

Drawing a Scale Model of the Solar System

Notes to the Teacher:

Astronomical distances, even within our own solar system, are very difficult for anyone, let alone children, to imagine. In this month's space-program-related activity, students have the opportunity to create a visual and kinesthetic model of the solar system on a scale that may begin to inspire an awed comprehension of how big space is—and how small Earth is. In addition, they will learn a little basic geometry in demonstrating for themselves the difference between a circular planetary orbit and an elongated elliptical cometary orbit.

As a space exploration first, The Jet Propulsion Laboratory (JPL), under contract to the National Aeronautics and Space Administration (NASA), is planning to send a spacecraft to rendezvous with and land on a comet, collect samples of the nucleus, and return them to Earth for analysis. The spacecraft that will perform this Comet Nucleus Sample Return mission will have to orbit the sun twice to get itself into enough of an elliptical orbit to meet up with the comet.

This activity was conceived by Enoch Kwok, a high-school teacher/consultant, and Sharon Mayeux, a fifth-grade teacher, both from La Crescenta, California. The article was written by Enoch Kwok and Diane Fisher, a technology and science writer at JPL and the designer and writer of **The Space Place**. This material is provided through the courtesy of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

This activity can be meaningful for students from grades 3 through 12—and beyond!

It is self-contained on the following pages, which can be photocopied and given to the students.

For younger children, we have a few suggestions:

1. Measure, cut, tie, and label the loops of string before class. It takes some time and concentration to do this.
2. If attention seems to be wandering, limit the number of comet orbits drawn to two (rather than the five in the instructions)—say, Halley and Tempel 1.
3. Sometimes younger children may have trouble keeping the string looped around the chalk as they are drawing the orbits. Carving a shallow groove around the chalk for the string to fit into may help.
4. Broom handles with rubber tips are easier to keep in place on the pavement when the string loop is pulled tight. Better yet, crutches, canes, or walking sticks are tailor-made for this purpose!

Comets: Very Eccentric Characters!



This beautiful image of Comet Hale-Bopp was captured by Terri Formico and Charles White on April 7, 1997, from the top of Mt. Pinos, near Los Angeles, California.

Comets occasionally appear in our night skies. We see them as bright—or faint—fuzzy balls of light, with one or two long tails streaming out. They look nothing like stars, the moon, or any other object we see in the sky. That is because they *really are* quite different!

The comets we see, and the trillions more we don't, are part of our own solar system. It is mostly the force of our Sun's gravity that influences their orbits. Comets are actually icy, leftover chunks of the stuff that formed our solar system four and one-half billion years ago.

We have learned a lot about comets from some previous space missions; but comets are still very mysterious objects. Comets have most likely played an important role in our solar system's development and maybe even helped lead to life on Earth. Maybe our oceans are really melted comets! Also, comets might play a role in Earth's future, if one should happen to cross our path at the wrong time.

A Cloud of Ice Balls

Most comets orbit the Sun in the *Oort Cloud*, a region of space 50,000 times farther from the Sun than we are. The rest of the comets reside in the Kuiper Belt, a region beyond the orbit of Pluto. As long as a comet stays in one of these regions, it is just an icy chunk—certainly not very interesting to look at, even if we could see it—which we can't, because they're too small and too dark. However, sometimes the gravity of a nearby star or planet disturbs one of the icy comets from its orbit, flinging it into the

inner solar system, where it may be captured into a very elongated orbit around the Sun.

As it comes closer to the Sun, the comet begins to heat up and its ice begins to *sublimate* (boil off) and glow. It develops a huge *coma* (cloud of gas and dust) nearly four times the size of Earth and brilliant tails of gas and dust millions of miles long. Since it is only the very few comets in this condition that we see, this is how we think of them, rather than in their usual state as dark, icy chunks.

The comets we see are categorized into two types, depending on how long it takes them to go once around the Sun. This time is called a comet's *period*. *Short-period comets* take 200 years or less to orbit the Sun, while *long-period comets* take longer than 200 years. Of the more than 875 comets humans have discovered, about 180 are short-period comets. One of the most famous of these is Halley's comet, which orbits the Sun and is visible from Earth once every 76 years. (By the way, comets are named after the people who discover them.)

