

Asteroid Compositions: Spectra

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Activity Description

In this activity, you will estimate the surface composition of selected asteroids by comparing their reflectance spectra with the spectra of meteorites that probably come from the asteroids. Some of the questions you can explore using these and similar data are: Do asteroids show similarities to meteorites that have been examined in the laboratory? What are the asteroids probably made of? Do minerals found on the asteroids exist on Earth? Can we say anything about the geologic process that operated on the asteroids? Do the asteroids contain minerals that will be worth mining someday?

Introduction

Asteroids appear in most images as only dots of light, like the stars. Yet each is a small world to itself, with a unique shape, composition, and history. How can we learn more about an asteroid without actually sending a spacecraft to visit it? In the last few decades, new observational techniques and instruments developed for both ground-based telescopes and spacecraft have provided enormous amounts of new data about the asteroids. We have also learned that collisions among the asteroids themselves have showered us with samples of their surfaces: the meteorites! But which meteorites came from which asteroids? By comparing the reflectance spectra of asteroids taken at the telescope with the spectra of meteorites taken in the lab, we can begin to unravel the connection. We can also begin to investigate geologic process that formed the meteorites and the asteroids and how those processes compare with the processes that formed rocks on Earth.

Description of the Data

The detailed albedo or reflectance spectrum of an unknown rock or mineral can be used to estimate the composition of the rock or mineral (see article: *Asteroid Spectra*). Figures 1a and 1b show the observed spectra* of several representative asteroids (over 500 asteroid spectra have been measured as of this writing). The horizontal axis is wavelength in microns (10^{-6} meters). The visible range extends from 0.39 (violet) to 0.7 (red) microns. Wavelengths between 0.7 and 1.1 microns are called near infrared. The vertical axis is the reflectance or albedo (A), or the decimal fraction of incident light that is reflected back from the surface. As you can see from Figure 1, asteroids have a wide range of albedos: some, like Bamberga, are as dark as coal, while others, like Vesta and Juno, are about as reflective as common Earth rocks.

Asteroid spectra also have distinct slopes and dips called spectral features. Careful measurement of the details of the reflectance spectrum of an object can help identify minerals present in the asteroid. For example, the deep dip at 0.95 microns in the spectrum of Vesta indicates the presence of pyroxene, a mineral common in terrestrial volcanic flows.

Asteroid spectra are combinations of many minerals mixed together on the surfaces of the asteroids, so it is helpful to compare these spectra with those characteristic of mineral combinations known to have come from space, namely, the meteorites, shown in figures 2a and 2b. These spectra are drawn to the same scale as the asteroid spectra, and represent averages of the major meteorite classes (see article *The Meteorite Connection*).

While these meteorite spectra have many similar features and are thus not unique, if you can find an asteroid spectrum that closely matches a meteorite spectrum, then you can begin to say something about the asteroid's composition. Not only that, but with an understanding of the nature of meteorites and the geologic process that shaped them, you can begin to outline the asteroid's geologic history as well.

*These spectra were derived by combining relative reflectance at different wavelengths – the spectral features – with average albedos. The detailed spectral features were obtained by photometric measurements obtained at the Mount Wilson and Palomar Observatories and the Kitt Peak National Observatory. The average albedos were obtained from simultaneous visual and thermal measurements at Mauna Kea. Details are given in Chapman, C. R., D. Morrison, and B. Zellner (1975) Surface properties of asteroids: a synthesis of polarimetry, radiometry, and spectrophotometry. *Icarus*, vol. 25, pages 104-130.

Materials

In this activity, you will need:

- Asteroid Composition: Spectra*** handout
- Meteorite spectra transparency
- Pencil or pen

Procedure

1. Work in small groups of 2 or 3. Carefully compare the asteroid spectra with the meteorite spectra to estimate the meteorite class of each asteroid by overlaying the transparency with the meteorite spectra on the figure with the asteroid spectra. Consider both albedo (height on the y-axis) and spectral features (the pattern of the spectral curve). Note that due to unknown grain size effects, the albedo is uncertain by a factor of ~ 2 , so it is "legal" to shift a whole curve up or down by a factor of ~ 2 (say from 0.2 to 0.4) to obtain a fit. As a team, decide on your estimate of the best-match meteorite spectrum to each of the asteroid spectra. Be prepared to defend your answer to other teams.
2. Choose two of the asteroids in the list and outline their geologic histories. Use the best-fit Meteorite Spectrum in Table 1 in ***The Meteorite Connection***, and the Background information and Diagram 1 that shows the genetic relations between important planetary materials in ***Meteorites, Mineralogy, and Geologic Process***. For example, does one asteroid have similarities to a C4 meteorite? Then the asteroid probably formed from compacted clouds of "solar dust" at the time the rest of the solar system was forming. It was heated by some undetermined process to form the chondrules. There is no evidence that the asteroid has changed since.

Discussion Questions

1. Describe any uncertainties or ambiguities you may have found in choosing matching meteorite and asteroid spectra. Did the patterns of the meteorite and asteroid spectra match perfectly? Were their albedos exactly the same values? Was there more than one possible match for an asteroid and a meteorite? If that was the case, why did you choose one possible match over another? What additional information or analysis do you think would help reduce the uncertainty of determining asteroid compositions?

2. Reflectance spectra only give information about the top few microns of the rocks and minerals on the surface of the asteroid that the light interacted with. How might this affect your interpretation of the asteroids' compositions?
3. How do sedimentary rocks like sandstone form on Earth? Why are sedimentary rocks not found among the meteorites? How do igneous rocks like granite form on Earth? Why aren't igneous rocks found among the meteorites? How do these missing types of rocks affect your interpretation of the geologic histories of the asteroids?

Going Further

Search online for additional asteroid spectra that you can classify using the meteorite spectra. Select several that orbit at different locations in the main asteroid belt and sample of the Earth-crossing asteroids. Can you find any patterns in the distribution of asteroid types?

Find the estimated diameters of the asteroids you have classified. Are there any correlations between asteroid size and spectral class?

Wilderness of Rocks Data Sheet

Guiding Questions for Graphs

To prepare for the

1. Look at your graph of the Asteroid Spectra.
 - a. What is being measured?
 - b. If there are two variables (factors) what is being compared? Which is the independent variable? Which is the dependent variable?
 - c. What are the units of measurement?
 - d. Describe the general pattern of values for the wavelengths of the spectra. For example, does the albedo increase consistently as the wavelength increases? Does the albedo start high at short wavelengths, and decrease at the medium wavelengths, then increase again at the longer wavelengths?
 - e. What is the range of albedo values? What is the range of spectra values?
 - f. What parts of the graphs seem to have the greatest variation? (the longer wavelengths, the shorter wavelengths, or the medium wavelengths?)
 - g. How are the patterns of all of the asteroids alike? How are they different?
2. What might cause the differences you see in the albedos of the asteroids. (Look at the Background information on the albedo of different materials in the Description of the Data.)

Asteroid	Best-fit Meteorite Spectrum
1 Ceres	_____
2 Pallas	_____
3 Juno	_____
4 Vesta	_____
16 Psyche	_____
230 Athamantis	_____

324 Bamberg

Short Geologic Histories

1.

2.



