

Exploring Meteorite Mysteries

Lesson 4 — The Meteorite-Asteroid Connection: Orbits in the Inner Solar System

“Where do they come from?”

Objectives

In Activity A students will:

- draw circles and ellipses to illustrate basic shapes of orbits in the solar system.
- define an elliptical orbit from three of its points (optional).

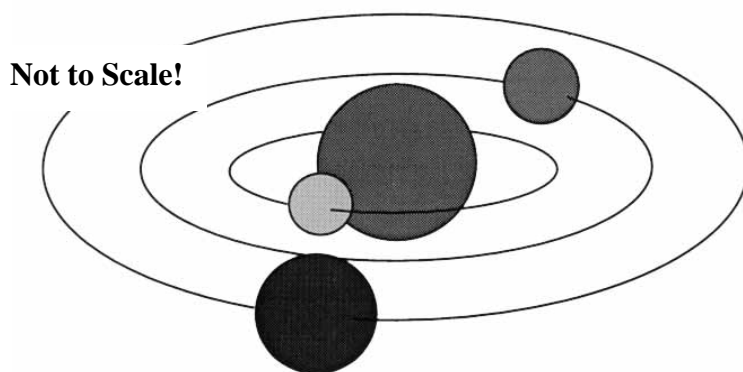
In Activity B students will:

- construct a scale model of the inner solar system including: the Sun, the inner planets, the asteroid belt, and the orbits of a few selected asteroids.
- observe relative distances and sizes within the inner solar system.
- plot the paths meteoroids might take in traveling from the asteroid belt to the Earth.
- manipulate models to demonstrate the concept of the ecliptic plane, and discover that some asteroids do not orbit in the ecliptic plane (upper grades).

(For Advanced Students)

In Activity C students will:

- graph the locations of the Earth and a near-Earth asteroid.
- observe from the graph that both time and location in space are important.
- estimate when an asteroid would cross the Earth's orbit.



About This Lesson

This lesson allows students to understand how meteorites get from the asteroid belt to Earth and how rare it is for the Earth to be hit by a large asteroid.

The students will build an exact-scale model of the inner solar system; the scale allows the model to fit within a normal classroom and also allows the representation of Earth to be visible without magnification. Students will chart where most asteroids are, compared to the Earth, and see that a few asteroids come close to the Earth.

Students will see that the solar system is mostly empty space unlike the way it appears on most charts and maps. Higher grade students can extend the activities as a transition to astronomy.

Vocabulary

ellipse, orbit, astronomer, asteroid, asteroid belt, ecliptic plane, retrograde

Background

To appreciate the Earth in respect to meteorites and asteroids in the solar system, it is important to know the configuration of the inner solar system, including the proper relative sizes and distances of objects. Most charts of the solar system show the planets' orbits at a different scale from the planets, so that the solar system appears as large planets close together. The student gets an incorrect impression of how far it is to other planets, how small planets are compared to the distances between them, and how small the Earth is as a target for meteorite impacts. The exact scale model of the inner solar system, from the Sun through the asteroid belt, will allow the student to appreciate the sizes and distances pertinent to these exercises (information in Tables 2 and 4).

Most meteorites are thought to be broken fragments of asteroids — small “planets” or bodies of rock or ice orbiting around the Sun. The largest asteroid is Ceres, 940 km in diameter, much smaller than our Moon (3,500 km diameter). Ceres was the first asteroid discovered (in 1801), and about 6,000 have been discovered since then. Asteroids are so small that telescopes on Earth can see them

only as points of light. Recently the *Galileo* spacecraft passed close to the asteroids Gaspra and Ida and sent us pictures of them. Both are irregular masses of rock, seemingly broken and covered with impact craters. As indicated by their colors (reflectance spectra), most asteroids are mixtures of metal and silicate minerals, possibly like chondrite meteorites. A few are made of basalt rock, just like the basalt meteorites (example: 1983RD in this lesson).

Asteroids Can Have Three Names!