Charting the Orbits of Comets

One of the many things that makes a comet different from a planet is its orbit—that is, the path it takes around the Sun. Planets tend to orbit their parent star in nearly circular paths. Comets, however, have very elongated orbits, with one end coming very near the Sun and the other end very far from the Sun.

In this activity, we will see how the orbits of comets compare to the orbits of the planets. We will use a loop of string to learn the difference between an ellipse in general and a circle in particular (a circle is a special kind of ellipse). We will then go outside to make a true-scale chalk drawing of the orbits of the planets in our solar system, including a few comets.

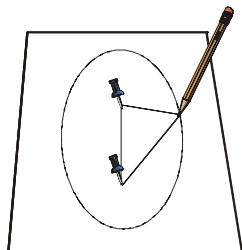
First, let's draw some ellipses.

You will need:

- Piece of corrugated cardboard at least 25 centimeters (10 inches) square
- String
- Ruler (metric or English units)
- Pencil
- 2 straight pins or push pins

1. Tie a 20-centimeter (8-inch) length of string into a loop. Push a pin into a piece of cardboard. Place the loop of string around the pin. Use a pencil inside the loop to trace out a shape as you pull the loop tight. What shape is made with one pin at the center?

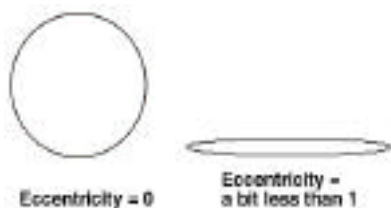
- Place a second pin 5 cm (2 in) from the first pin. With the loop of string enclosing both pins, trace another shape with the pencil. This shape is called an *ellipse*. How is this shape different from the first shape?



A circle has a single center, but an ellipse has two centers, called foci (FO-sigh). The pins represent the foci of the ellipse you have drawn.

- Move one of the foci so it is 8 cm (3 in) from the other one. Trace a loop with the pencil. How did the shape of the ellipse change?

The amount of flattening of the ellipse is called its *eccentricity*. A circle is a special kind of ellipse with no flattening, so we say it has an eccentricity of 0 (zero). An ellipse that is so flat it looks almost like a straight line has an eccentricity of almost 1.

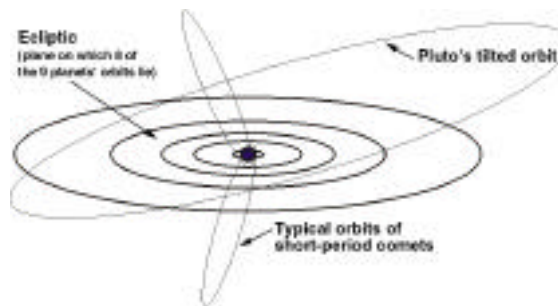


The orbit of anything that orbits the Sun has two foci, with the Sun at one and empty space at the other. As a comet comes near the Sun, the Sun's gravitational pull speeds it up until it is going fastest when closest to the Sun. The comet's path is bent by the increasing pull of the Sun's gravity until it swings around the Sun and heads back into deep space. The comet's momentum sends it far into space, although it slows down because of the Sun's gravitational pull. Sometimes, comets come so close to the Sun, they just crash into it, instead of swinging around it. Well, they don't really "crash," because all the ice has evaporated long before they actually hit the Sun.

Nearby planets, especially the larger planets like Jupiter and Saturn, can disturb comets' orbits. These giant bodies have enough gravitational pull to change a comet's orbit dramatically, flinging it in toward the Sun, into a planet, or out farther into deep space never to return. Comet Shoemaker-Levy 9 was captured and broken up by the huge gravitational forces of Jupiter, and ended up crashing into the planet in 1994. Scientists now believe that Jupiter's gravity has helped deflect many comets away

from Earth since its formation, helping protect our fragile environment enough to allow life to evolve and flourish over a long period.

Comets' orbits differ from those of planets not only in their shape (eccentricity), but also in their orientation. All planets' orbits lie very close to an imaginary flat plane called the *ecliptic*. In fact, all planets even orbit the Sun in the same direction. The orbits of comets, on the other hand, are tilted at random angles to the ecliptic.



Let's draw the orbits of the solar system.

