Size Models: The Diameters of the Planets

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Background:

Planetary scientists sometimes use the Earth as a reference point in making measurements. For example, the distance between the Earth and the Sun is called an Astronomical Unit or AU, and is used to describe distances in the Solar System. Another example is Earth's atmospheric pressure (14.7 lb per square inch); it is referred to as one atmosphere (1 atm), and the atmospheric pressures of the other planets are sometimes expressed in this unit. In the following tables, we use Earth's diameter and Earth's distance from the Sun as base units for constructing scale model diameters of the planets and scale model distances from the Sun to the planets and to objects beyond the Solar System. You can think of these as roadmaps of the Solar System and the Universe. Below are two models of the Solar System, the first representing the diameters (sizes) of the planets and the second representing the distances to the planets.

Materials for Size Model of the Solar System:

Beads and Styrofoam balls to match the sizes of the planets (see Table I)

Procedure:

You will need about 11 girls for this activity. Ask the girls which star is closest to us. They should answer the Sun! Have one girl (about 5 feet tall) stand to the left of what will eventually be a line of 11 girls.

Next, ask the girls which planet is closest to the Sun. They should answer Mercury. The one who answers first should become Mercury and stand next to the "Sun." We usually do left to right as you are facing them since that is the way one usually sees the Solar System illustrated in books. Hand that girl the bead (example below) that represents Mercury. Explain to them that you are creating a scale model of the sizes of the planets in the Solar System. Continue this with Venus, Earth (and the Moon), Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. **Note:** there is still disagreement as to how one should classify Pluto. Based on its physical properties (atmosphere, active surface, etc.) and not on just its size and location in the Solar System. Many planetary astronomers still consider Pluto to be a planet. Just a small one!

Size Model:

The table on the following page (Table I) shows the names of the planets and their true diameters (in miles and kilometers). Column 4 is to be used for determining the sizes of the planets relative to Earth (Earth = 1.0). Column 5 is to be used for determining a scale model of the planetary sizes relative to a 1.28-cm (0.5-in) Earth. This is the scale model that we will use in class. This is a 1:1,000,000,000 scale where 1cm represents 10,000 km.

TABLE I
MAKING A MODEL OF THE DIAMETERS OF THE PLANETS AND THE SUN

Scale: One Earth Diameter = 1.28 Centimeters (0.5 in)
(**1 cm = 10,000 km**, 1:1,000,000,000)

Planet	Diameter Kilometers	Diameter Miles	Dia. Relative to Earth	Diameter to Scale	Object
Sun	1392000	865000	108.7	139.20 cm	5-ft person
Mercury	4878	3031	0.38	0.49 cm	5 mm bead
Venus	12104	7521	0.95	1.21 cm	½ inch bead
Earth	12756	7926	1.00	1.28 cm	½ inch bead
Moon	3476	2160	0.28	0.34 cm	3 mm bead
Mars	6794	4222	0.53	0.68 cm	7 mm bead
Jupiter	142984	88730	11.21	14.3 cm	6 in ball
Saturn	120536	74940	9.45	12.1 cm	5 in ball
Uranus	51118	31763	4.01	5.11 cm	2 in ball
Neptune	49528	30775	3.88	4.95 cm	2 in ball
Pluto	2302	1430	0.18	0.23 cm	2 mm bead

Closure:
Remind them that this is just a scale model of the sizes of the planets. Ask them what the beads and Styrofoam balls represent [the relative sizes of the planets]. Then ask them what is not represented by this model (what is not correct) [planets not lined up like this and their distances are greater than in the model].

Distance Model of the Solar System

Materials for Distance Model of the Solar System:

½-inch bead (the Sun)
½-inch dowels (2), 1 foot long (for Mercury Venus, Earth, and Mars). **Note:** dowels, or something similar, are used to wrap the macramé around
¾-inch dowel, 15 inches long (for Jupiter)
1-inch dowel, (3 15-inch and 1 18-inch) (for Saturn, Uranus, Neptune, and Pluto)
macramé (thin) for Mercury, Venus, Earth, and Mars
macramé (medium) for Jupiter
macramé (thick) for Saturn, Uranus, Neptune, and Pluto

Procedure:

You will need at least 10 girls for this activity. Other girls can become asteroids and comets. If you have just done the size model, ask the girl who is Mercury to get in front of the "Sun" and walk away from the Sun to what they think is the "correct" distance (on this model) from the Sun. Have the others coach them to get the "correct" distance. After a few guesses, tell them that, on this scale, Mercury would be almost 200 feet away! Therefore, you are going to use a smaller scale model to represent the distance to the planets. If they ask, Pluto is over 4 miles away on the original!

The next part of the activity is best done outside. The girl who was the Sun should be given the ½-inch bead. Tell the girls that this bead now represents the size of the Sun, 1/100 the original scale.