When one is found, it is given a temporary name, like 1983RD, showing what year it was found. After the asteroid's orbit is known well, it gets a number and can be given a 'real' name by the person who found it. The names of the asteroids in this lesson are “1 Ceres,” “1566 Icarus,” and “3551 1983RD.” The last doesn't have a 'real' name yet. Asteroid names come mostly from mythology, but also include famous people, including: “3352 McAuliffe” (after Christa McAuliffe, the teacher/astronaut who was killed when the Space Shuttle *Challenger* exploded), “2266 Tschaikovsky” (after the Russian composer), “1744 Paavo Nurmi” (after a Finnish marathon runner), “1569 Evita” (after Evita Perón, wife of ex-president Juan Perón of Argentina), and “2578 Saint-Exupéry” (after the author of “The Little Prince”).

Most asteroids orbit in the asteroid belt between 2.2 and 3.2 times the Earth's distance from the Sun; their orbits are ellipses, oval-shaped curves that carry them nearer and farther from the Sun. Only a few asteroids follow orbits that get near the Earth, and these asteroids are probably the sources of some meteorites.

An asteroid that crosses the Earth's orbit could collide with the Earth and cause a devastating impact explosion. About 200 of these Earth crossing asteroids are known, and it is estimated that 20-40 percent of them will collide with the Earth over the next million years. No known asteroid will hit the Earth for at least 200 years. We will likely have many years of warning before an asteroid collision like this, and the students will see from the solar system model that the Earth is really a very small target. But when there are a million shots, over a long time, one is likely to hit.

To hunt for asteroids, astronomers photograph the night sky, and look for “stars” that move compared to real stars. A long exposure photograph would show a background of stars as spots, with a streak from an asteroid, due to the asteroid's motion across the sky. To discover the orbit of an asteroid, it is not necessary to observe the asteroid as it follows its whole orbit; knowing its location a few times, over several weeks or months, is sufficient.



Lesson 4 — The Meteorite-Asteroid Connection

Activity A: Drawing Circles and Ellipses

Objectives

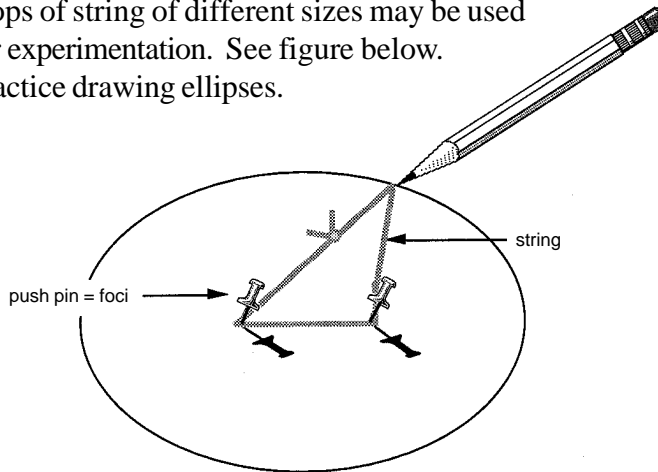
Students will:

- draw circles and ellipses to illustrate basic shapes of orbits in the solar system.
- define an elliptical orbit from three of its points (optional).

Procedures

Advanced Preparation

1. The instructor should prepare a loop of string, approximately 40 cm in circumference, for each group. Additional loops of string of different sizes may be used for experimentation. See figure below.
2. Practice drawing ellipses.



Classroom Procedure

Part 1. Drawing a Circle. Have each group of students stick one pushpin into the center of their cardboard sheet. Put the loop of string around the pushpin, put the point of the pencil within the loop, and draw the loop tight with the pencil tip (not so tight as to pull out the pin!). Draw a line with the pencil, **keeping the string tight**. The pencil line will be a circle around the pushpin.

Part 2. Drawing Ellipses. Have each group of students stick two pushpins into their cardboard sheet near its center, placing the pins 10-15 cm apart. Put the loop of string around **both** pushpins, and carefully draw the loop tight with the pencil tip forming a triangle. Draw with the pencil, keeping the string tight around both pins. The pencil line will be an oval, or **ellipse**. Students may experiment with different distances between pins and different lengths of string. Optional: paper may be taped to the cardboard if desired.

