Student Guide to Asteroid 101

LINKS TO WEBSITES AND DOCUMENTS NECESSARY TO COMPLETE "ASTEROID 101" CAN BE FOUND AT:

http://www.lpi.usra.edu/exploration/education/hsResearch/asteroid_101/

PART 1 - METEORITES

Before learning about asteroids, it is helpful to become familiar with the basic types of meteorites, as you will come across these terms in the readings. Most meteorites, after all, come from asteroids (except for lunar and Martian meteorites).

To learn about different meteorite types and their characteristics, you will read through a website created by the Center for Meteorite Studies at Arizona State University. Begin with the **Meteorite Types** page. From this page, click to read about stony, stony-iron, iron meteorites, and their categories: chondrites and achondrites (stony) and pallasites and mesosiderites (stony-iron).

Meteorites can be further sub-classified. You will come across a few of these other classifications (e.g., HED meteorites) in your readings. If you are curious to learn more, feel free to explore these other types further on your own!

Consider the following as you read about meteorite types:

> Create a concept map in which you map out the different types of meteorites and their characteristics. For more information on concept maps, click the **Concept Maps** link under Part 1 on the Asteroid 101 webpage.

PART 2 – ASTEROID FORMATION, PROPERTIES, ORBITS, AND CONNECTIONS TO METEORITES

In this section, you will read a series of articles about asteroid science and exploration. The articles summarize the current state of scientists' knowledge of asteroids, what they have yet to learn, and how upcoming spacecraft will help fill in the gaps. These articles appeared in the February 2014 edition of the magazine "Elements." Links to PDFs of these articles are available on the Asteroid 101 homepage.

****Permission to distribute these articles has been obtained from "Elements" magazine, published by the Mineralogical Society of America on behalf of the participating Societies.****

Asteroid Readings

1) *Asteroid What?,* by John Valley. An editorial introducing asteroid science and exploration, and the related articles that follow.

2) *Asteroids: New Challenges, New Targets,* by Guy Libourel and Catherine M. Corrigan.

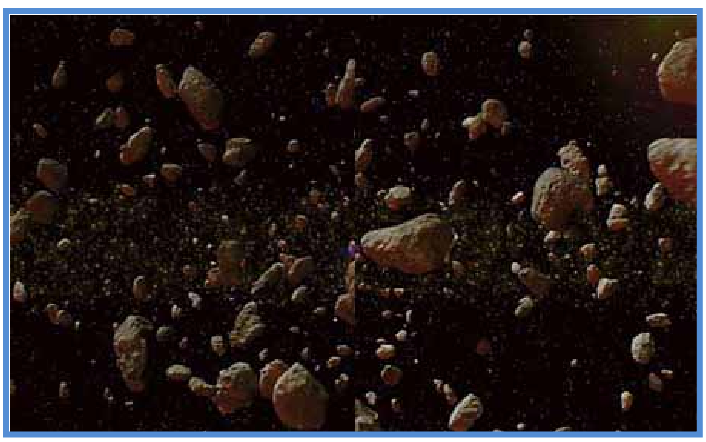
> At present, we know of ~600,000 asteroids in the asteroid belt, and there are very likely millions more. Orbiting the Sun between Mars and Jupiter, they are thought to be the shattered remnants of small bodies formed within the young Sun's solar nebula that never accreted enough material to become planets. These “minor bodies” are therefore keys to understanding how the Solar system formed and evolved. As leftover planetary building blocks, they are of great importance in understanding planetary compositions. They may also provide clues to the origin of life, as similar bodies may have delivered organics and water to the early Earth. For these reasons, several international space agencies have funded sample-return missions to asteroids.

Consider the following as you read this article:

A. What two methods have been used to estimate the number of asteroids in the main asteroid belt?

B. What three orbital elements are used to describe an asteroid’s orbit around the sun?

C. The image below is from a famous movie and depicts an asteroid field encountered by the main characters. Do you think this image accurately portrays the density of main belt asteroids in our solar system?



D. What does it mean to say that an asteroid has a 3:1 orbital resonance with Jupiter? What happens to objects that have an orbital resonance with Jupiter?

