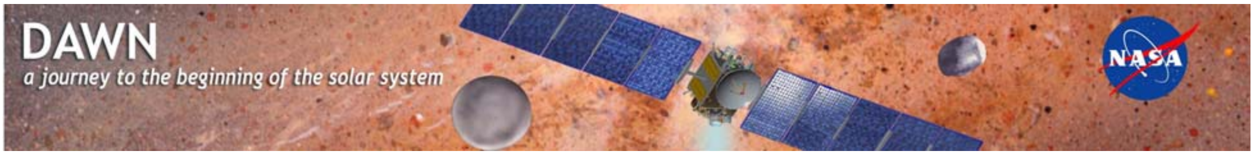

History and Discovery of Asteroids

Vegetable Light Curves

TEACHER GUIDE

BACKGROUND

In the Activity, “Vegetable Light Curves,” students will observe the surface of rotating potatoes to help them understand how astronomers can sometimes determine the shape of asteroids from variations in reflective brightness. When astronomers graph data relating to reflective brightness as a function of time, the resulting graph is called a “light curve.” A good animation that illustrates and presents additional information about light curves can be found at: http://spaceguard.rm.iasf.cnr.it/tumblingstone/issues/special-palermo/lightcurve.htm.

MATERIALS

- Activity Sheet, “Vegetable Light Curves”
- Several sheets of graph paper
- A watch with a second hand

Materials for each team of three:

- Two potatoes—one spherical and one elongated; a cucumber and carrot are optional
- An illumination system—a 40-watt lamp and a dark background or a darkened room
- An assembled potato-rotating system
- Sharpened dowel sticks to mount the vegetables. (There are several ways in which you can prepare the equipment for this activity. See “Vegetable Light Curve Assembly Instructions” for equipment sources, complete assembly instructions, and safety precautions. You will need to select the method most appropriate for your classroom setting and your students’ experience in the laboratory.
  - You may assemble all the equipment yourself.
  - You may assemble part of the rotating system yourself and have your students mount the vegetables themselves.
  - You may have students assemble all the equipment.

> An alternative method would be to have two or more sets of equipment assembled and have teams rotate from station to station until they have completed their observations.

Optional

- Copies of the assembly instructions and safety precautions from “Vegetable Light Curve Assembly Instructions” if you decide that students should set up their own equipment.

PROCEDURE

Part 1: Light Curves

Section One

1. Divide students into teams of at least three members and distribute copies of the Activity Sheet, "Vegetable Light Curves," to each team.

2. For Section One, Question 1, ask team members to engage in a general discussion of the various factors that might affect the apparent brightness of an asteroid. Tell students that they can assume observations are being made from a space platform and that clouds and dust are not factors to be considered. Then have them address the remaining questions. Circulate among the groups and ask appropriate, leading questions to stimulate their discussion.

3. After allowing sufficient time for teams to complete their answers, call the class together for a share-out session. Have each team share one factor from their list of answers to Question 1. Students probably will quickly identify size and distance from Earth as factors that affect brightness. They may also conclude that reflectivity or albedo of the asteroid will have an effect on its brightness, especially if they have completed the Activity, "Seeing Circles—Studying Albedo." Less obvious will be the effect that phase or degree of illumination has on asteroid brightness.

   Make sure the students' answers to Question 2 include a clear understanding that asteroids are not like stars—they do not emit light. Instead, like the moon, we see them only because they reflect light from the sun. Hold up a potato and ask students if they could see the potato in a totally dark room. They should recognize that you could not see the potato at all since **reflected light** provided by a source such as a lamp or the sun is what enables you to see the potato. This point should be emphasized here because "seeing things" is often taken for granted without thinking about what makes it possible for us to see them. Ask them what fraction of the total surface of the potato they can see. The fraction (or percentage) of the surface we can see, which at most is 50%, is directly related to the amount of light reflected from the surface back toward you.