About This Activity

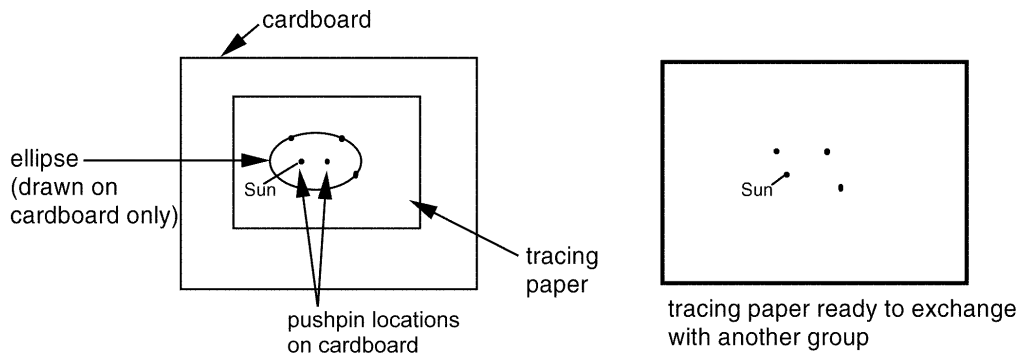
In this activity, students will learn how to draw circles and ellipses using a pencil, pushpins and string. They will learn what an ellipse is, how it is different from a circle, and how an astronomer can determine the elliptical orbit of an asteroid.

Materials for Activity A

- poster board or cardboard, about 60 cm x 60 cm, thick enough to hold a pushpin (*old science fair trifolds work*), one for each group
- tracing paper, about 60 cm x 60 cm, one or more for each group
- pushpins, 6 per group
- pencil/pen
- string
- scissors

Part 3. Find the Asteroid Orbits. The orbits of asteroids are ellipses, not circles, around the Sun. Astronomers can figure out the whole elliptical orbit of an asteroid by knowing just three points in the orbit. In this activity, a team will draw an ellipse, and another team will work like astronomers to try to reconstruct that ellipse knowing only the locations of three points and the “Sun.” **It is important that all the teams have strings of the same length.**

Have each team draw an orbit for an asteroid on their cardboard by drawing an ellipse (Part 2), and designating one pushpin as the “Sun.” Have each team remove the pushpins, place the tracing paper over the orbit drawing, tack the tracing paper to the cardboard at the corners, and using a pen, mark on the tracing paper the “Sun” position and three points on the orbit ellipse (do not draw the entire ellipse). These three “data points” represent observations made by astronomers which are used to plot the orbit of an asteroid. See figures below.



Teams label their ellipses, trade tracing papers, tack their new paper down at the corners, and put a pushpin in at the “Sun” position. Each team of “astronomers” then tries to find a placement for the second pushpin, so that an ellipse drawn with their loop passes through the three points on the tracing paper. When complete, compare with the original group’s ellipse that includes the three data points.

Questions

1. How are ellipses different from circles?
2. What shape is drawn when the pushpins are right next to each other?

Extensions

1. If you wanted to describe an ellipse to another person, what would you say? (length of string, length of ellipse, breadth of ellipse, orientation) What more would you need if the ellipse could be in the air oriented in any way?
2. Part 3 can be extended by having the asteroid orbits drawn with different lengths of string, and having each “astronomer” team determine the string length in addition to the location of the second pin.

Lesson 4 — The Meteorite-Asteroid Connection
**Activity B: The Long and Winding Road
to Earth**

Objectives

Students will:

- construct a scale model of the inner solar system including: the Sun, the inner planets, the asteroid belt, and the orbits of a few selected asteroids.
- construct circular and elliptical planetary orbits.
- conclude that the relative sizes of the Sun and the inner planets are often misrepresented.
- observe relative distances and sizes within the inner solar system.
- plot the paths meteoroids might take in traveling from the asteroid belt to the Earth.
- observe that the Earth is a very small target.
- manipulate models to demonstrate the concept of the ecliptic plane and discover that some asteroids do not orbit in the ecliptic plane (upper grades).

Procedure

Advanced Preparation

1. Gather materials, prepare string loops ahead if desired.
2. Practice procedure.

Classroom Procedure

1. Preparation of the Board.

Mark the center of the large sheet of cardboard; this will be the Sun's location. Draw a circle 1.8-2 mm diameter around the point; this is the scaled diameter of the Sun. If the exact orientations of orbits are desired for upper grades, draw a light reference pencil line from the Sun's center toward a side; angles for orientations of elliptical orbits will be measured from this line.