E. What can happen when asteroids collide? What factors determine the result of a collision?

F. What observations are used to infer the composition of an asteroid?

G. What are the three main categories of asteroids found in the main belt? Where in the main belt are they located?

H. What characteristics do asteroid families share?

I. Describe how a main belt asteroid can become a near-Earth asteroid (NEA).

J. Why do NEAs have a shorter lifetime than main belt asteroids?

K. It is thought that most meteorites that fall to Earth originate in the asteroid belt. Why is our sample of meteorites biased to certain parts of the asteroid belt?

L. Why is it difficult to determine from exactly which asteroid a meteorite originates?

M. What future (and current) spacecraft missions will study asteroids and what do we hope to learn from them?

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3) *Formation and Physical Properties of Asteroids*, by Patrick Michel.

Asteroids are the leftover precursors to the terrestrial planets. Before the first images of them were sent from space, our knowledge of asteroids relied entirely on ground-based observations and meteorite analysis. Spacecraft images revolutionized our knowledge and geological understanding of their physical properties. They also showed us that asteroids are subjected to various kinds of processes and are incredibly diverse in size, shape, structure, composition, and rotational properties. Therefore, space missions remain necessary to enhance our knowledge of the various components of the asteroid population. In addition, numerical modeling is required to interpret spacecraft images and improve our understanding of the physical processes asteroids experience over their lifetime.

Consider the following as you read this article:

A. How does the current distribution of asteroid types in the main belt compare to the early structure of the solar system?

B. Studies of material from Comet 81P/Wild 2 have shown that the solar system may have reorganized itself early in its life. What other evidence supports the idea that the planets migrated?

C. What holds smaller asteroids (smaller than a few hundred meters wide) together? What forces are most responsible for holding larger asteroids together?

D. What is meant by a “primordial body?” How wide should an asteroid be to be considered a primordial body?

E. What limits our knowledge of asteroids from ground-based observations (telescopes)?

F. What properties of an asteroid can be determined from light-curve measurements?

G. What property of an asteroid can be determined from spectroscopy? What is a limitation of spectroscopic data?

H. What can observations from radio telescopes like the Arecibo Observatory tell us about asteroids? Which measurements can help protect the Earth from potential asteroid impacts?

I. What are limits to space-based observations of asteroids from spacecraft such as NEOWISE and Spitzer?

J. What types of indirect measurements of asteroids can be made to infer their interior structure?

K. Has the formation of asteroid families been successfully modeled? What do these models show?

L. What are two possible explanations for the appearance of large boulders on the surface of small asteroids (such as Itokawa)?

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4) *Establishing Asteroid-Meteorite Links*, by Edward A. Cloutis, Richard P. Binzel, and Michael J. Gaffey.

Asteroids are arguably the most accessible remnants of building blocks of the early Solar system and an essential piece of the terrestrial planet–formation puzzle. Determining their compositions and physical properties can provide important and otherwise unobtainable information concerning the origin, structure, and dynamic history of the Solar system, as well as insights into the sources of materials from which the terrestrial planets were constructed. Our understanding of the compositional structure of the asteroid belt and of individual asteroids has advanced significantly since the 1970s. Strong associations between asteroids and meteorites are emerging thanks to multitechnique observations, the synthesis of observations and modeling, in situ measurements, and sample-return missions.

Consider the following as you read this article:

A. Why is it difficult to study Earth's origin and early history?

B. What is a major shortcoming in using meteorites to study the history of the solar system?

C. What is the best way to establish a link between a meteorite (or between several meteorites) and an asteroid?

D. What techniques have been used to study the physical properties of asteroids and what properties do these techniques reveal?

E. What techniques are used to study the composition of asteroids?

F. The strongest asteroid-meteorite links have been made between HED meteorites and LL chondrite meteorites. What parent bodies have they been linked to and how were these links definitively made?

G. What makes C-class asteroids unique compared to other classes?

H. Have scientists identified all possible asteroid classes?

I. Why is it difficult to make good optical spectral matches of ordinary chondrites to presumed parent bodies?

J. What types of processes can modify an asteroid's surface?

K. Why is the modification of asteroids' surfaces problematic in establishing asteroid-meteorite links?

Optional Readings

1) *Unique, Antique Vesta*, by Harry Y. McSween, Maria Cristina De Sanctis, Thomas H. Prettyman, and the Dawn Science Team.