We will include the planets and a few comets. Except for Pluto, the planets' orbits have such a small eccentricity, we will draw their orbits as circles. We can draw Pluto's more eccentric orbit as similar to the orbits of comets using the two foci method we used before.

We will need lots of room for this drawing if the orbits are to be to scale. Let's go outside and draw with chalk on some pavement, so we can really get a feel for some distances.

You will need:

- Clean, dry area of pavement outside at least 8 meters (27 ft) long and 6 meters (20 ft) wide
- Sidewalk chalk, several large pieces, two colors
- Two broom or mop handles (rubber tips are helpful)
- String
- Meter (or yard) stick or tape measure
- Small pieces of paper (for string labels)
- Stapler
- At least three participants

First, draw the orbits of the first eight planets:

- Cut pieces of string for each orbit with the lengths (either in centimeters or inches) given in the first table on the next page. (These measurements already include an extra 15 cm [6 in] for tying a knot and looping the string around the broom handle.)
- Tie each length of string into a loop. Write the planet name on a small piece of paper and staple it to the string.



Photo by Lilitana Novati

| Orbit of Planet . . . | String Length (cm) | String Length (in) |
|-----------------------|--------------------|--------------------|
| Mercury | 25 | 10 |
| Venus | 29 | 11.5 |
| Earth | 35 | 14 |
| Mars | 49 | 19.5 |
| Jupiter | 125 | 50 |
| Saturn | 215 | 86 |
| Uranus | 415 | 166 |
| Neptune | 615 | 246 |

| Orbit for .. (Comet period) | String cm | Length, (in) | Foci cm | distance, (in) |
|----------------------------------|-----------|--------------|---------|----------------|
| Pluto | 1015 | (406) | 200 | (80) |
| Comet Encke (3.3 yrs) | 95 | (38) | 38 | (15) |
| Comet Halley (76 yrs) | 715 | (286) | 340 | (136) |
| Comet Tempel 1 (5.7 yrs) | 110 | (44) | 33 | (13) |
| Comet Giacobini-Zinner (6.5 yrs) | 135 | (54) | 50 | (20) |
| Comet Tuttle (13.5 yrs) | 215 | (86) | 90 | (36) |

3. Mark a spot on the pavement to represent the position of the Sun. Have one person stand the end of the broom handle on this spot.
4. Anchor the loop at the pin or broom handle. Use one color of chalk for all the planets' orbits. With the chalk inside the loop, stretch it all the way out and draw a circle. If the Mercury and Venus loops seem too small to work with, first draw the Earth orbit, then free-hand sketch in the two smaller orbits, using the lengths of their loops as an eyeball guide.

Draw the rest of the planets' orbits through Neptune. For the outer orbits, be sure to keep that string stretched tight! These orbits are *big*!

Now, draw orbits for Pluto and some short-period comets:

1. Make loops of string with lengths given in the "string length" columns of the chart in the next column. Label them as you did for the planets' orbits.

2. For each orbit, in addition to a broom handle placed at the Sun position, place a second broom handle at the foci distance stated in the chart.
3. Using the second color of chalk for the comet orbits, draw the elliptical orbits using the loops with the two broom handles as foci.

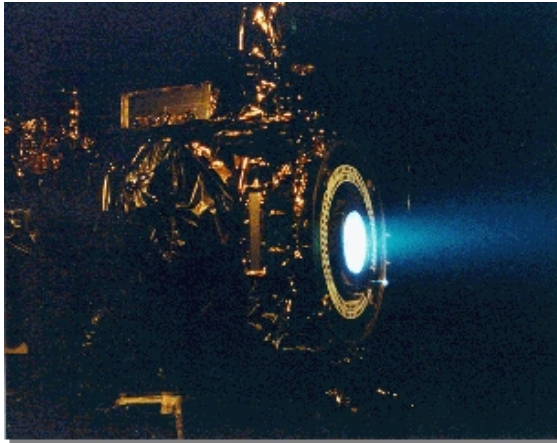
What is unique about Pluto's orbit compared to Neptune's, the next planet in toward the Sun?

How are the orbits of short-period comets different from those of the planets? Long-period comets, like Hyakutake, which recently passed Earth, have orbits that stretch far beyond Pluto's orbit and can take over 10,000 years to travel just once around the Sun. Their orbits are much too large and elongated to fit on your pavement, even if it covered the entire school yard!