2. Prepare Strings.

A loop of string is needed for each orbit. The instructor may prepare the loops ahead of time; or student teams may measure, cut, and knot a loop for their own orbit. To keep

About This Activity

In this activity, the class will learn how meteorites and asteroids travel from the asteroid belt to the Earth. The focus here is on construction of an exact scale model of the inner solar system (Sun to asteroid belt), including some asteroids that might hit the Earth. At the given scale (which can be expanded or reduced), the model will fit on a 1.2 m x 1.2 m piece of cardboard or poster board, and the Earth will be just large enough to be seen.

Materials for Activity B

- 1.2 m square or larger piece of corrugated cardboard (*refrigerator box?*) or very stiff posterboard
 - 60 cm x 30 cm piece of corrugated cardboard or very stiff poster board (*upper grades*)
 - pushpins, two per group
 - colored and regular pencils
 - string, or loops of string in the lengths indicated in Table 1
 - scissors, ruler, and protractor
 - clay-dough (*or similar substance*) in yellow or white
 - magazines with colored pictures
 - Table 1 (*pg. 4.6*) and Table 2 (*pg. 4.7*) from this lesson
- Optional for upper grades**
- razor knife or other knife (*to be used only with supervision*)

the proper scale, use the string lengths in Table 1. If the loop turns out too long, it can be shortened with an overhand knot.

3. Draw the Orbits.

Each student team should draw their orbit on the cardboard, using the pin(s) and string technique in Activity A, Part 2 and the data of Table 1; lower grades include the asteroid Icarus here, upper grades may do Icarus separately (See optional section below—Asteroid Icarus in the Third Dimension.).

Circular orbits require one pin at the Sun position. Elliptical orbits require two pins each: one at the Sun and the other at the distance from the Sun shown in Table 1. The ellipses may be oriented at any convenient angle on the board; to make the model exact, the second pins should be oriented at the angles in Table 1 from the pencil line drawn in Part 1 (exact orientations are not used later). See illustration on page 19 in the Teacher’s Guide. To draw the orbit of the Earth’s moon, pick a point on the Earth’s orbit to be the Earth’s position. Around that point, draw a circle of 5 mm radius (10 mm or 1 cm diameter) to represent the Moon’s orbit.

Table 1. Drawing Orbits in Scale Model

Orbit	Loop		Pin 2 from Sun	
	Circumference (knot to knot)	# pins	Distance	Angle
Mercury	18 cm	2	3.1 cm	270°
Venus	27 cm	1	--	--
Earth	39 cm	1	--	--
Mars	64 cm	2	5.6 cm	45°
Asteroid Belt: Inner Edge	84 cm	1	--	--
Asteroid Belt: Outer Edge	122 cm	1	--	--
Asteroid Ceres	114 cm	2	8.4 cm	78°
Asteroid 1983RD	118 cm	2	39 cm	173°
Asteroid Icarus	85 cm	2	38 cm	330°

4. Adding the Sun and Planets.

To complete the model, add the Sun and planets at the same scale as their orbits. Real and to-scale diameters are given in Table 2. At this scale the Sun should be a ball just under 2 mm diameter, about the size of a BB or a ball bearing from a bicycle.

The Earth and Venus should be 1/50 mm across, which is almost invisible; smaller than a grain of salt or a pin-prick in paper (~1/5 mm), and about the thickness of standard copier paper. A single dot out of a half-tone print (as in a magazine) is about 3 times too large, but gives the

right idea of scale. The individual dots in a half-tone print can be seen with a 5 or 10X magnifying glass. The Moon, Mercury, Mars and the asteroids are too small to be visible at this scale!

5. Discussion.

Encourage students to share their observations about size and scale as they construct and view the scale model. Help students to observe that there is mostly open space in the solar system. Lead students to the observation that Earth is a small moving target and is not frequently hit by large impacting asteroids or comets.

Table 2. Real and Scaled Diameters of Solar System Objects

Object	Real Diameter	Scaled Diameter
Sun	1,400,000 km	1.8 mm
Mercury	4,880 km	1/150 mm
Venus	12,100 km	~1/50 mm
Earth	12,800 km	~1/50 mm
Moon	3,480 km	1/200 mm
Mars	6,800 km	~1/100 mm
Ceres	940 km	~1/1000 mm
1983RD	0.8 km	~1x10 ⁻⁶ mm
Icarus	0.9 km	~1x10 ⁻⁶ mm

6. Optional - Upper Grades

Asteroid Icarus in the Third Dimension. The orbits of all the planets (except Pluto) and most of the asteroids are nearly in the same plane, the **ecliptic** plane. In the model, the ecliptic plane is the main cardboard. The asteroid Icarus orbits outside the ecliptic, and so provides an exercise in three-dimensional geometry.

