance spectrum at 1.4 microns, 1.9 microns, and 2.2 microns means that it absorbs electromagnetic radiation from the sun at those wavelengths. Therefore, if your spectrum shows absorption at those particular wavelengths, there is a possibility that your mineral may be red sandstone.

Now, take another look at your *Mineral Standards* reference sheets. Many of these descriptions include a sentence that says something like this: "This mineral is one of a series or one of a group." This means that there are some very closely related minerals that have various concentrations of the same chemical element compositions. In some cases, the percentage compositions of these elements may relate to the temperatures at which they were formed or to the compositions of minerals surrounding them as they formed.

For example if you check the spectral standards collected in the Digital Spectral Library by the United States Geological Survey (USGS),
[http://speclab.cr.usgs.gov/spectral.lib04/spectral-lib.desc+plots.html]
the source of the spectra in your *Mineral Standards* reference sheets, you will find duplicate spectra for individual members of a group or species of numerous minerals. Some will show deeper absorbance bands or greater and wider reflectance bands, but the absorbance and reflectance bands are usually centered on the same wavelengths. Any differences found are usually the result of different percentage compositions of the same elements in the mineral group.

So, as you compare your experimental data spectrum with those in the Mineral Standards reference sheets, remember that you may not find an exact match. What you should look for is a match of the absorbance and reflectance band wavelengths.

Allow time for students to complete Step 3 of the Student Activity Procedure Sheet.

Mineral Identification Activity: Assist any students who are having difficulty eliminating minerals as possible matches for their assigned locations.

6. Distribute the handout. Using the *GRaND Chemical Composition/Concentration Data* (Card Number 4 in the *Instrument Data* packet), to all students and the individual *GRaND Chemical Composition/Concentration Data* cards to the students assigned the specific locations.

   Then say:

   Let's first examine Card Number 4 entitled "Using the GRaND Chemical Concentration Data." The data table on this sheet shows the name, symbol, and atomic number of chemical elements having greater than trace concentrations in the minerals that are described in the *Mineral Standards* reference sheets.

   Have each of the groups study the *GRaND Chemical Composition/Concentration Data* card for their specific location. This graph is very similar to the way in which the Gamma Ray and Neutron Detector (GRaND) aboard the Dawn Spacecraft will identify the concentration of specific elements in specific locations as it orbits above the surfaces of Vesta and Ceres.

Do you see that the atomic numbers of the elements are plotted on the horizontal axis? And the specific atomic number of elements that comprise greater than a trace is shown directly below the line? For example, do you all see the line that shows the concentration of oxygen labeled atomic number 8 on your graph?

That's right, the minerals in all the locations identified on the simulated surface contain significant percentages of oxygen. You can determine the specific concentration of oxygen at your site by reading the concentration percentage scale on the vertical axis of the graph. How can you use your graph to further identify the mineral present at your assigned location?

Allow time for students to complete Step 4 of the Student Activity Procedure Sheet.

Mineral Identification Activity: Assist any students who are having difficulty eliminating minerals as possible matches for their assigned locations.

7. During a wrap-up session, ask questions similar to the following:
    - Taking into account all these sources of information, how confident are you that you correctly identified the mineral at your assigned location? Describe all the evidence that you used.
    - Did you have difficulty identifying the mineral at your assigned location using the data available to you? Why or why not?
    - Which information was most helpful in identifying the mineral at your location? Why?
    - How were the other data sources helpful in getting an overall picture of the simulated surface?
    - What were the benefits in having four different data sources?
    - What other information would you like to have in order to learn more about the surface of the simulated asteroid?
    - What other information would you need to be more confident that you had correctly identified the mineral at your assigned location?
    - How might you obtain this information?

## Definition of Terms

**Acceleration**—The change in velocity of a body with respect to time
**Albedo**—The ratio of the amount of light reflected from a surface to the amount of incident light
**Atomic number**—The number of protons found in the nucleus of an atom; it uniquely identifies a chemical element
**Centripetal acceleration**—Property of the motion of an object traveling in a circular path. Centripetal describes the force on the object, directed toward the center of the circle, which causes a constant change in the object's direction and thus its acceleration. The magnitude of centripetal acceleration ($a$) is equal to the square of the object's velocity $v$ along the curved path divided by the object's distance $r$ from the centre of the circle, or $a = v^2/r$.
**Density**—The mass per unit of volume of a given material
**Doppler Shift**—The change in frequency of a wave for an observer moving relative to the source of the wave. Red shifts are moving away from the observer and blue shifts are moving towards the observer
**Electromagnetic radiation (EMR)**—"Waves" of electrical and magnetic "disturbance", radiated as visible light, radio waves, or any other manifestation of the electromagnetic spectrum.
**Force**—A quantity that changes the motion, size, or shape of a body
**Gravity**—An attractive force proportional to the mass of the bodies
**Latitude**—The imaginary lines that denote the distance north or south of the equator of a body. Their angular distance (in degrees) is measured from the equator of Vesta with positive values going north and negative values going south
**Line of sight velocity**—The component of the velocity of a body, such as a spacecraft, that is parallel to a line from an observer or reference point to that body
**Longitude**—The imaginary lines drawn through the North and South Poles of a body, such as the Earth or Vesta. Their angular distance (in degrees) is measured from a prime meridian with positive values going east and negative values going west
**Mass**—The quantity of matter in a body
**Mass concentration**—An excess or deficiency in the distribution of mass on or beneath the surface of an object
**Mass distribution**—The spatial distribution of mass within a solid body
**Mineral**—A naturally occurring, homogeneous inorganic solid substance having a definite chemical composition and characteristic crystalline structure and hardness
**Newton's Second Law of Motion**—The strength of a force (F) is equal to the amount of mass ($m$) involved multiplied by any acceleration (a) applied to it, or $F = ma$
**Spectra**—The energies of the photons emitted or absorbed by an atom or compound are distinct. Photon energies are directly related to their frequencies and thus wavelengths, which dictate the colors in the spectrum. By observing the wavelength or frequency of a reflected or emitted photon, it is possible to determine which atoms or compounds comprise the body being observed. Spectra can be detected from the light reaching us from stars and planets, near or very distant, enabling us to identify the composition of the observed object
**Spectroscope**—An optical instrument used for producing and observing spectra of light or other radiation
**Velocity**—The speed and direction in which a body moves