   > If your students do not understand moon phases, you may wish to have them access http://www.usno.navy.mil/USNO/astronomical-applications/astronomical-information-center/phases-percent-moon for an explanation.
   >
   > Click on this (see obtain a moon phases activity guide: http://lhsgems.org/GEM250.html

   Students' answers to Question 3 should indicate an understanding that asteroids pass through phases, just as the moon does. You may wish to engage them in a discussion or review of moon phases.

   To help students answer Question 4, ask how the motion of an asteroid might affect its brightness. Make sure student answers include the fact that asteroids revolve in an elliptical orbit as well as about internal axes.

To stimulate students' reflection on Question 3, ask what factors other than surface area might affect the observed amount of light. Student answers might include the difference in reflectivity (albedo), which might be due to differences in color or texture due to cratering.

4. Pose the question, "How might Earth-bound astronomers obtain an estimate of the shape of an asteroid?" Emphasize that "shape" implies three-dimensional characterization. After students have exhausted their possible answers, tell them that they will be modeling a technique that astronomers have used for many years to obtain information about the shape of asteroids.

Section Two

Your explicit student instructions for Section Two will depend upon how much of the equipment assembly you have decided to have your students complete and how many complete set-ups you have for your class. See your options in "Vegetable Light Curve Assembly Instructions."

1. Divide the class into teams of at least three members. (These groups may be the same as the ones in Section One or they may be different.) Each team should determine the time that is necessary for an elongated potato to make 10 complete revolutions.

2. Instruct the students to follow the directions in Section Two of the activity sheet as they make observations. All team members should make individual observations of the rotating potatoes, except as noted above. As you move about the room, make sure that the observing student's line of sight is level with the potato.

Sections Three and Four

1. Sections Three and Four of the activity should be completed as a team.

2. When all teams have finished, collect the reporting sheets and graphs and post them around the room.

3. Engage students in a discussion of the conclusions that were reached in Section Four. Below are some important concepts that you should bring out as students discuss the answers to their conclusions.

   Question 2. Pay particular attention to the rotational aspects of asteroid brightness. Make sure students understand that asteroids are expected to rotate about internal axes. As a consequence, the image of an asteroid at a particular time will depend on its rotational position with respect to the observer unless the asteroid is spherical, in which case there will be no rotational dependence of the brightness.

   Question 3. It might be concluded that the area of the larger side is twice that of the smaller side. However, if there is a difference in the albedo of different areas of the asteroid, then that conclusion may not be valid. For example, in the Vignette, "More Discoveries…Better Descriptions," there is a sentence that describes Vesta:

   > "In 1987 speckle interferometry showed that 4 Vesta is **dimmest** when its maximum cross section faces Earth and that its surface features have more influence on its light curve than does its shape."

   Question 4. If the observed end of the asteroid is uniform in albedo and not distorted by craters, the light curve would be much like that provided by a sphere. In other words, a graph of light reflected versus time would be a straight line if the end of the asteroid were perfectly circular.

Question 5. At any one observational time, one measures the light curve of a rotating asteroid at a particular point in its orbit. This means that it is impossible to see all of an asteroid's reflective properties from a single observational point of view, i.e., the backside or the ends of the asteroid will remain obscure. However, as an asteroid moves around the sun in an elliptical orbit, its position (think "tilt" or "inclination") with respect to the Earth changes. This positional change coupled with its rotational properties provides a different view over time. Therefore, a sequence of light curves measured over a long time frame may provide sufficient information to determine an asteroid's entire shape.

Question 6. You might want to have a potato mounted at a 45-degree angle for students to observe as they discuss their answers to this question.

Questions 7 and 8. Students' answers to these questions will depend upon their original measurements in Section Two. The main emphasis here is to help students see the relationship between rotational rate and the angle through which a potato rotates during a given period of time. If you have the students pursue the "Quantitative Extensions" (below), they will use the rotational rate determined in the activity.

Question 9. You should be able to read the answers to these questions from the light curve.