On a separate piece of cardboard, draw an ellipse following the method of Activity A with the string length and pin distance for Icarus from Table 1. Cut out the ellipse. Draw a straight pencil line through the pin holes from one end of the ellipse to the other. Select one pin hole to be the Sun's location. Draw a straight pencil line through the Sun pin hole at a 30° angle to the end-to-end line; this last line is at the intersection of Icarus's ellipse and the ecliptic plane. Measure and write down the lengths of this intersection line on both sides of the Sun hole; the distances will not be the same. In the ellipse, cut out a hole about 1 cm diameter around the Sun point.

On the main solar system board, cut a slit through the Sun position as long as the intersection line, so that the Sun point on the main board and the Sun hole in the Icarus ellipse can coincide. The slit may be at any convenient orientation; to make the model exact, cut the slit at an angle of 87° clockwise from the reference line, with the shorter part of the slit pointing to 87° and the longer part pointing to 273°.

To attach the Icarus ellipse to the main board, insert the Sun end of the ellipse into the slit from below the main board. Adjust the ellipse so that the intersection line is at the main board, and the Sun point of the main board and the Sun hole on the ellipse coincide. Tape in place along the intersection line.

Finally, tilt the Icarus ellipse (flexing the tape along the intersection line) so that its plane makes a 25° angle to the main board (ecliptic plane). Tape or wire in place. Reinforce as needed to correct possible sagging.

Extensions

1. Who was Icarus? Why name this particular asteroid after him? Another asteroid with a similar orbit is named Phaethon. Who was Phaethon, and why might an asteroid be named after him?
2. At the scale of this model, a light year (the distance light travels in a year) is about 12.1 km. In this model, how far from the Sun would it be to the nearest star, Proxima Centauri at 4.3 light years distance? (52 km) How far to the nearest star visible in the Northern Hemisphere, Sirius at 8 light years distance? (96.8 km) At this scale, how far away is the center of our Milky Way galaxy at 30,000 light years distance? (363,000 km) How is this image of the distances between stars different from the images shown in TV shows or movies about space? (Space is more empty and much larger than it is usually depicted.) (See Table 3 for additional information.)
3. View the video “Powers of 10.”

Table 3. Solar System and Nearest Star at this Scale

Distances are averages from Sun, except for Earth’s Moon* which is from Earth.

Object	Real		Scaled	
	Distance	Diameter	Distance	Diameter
Sun	---	1,400,000 km	---	1.8 mm
Mercury	58 million km	4,880 km	7.3 cm	0.005 mm
Venus	108 million km	12,100 km	13.8 cm	0.015 mm
Earth	150 million km	12,800 km	19.5 cm	0.016 mm
Moon *	0.38 million km	3,480 km	0.49 cm	~0.004mm
Mars	228 million km	6,800 km	32 cm	0.09 mm
Asteroid Belt: Inner Edge	330 million km	---	42 cm	---
Asteroid Belt: Outer Edge	480 million km	---	61 cm	---
Jupiter	778 million km	143,200 km	1.0 m	0.18 mm
Saturn	1.42 billion km	120,000 km	1.9 m	0.15 mm
Uranus	2.87 billion km	51,800 km	3.7 m	0.06 mm
Neptune	4.48 billion km	49,500 km	5.8 m	0.06 mm
Pluto	7.4 billion km	2300 km	9.4 m	0.004 mm
(Aphelion- farthest point from Sun)				
Alpha Centauri (Star)	4.1x10 ¹³ km or 41 trillion km	2,500,000 km	52 km	~3 mm

Lesson 4 — The Meteorite-Asteroid Connection

Activity C: Collision Course

Objectives

Students will:

- graph the locations of the Earth and a near-Earth asteroid.
- observe from the graph that both time and location in space are important.
- estimate when an asteroid would cross the Earth's orbit.
- determine if a collision would take place.

Procedure

Advanced Preparation

1. Have materials ready. Instructor may prepare the papers and the circular Earth orbit as in Part 1. Use a string, 30 cm knot to knot. The instructor may choose to draw the Earth orbit with a pushpin and string, or any other method. Distances in Table 4 assume that the Earth orbit is 30 cm diameter, and can be scaled for other sizes.