A Daring New Mission

At the National Aeronautics and Space Administration's (NASA's) Jet Propulsion Laboratory (JPL), scientists and engineers are designing a mission to land on a comet for the first time ever and bring samples of it home to Earth. The Comet Nucleus Sample Return (CNSR) mission will launch sometime in 2005 or 2006. It will

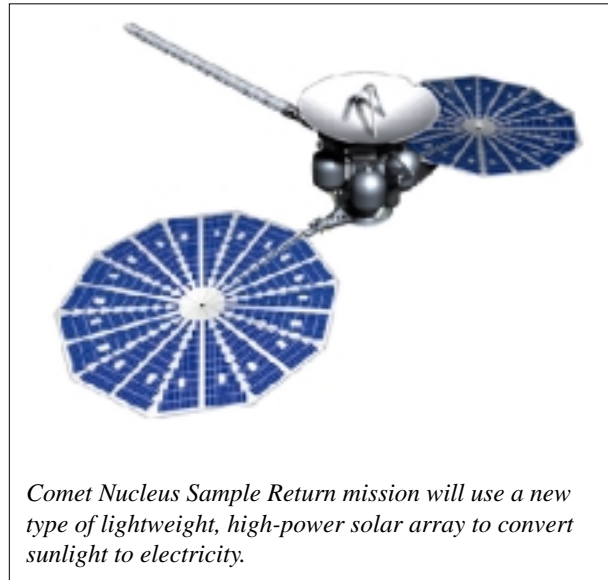
- meet up with a comet (which hasn't yet been selected),
- land and anchor itself to the comet's nucleus,
- measure and observe properties of the nucleus,
- take images of the surface,
- drill into the nucleus and collect samples of the material,
- store the samples,
- and return the samples to Earth in a special capsule that will withstand re-entry into Earth's atmosphere and soft landing.



The Comet Nucleus Sample Return mission will use solar electric, or ion, propulsion.

The CNSR mission will use several advanced space-age technologies. For one thing, it will use ion propulsion to reach its destination. Ion propulsion was recently tested in space for the first time by the Deep Space 1 spacecraft and proved itself to be the fastest, most fuel-efficient means of space travel yet invented.

CNSR will also use an advanced solar array to convert sunlight to electricity to power its computers, heaters, and ion engine. Anchoring the spacecraft to the surface of the

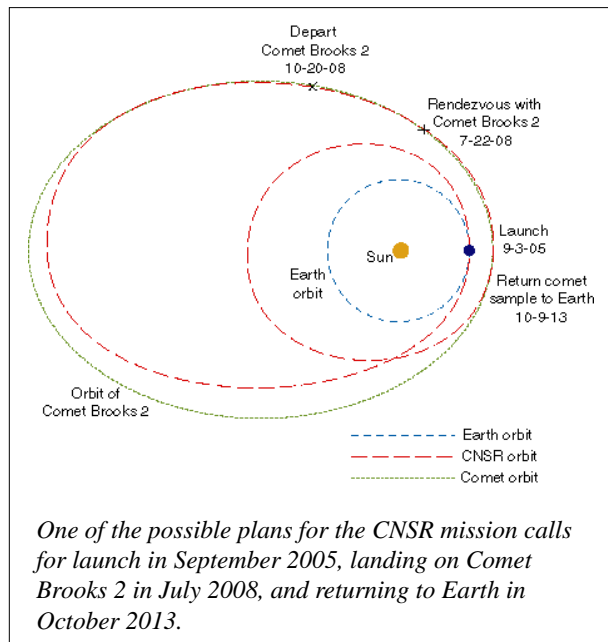


Comet Nucleus Sample Return mission will use a new type of lightweight, high-power solar array to convert sunlight to electricity.

comet so that the sample drill will work will also be a big challenge. We don't even know what the surface is like. It could be hard as concrete or soft as cotton.

And keeping the comet sample safe and frozen for its several-year journey back to Earth will present another set of problems to solve.

This new mission will help us learn a great deal about the formation of the solar system and the origin of the chemical building blocks of life from one of these cometary "time capsules."



One of the possible plans for the CNSR mission calls for launch in September 2005, landing on Comet Brooks 2 in July 2008, and returning to Earth in October 2013.