Most asteroids are collisional rubble from eons past, and few of them have survived intact. Vesta, the second most massive asteroid, is the only differentiated, rocky body in this category. This asteroid provides a unique view of the kinds of planetesimals that accreted to form the terrestrial planets. We know more about this asteroid than any other, thanks to its recently completed exploration by the orbiting Dawn spacecraft and studies of the ~1000 meteorites derived from it. The synergy provided by in situ analyses and samples has allowed an unparalleled understanding of Vesta's mineralogy, petrology, geochemistry, and geochronology.

2) *Asteroid Itokawa: A Source of Ordinary Chondrites and a Laboratory for Surface Processes*, Akira Tsuchiyama.

The Japanese spacecraft Hayabusa returned samples from the surface of an asteroid (near-Earth S-type asteroid 25143 Itokawa) for the first time in human history. This article describes the results of the initial analysis of the mineralogy, micropetrology, and elemental and isotopic compositions of regolith particles from Itokawa measuring 30-180 μm in diameter. The results show a direct link between ordinary chondrites and S-type asteroids. The regolith particles provide evidence of space-weathering rims and grain abrasion, and the information obtained has elucidated various processes on the airless surface of Itokawa, such as the impact of small objects, grain motion, and irradiation by solar wind.

PART 3 – LIGHT CURVES

In planetary research, a light curve can be used to estimate the rotation period of a solar system small body, e.g., minor planet, asteroid, moon, or comet nucleus. Often telescopes on Earth, even the most powerful, cannot image a small object in our solar system. Instead, astronomers measure the amount of light reflected by an object over a period of time. Plotting this data (brightness or magnitude vs. time) produces a light curve. The time separation of peaks in the light curve gives an estimate of the rotational period of the object. The difference between the maximum and minimum brightness (peaks and valleys) may be due to the shape of the object, or may be due to differences in the surface albedo. In general, an asymmetrical asteroid's light curve generally has more prominent peaks and valleys, while a more spherical object's light curve will be flatter.

Light Curve Interactive Game

The Space Science Institute in Boulder, CO has created an online game that helps visualize the relationship between the motion of an asteroid and its light curve. The link to this interactive game can be found on the Asteroid 101 homepage.

PART 4 – REFLECTANCE SPECTRA

Most of what is known about the composition of asteroids comes from reflectance spectra. Albedo is a measure of the percentage of light reflected off the surface of an object, e.g., the percentage of sunlight reflected by an asteroid. A reflectance spectrum is a plot of the albedo of an object observed at various wavelengths.

To learn more about the basics of reflectance spectra, read the **Reflectance Spectra Tutorial** from the astronomy department at the University of Washington. This tutorial was written for astronomy classes at the university and you will see references to the Moon and Mars, but the same principles apply to asteroids.

Consider the following as you read the tutorial:

A. At a basic level, what is the difference between the light we see from stars versus the light we see from asteroids?

B. What is albedo a measure of? Which has a higher albedo, a freshly paved sidewalk or a freshly paved road?

C. Do the different colors of the visible spectrum end at definite wavelengths, or are color changes in the visible spectrum gradual?

D. Is it more accurate to characterize an object's spectra by colors or by wavelengths?

E. Examine the three plots in the "Spectra – Brightness" section (you can click on the individual plots to see bigger versions). Approximately where do you think a plot of the reflectance of a purple piece of paper would be located (what percentage)?

F. Look at the plot in the "Spectra – Color" section. If this was a plot of a bright, blue ball, at what wavelength (approximately) would the spectrum peak?

G. Is it useful to describe a rock's spectra in terms of color? Why or why not?

H. What investigative technique do planetary spacecraft use to determine the composition of a planet's surface without landing on it?