Classroom Procedure

1. Get Set . . . (Earth's orbit)

Each team should mark the Sun point at the center of its paper, and a pencil line from the Sun extending 30 cm in any direction. This will be the reference line from which angles are measured (see diagram below).

2. Go! (Graphing orbits)

Each team should graph the orbit of the Earth and the orbit of one asteroid on their paper. To draw an orbit from the numbers in Table 4, begin with a single time at the left of the Table 4. On that line in the Table, read the angle and distance for that time in the orbit.

On the large piece of paper, use a protractor to measure the angle (clockwise) from the Sun and the reference line, and draw a line at that angle. Measure outward along that line to the distance listed in the table, and draw a mark at that distance (color-coded, perhaps). Label the mark with the month and half-month.

After all the points are graphed and labeled, connect them freehand to make a smooth curve. The points may not make a full orbit.

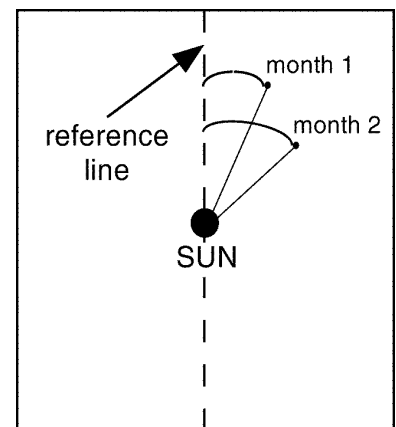
About This Activity

For Advanced Students

Even if the orbit of an asteroid crosses the orbit of the Earth, there may be no collision if the asteroid and Earth are at different places in their orbits. In this exercise, each group of students will graph orbit positions of the Earth and an asteroid. Students will compare their results, and see which asteroid makes the closest approach.

Materials for Activity C

- Kraft or butcher paper, approx. 60 cm x 60 cm for each group
- pencil/pen (*colored pencils optional*)
- rulers, one per group
- protractors, one per group
- Table 4 (*pg. 4.11*)



Graphing Asteroid Orbits

3. And the Winner Is . . .

Each team should then estimate when (month number and a fraction) their asteroid crosses the Earth's orbit. Then, each team should measure the closest approach between their asteroid and the Earth, by measuring the distance between corresponding time steps in their orbits. Which asteroid comes closest to hitting the Earth? How close does the closest asteroid really come to the Earth?

The scale here is 1 cm = 10,000,000 kilometers, and the Earth (to scale) would be 1/100 mm.

Note: This scale is not the same as in Activity B!

Extensions

1. The speed of an asteroid (distance/time) can be estimated here as the distance between successive points from Table 4. How does the speed of an asteroid change as it goes through its orbit (perhaps students could graph speed versus distance from the Sun)? How fast is each asteroid going as it passes Earth's orbit? If the asteroid(s) hit the Earth, would the differences in speed have any effect on the force of the impact or the size of a resulting crater? (See Lesson 6)
2. The distance between the Earth and an asteroid depends on the relative positions of both the asteroid and the Earth. Tabulate the distances between the Earth and the asteroids through time and make graphs of distance versus time. Why do the graphs have hills and valleys?
3. Astronomers have to know where in the sky to look for asteroids in order to study them. They measure directions in the sky as angles compared to a reference direction, just as on the drawings in Activity C. To find out where in the sky you would look for your team's asteroid, pick a time point for the Earth, and draw a line through that point parallel to your reference line (that goes through the Sun). Draw another line from the Earth to the asteroid's position at that time point. Measure and write down the angle between these two lines; this is the direction (the longitude) in the sky you would have to look (to an astronomer, the "right ascension"). For your team's asteroid, tabulate the directions you would have to look from Earth, and graph that angle versus time. Does your asteroid appear to move at a constant speed in the sky? Do any of the asteroids appear to move backwards (retrograde motion)?