- Eros was brightest at about the three-hour mark.
- It was dimmest shortly after the four-hour mark.
- One Eros "day" is about 5.25 hours. (The day ends before the light curve does. The last peak you see is the beginning of another day.)

Question 10. The two brightest peaks were different in amplitude because light was reflecting from two different surfaces. The same is true for the two lowest reflecting surfaces.

Question 11. The light curve of a regularly shaped asteroid would be very close to a straight line because its surface would reflect the same amount of light regardless of what part of its surface we were viewing. The greater the differences in light reflected during the period of rotation, the greater the irregularities of the asteroid surface reflecting the light.

4. Ask students how much more difficult this activity would be if the observer were sitting:
   a) Across the room from the rotating potato.
   b) The length of a basketball court away from the rotating potato.
   c) The length of a football field away from the rotating potato.
      - How does the distance between the rotating vegetable and the observer affect the accuracy and reliability of the observations?
      - How does the length of a football field compare with the distance between an Earth-bound telescope and an asteroid? Between a space telescope and an asteroid?
      - Would the observer's eyesight affect the reliability of the observations? How do the differences among the observer's visual abilities model the differences in technology used by early astronomers (small, Earth-bound telescopes) and that used today (Hubble Space Telescope)?

5. Distribute copies of the Vignette, “I Can See You More Clearly Now.” Allow students time to read the vignette and then ask:
   a) Do you think that these images of Vesta and Ceres taken from the Hubble Telescope are clear enough for scientists to make accurate observations? Why or why not?
   b) How might better images of Ceres and Vesta be made? (One possible student answer might be for a spacecraft—manned or unmanned—to travel to the asteroids for a “close-up” look.)

Quantitative Extensions

The procedures provided in this activity provide dynamic—but only qualitative—information about light curves. Should you wish to do so, you can place the activity on a more quantitative footing by having the students pursue one or both of the procedures outlined below.

- This more quantitative exercise is made possible by the fact that in the activity the students have determined the **rotational rate** for their potato in **degrees per second**. Ask the students to use a protractor and prepare a sheet of paper with lines drawn on it from a center point of the paper out to the edges so that the lines are separated by 30-degree intervals. They should complete a 360-degree pattern of repeating lines. Have the students label these index lines by placing 0, 1, 2, 3, etc. at the ends of the lines. Now have them orient the paper so that index line 0 extends to their right. Index line 3 should point toward them. Next, have them place their long potato on the paper such that its long axis is aligned with index line 0, with the potato center at the origin of the lines. Have them place a mark with a pen on the end of the potato near and in line with index line 0. Now ask them to visually estimate the fraction (or percentage) of surface they can see, and record their estimate along with the index number (0 in this case). Now instruct the students to rotate the potato by hand until the mark on the potato lines up with index line 1. Again, they should estimate the fraction of visible surface area and record the result along with the index number. This procedure should be repeated until the potato is rotated through 360 degrees (or more). Now the students can use their previously determined value of **rotational rate** in degrees per second to evaluate the time it took for the potato to reach the position corresponding to a given index line when the potato was on the rotation apparatus! In effect, the students are setting up a snapshot of what the potato would have looked like when it passed through 30, 60, and so on degrees. To have them complete the activity, instruct them to determine the number of degrees of rotation for each index mark and divide the degrees by their previously determined rotational rate to provide the **time** required for the potato to reach that snapshot point when it was on the rotation apparatus. They can then plot a graph of percentage (or fraction) of surface area visible vs. time and produce a reasonably accurate “potato light curve.” To aid them in making estimates of surface area it may be helpful to draw lines around the circumference of the potato at roughly 1 cm intervals. It also might be instructive to pursue with them the interpretation of the number they obtain when they divide 0 (the degrees corresponding to index line 0) by the rotation rate.

- The above activity can be made even more accurate by setting up a camera (digital preferred) and photographing the potato at each index mark. For best results, zoom in so that the potato fills the frame. The resulting set of photographs can now be printed on plain paper with a standard printer and appropriate software. The image of the potato can be cut out from each photograph and weighed on a good balance. The weight of each piece can then be expressed as a fraction of the weight measured in the photo with the potato exposed to the maximum extent. This procedure provides a reasonably quantitative measure of visible surface area, which can then be graphed against time as determined above.