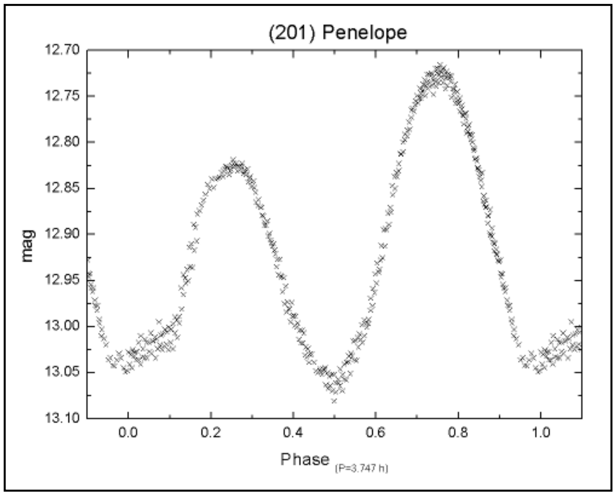
PART 5 – ASTEROID DATA ANALYSIS

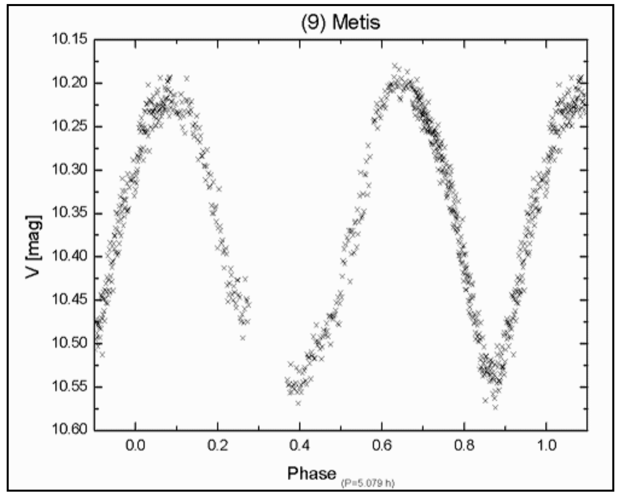
1) Light Curves

The two light curves at the top of the next page are from observations of the asteroids (201) Penelope (left) and (9) Metis (right). Examine these light curves and answer the following questions.

A. How do these objects' rotation rates compare to each other? How do you know?

B. What do the shapes of the curves suggest about the shapes of the asteroids? Why do you think this?





2) Spacecraft Imagery

Examine the three asteroid surface images (Asteroid 101 Image 1, Asteroid 101 image 2, Asteroid 101 Image 3) and answer the questions below for each image. The images are available on the Asteroid 101 homepage.

A) What types of features are seen on each surface?

B) Based on your readings, how did the different types of features form? When did they form relative to each other?

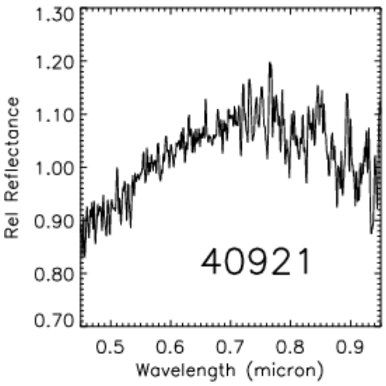
3) Reflectance Spectra

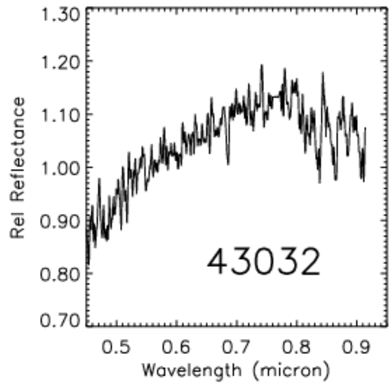
The three reflectance spectra on the next page are actual data from three different asteroids found in the outer main asteroid belt. Examine these spectra and answer the following questions. Note: The unit for wavelength along the x-axis is “microns”, which is short for “micrometers” (1 millimeter = 1,000 microns).

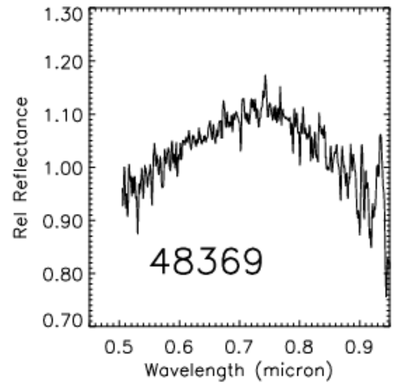
A. Compared to each other, what can you infer about these objects’ brightness and composition? Why?

B. In which part of the electromagnetic spectrum do these objects have the most reflectance? How do you know?

C. Could these asteroids be related (come from the same parent body or family)? Why or why not?







PART 6 - ASTEROID 101 PRESENTATION

Create a PowerPoint summarizing the geologic history of the surface seen in each of the three Asteroid 101 images from Part 5, Exercise 2. What geologic features are present? How did they form? How old are they relative to each other and how do you know that?