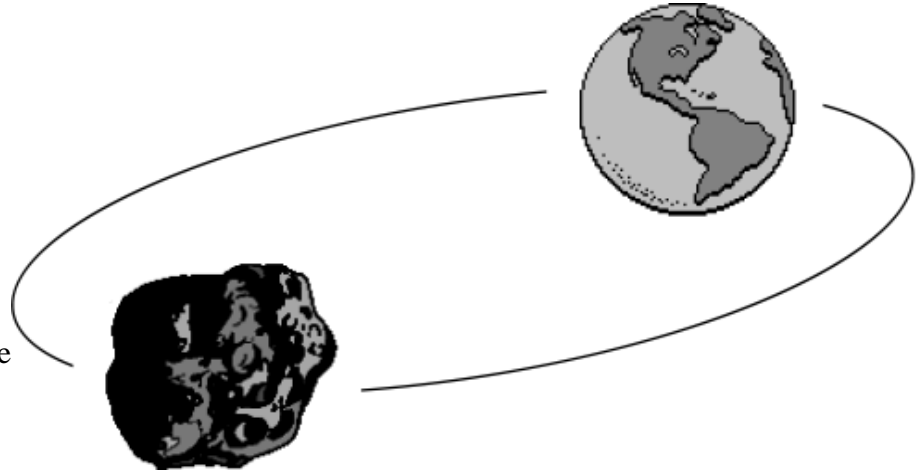


Table 4. Distances from Sun and Angles from Reference Line for Earth and Asteroids

Month	Earth		Asteroid 1		Asteroid 2		Asteroid 3		Asteroid 4		Asteroid 5		Asteroid 6	
	Dist	Angle	Dist	Angle	Dist	Angle	Dist	Angle	Dist	Angle	Dist	Angle	Dist	Angle
0	15 cm	0°	8.4 cm	0°	23.7 cm	322°	30.6 cm	195°	55.4 cm	50°	23.6 cm	56°	51.1 cm	261°
1	15 cm	30°	10.8 cm	72°	23.5 cm	333°	27.0 cm	205°	53.9 cm	48°	21.4 cm	71°	49.5 cm	264°
2	15 cm	60°	14.8 cm	110°	22.6 cm	344°	23.1 cm	218°	52.1 cm	46°	19.0 cm	90°	47.7 cm	267°
3	15 cm	90°	18.2 cm	133°	20.8 cm	356°	19.2 cm	236°	50.1 cm	44°	16.7 cm	115°	45.6 cm	270°
4	15 cm	120°	20.7 cm	149°	18.2 cm	11°	15.6 cm	263°	47.7 cm	42°	15.0 cm	146°	43.2 cm	273°
5	15 cm	150°	22.4 cm	162°	14.7 cm	30°	13.4 cm	303°	45.1 cm	40°	14.6 cm	182°	40.4 cm	277°
6	15 cm	180°	23.3 cm	174°	10.8 cm	59°	14.1 cm	347°	42.0 cm	37°	15.5 cm	216°	37.4 cm	282°
7	15 cm	210°	23.3 cm	185°	8.6 cm	113°	17.2 cm	21°	38.6 cm	33°	17.5 cm	245°	33.9 cm	288°
8	15 cm	240°	22.5 cm	197°	11.1 cm	192°	21.0 cm	43°	34.7 cm	29°	19.9 cm	276°	30.1 cm	294°
9	15 cm	270°	20.9 cm	210°	15.0 cm	244°	25.0 cm	59°	30.3 cm	24°	22.2 cm	285°	25.8 cm	303°
10	15 cm	300°	18.5 cm	225°	18.4 cm	272°	28.8 cm	70°	25.2 cm	17°	24.4 cm	299°	20.9 cm	316°
11	15 cm	330°	15.2 cm	247°	20.9 cm	290°	32.2 cm	79°	19.1 cm	6°	26.2 cm	311°	15.6 cm	338°
12	15 cm	0°	11.2 cm	283°	22.7 cm	304°	35.4 cm	86°	11.9 cm	342°	27.7 cm	321°	10.7 cm	21°
13	15 cm	30°	8.5 cm	352°	23.6 cm	317°	38.3 cm	92°	5.4 cm	240°	28.8 cm	331°	10.0 cm	94°

Asteroid 1 = Castalia, (0 month is 1.5 months after perihelion at 0°)
 Asteroid 2 = Cerebrus, (oriented so perihelion is on-line with Earth and Sun)
 Asteroid 3 = Antinous, (starting 71 half-months after perihelion)
 Asteroid 4 = Hephiaistos, (starting at perihelion, but turned to retrograde orbit)
 Asteroid 5 = Nereus, (arranged for a near-miss)
 Asteroid 6 = Oljato, (starting at 51 half-months after perihelion, angle advanced by 85°)