- Light meter on Calculator Based Lab (CBL) with light probe. Illuminate the potato in a darkened room. Measure the reflectivity. Then compare with measurements above.

ADDITIONAL TEACHER RESOURCES

WEB SITES

http://nssdc.gsfc.nasa.gov/planetary/factsheet/asteroidfact.html
Asteroid Fact Sheet

http://solarsystem.nasa.gov/educ/educators/index.cfm
Solar Systems Exploration

http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Alpha&Letter=D&Alias=Dawn Missions to Asteroids: Dawn

http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Alpha&Letter=D&Alias=Deep%20Space%201
Missions to Asteroids: Deep Space 1

http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Alpha&Letter=G&Alias=Galileo
Missions to Asteroids and Planets: Galileo

http://neo.jpl.nasa.gov/missions/hayabusa.html
Missions to Asteroids: Hayabusa (MUSES-C)

http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Alpha&Letter=N&Alias=NEAR%20Shoemaker
https://solarsystem.nasa.gov/missions/near
Missions to Asteroids: NEAR

http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Alpha&Letter=S&Alias=Stardust
Missions to Comets: Stardust

https://stardustnext.jpl.nasa.gov/
Missions to Comets: Stardust-NExT

http://solarsystem.nasa.gov/missions/profile.cfm?Sort=Target&Target=Comets&MCode=Rosett a
Missions to Comets: Rosetta

http://www.astro.uu.se/planet/asteroid/shapes/
Interactive showing examples of irregular-shaped asteriods in 3-D.

https://www.nasa.gov/mission_pages/hubble/news/vesta.html
Hubble Space Telescope and Keck images of Vesta

https://www.youtube.com/watch?v=votluBtFCys
Animation of Vesta rotation

http://www.figurethis.org/challenges/c61/challenge.htm
This activity asks students to determine if the Statue of Liberty's nose is out of proportion to her body size. The activity, from the Figure This! list of 80 math challenges, illustrates how to use

similarity and scaling to design HO gauge model train layouts and analyze the size of characters in Gulliver's Travels.

https://dawn.jpl.nasa.gov/
Missions to Asteroids: Dawn

PRINT RESOURCES

McSween, H.Y. (1999). *Meteorites and their parent planets***.** Cambridge; NY: Cambridge University Press.

Peebles, C. (2000). *Asteroids: A history*. Washington, DC: Smithsonian Institution Press.

Roth, G.D., (1962). *The system of minor planet*. Princeton, NJ: Company Inc.

APPENDIX C—STANDARDS ADDRESSED

National Science Education Standards addressed:

Science as Inquiry

Understandings about Scientific Inquiry

- Different kinds of questions suggest different kinds of investigations. Some involve observing and describing objects; some involve making models.
- Current scientific knowledge and understanding guides scientific investigations.
- Mathematics is important in all aspects of scientific inquiry.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
- Scientific explanation emphasizes evidence.
- Science advances through legitimate skepticism.
- Scientific investigations sometimes result in new ideas for study.

Physical Science

Motions and Forces

- The motion of an object can be described by its position, direction of motion and speed. That motion can be measured and represented on a graph.

Transfer of Energy

- Light interacts with matter by reflection. To see an object, light from that object must enter the eye.

Earth and Space Science

Earth in the Solar System

- The Earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects such as asteroids and comets.
- Most objects in the solar system are in regular and predictable motion.

Science and Technology

Understandings about science and technology

- Scientific inquiry and technological design have similarities and differences.
- Many different people in different cultures have made and continue to make contributions to science and technology.
- Science and technology are reciprocal.
- Perfectly designed solutions do not exist.
- Technological designs have constraints.
- Technological solutions have intended benefits and unintended consequences.