Next, ask the girls which planet is closest to the Sun. They should answer Mercury, as before. The one who answers first should become Mercury. Hand that girl the string that represents the distance to Mercury. Explain to them that you are creating a scale model of the distances to the planets in the Solar System. Continue this with Venus, Earth (and the Moon), Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. Have them go out in different directions and either ask them or tell them why they are doing this [planets are never exactly lined up in a row]. **Caution:** "Pluto" will be about 200 feet away and it takes time for them to get there and even longer to rewind the macramé!

Distance Model:

As we saw with the size model, we cannot do a reasonable scale model of planetary distances on the same scale as we do planetary diameters. We use a scale that is 100 times smaller than in Activity 1—1:100,000,000,000 in Activity II. For example, the scale distance from the Sun to the Earth (1 AU = 149,600,000 km = 14,960,000,000,000 cm) is 150 cm (149.6 cm, rounded; 1 cm = 1,000,000 km).

Table II gives the true (mean) distances of the planets from the Sun: Columns 2 and 3, in millions of miles and kilometers; Column 4, their distances in Astronomical Units (1 AU = the mean distance of Earth from the Sun); and Column 5, their distances in solar diameters (e.g., 107 Suns laid side-by-side would be needed to stretch from the Sun to Earth). Column 6, light time (minutes), gives the time it takes light to travel from the Sun to each planet (186,000 miles or 299,800 km in a second). **Note:** for the Moon distances are from Earth, distance in Earth diameters, light time from Earth, and time it takes to orbit the Earth.

TABLE II: PLANETARY (SOLAR) DISTANCES

PLANET	DISTANCE (Millions)			Solar Diameters	Light Time (Min.)	Distance to Scale (macramé length)
	Miles	Km	AU			
Mercury	36.0	57.9	0.387	42	3.2	58 cm
Venus	67.2	108.2	0.723	78	6.0	108 cm
Earth	93.0	149.6	1.000	107	8.3	150 cm 1.5 m
Moon	0.238	0.383	0.003	30[a]	1.3[b]	
Mars	141.7	228.0	1.524	164	12.7	2.3 m
Jupiter	483.7	778.4	5.203	559	43.3	7.8 m
Saturn	885.2	1425.0	9.523	1025	79.5	14.2 m
Uranus	1785.0	2873.0	19.210	2061	159.7	28.7 m
Neptune	2797.0	4501.0	30.090	3230	250.4	45.0 m
Pluto	3670.0	5906.0	39.482	4238	328.6	59.0 m

[a]Relative to diameter of Earth
[b]Number of seconds for light to travel from the Earth to the Moon

Closure:
Remind them that this is a scale model of the distances from the Sun to the planets in the Solar System. Tell them that, as they stand at the ends of the macramé and look back at the "Sun," the bead is what the Sun would look like from that planet. Also, while they are not lined up, in the real Solar System, the individual planets are all moving around the Sun at different speeds. Finally, on this scale, the next nearest star is about 250 miles away. For older girls, you might mention that the orbits of the planets are not circular and that this model is showing just the average distances of the planets from the Sun.


Scale model of planet diameters


Scale model of planet distances

FASTER THAN THE SPEED OF LIGHT

Background:

In the Junior Space Science Investigator Badge Requirement Booklet, one of the activities is called "Find Your 'Girl Scout Minute'" to create a girl's personal unit of measurement. The Distance Model of the Solar System can be used in a similar fashion to demonstrate the time it takes to send a signal from the planets back to the Earth. Astronomers use the speed of light as a way of measuring the distances to the stars and to distant galaxies. A light-year is the distance the light travels in a year, 9.46 trillion km or 5.88 trillion miles. The nearest star, Proxima Centauri, is 4.24 light-years away! While we generally use kilometers or miles when we talk about distances in the Solar System, we can also use light-minutes. This measurement is important for astronomers who are sending instructions to and receiving data and images from spacecraft. If one sends a signal from the Earth to a rover on Mars, at the speed of light (299,792 kilometers per second or 186,282 miles per second) it would take anywhere from 3.0 minutes up to 22.4 minutes for the signal to reach the rover on Mars, depending on where the Earth and Mars were in their orbits around the Sun. In this activity, we will send signals from each of the planets that are beyond the Earth so that they all reach the Earth at the same time. In astronomy, we call this "lookback time"—when we receive the light from a planet or star, how long did it take for that light to get to us? In the case of Proxima Centauri or a planet in orbit around it, this would be 4.24 years! Planet to Sun light-minute times are listed in Table II.

Materials for Faster Than the Speed of Light:

the macramé model of the Solar System
masking tape
21 markers, such as small (sports training) "traffic cones"
stopwatch

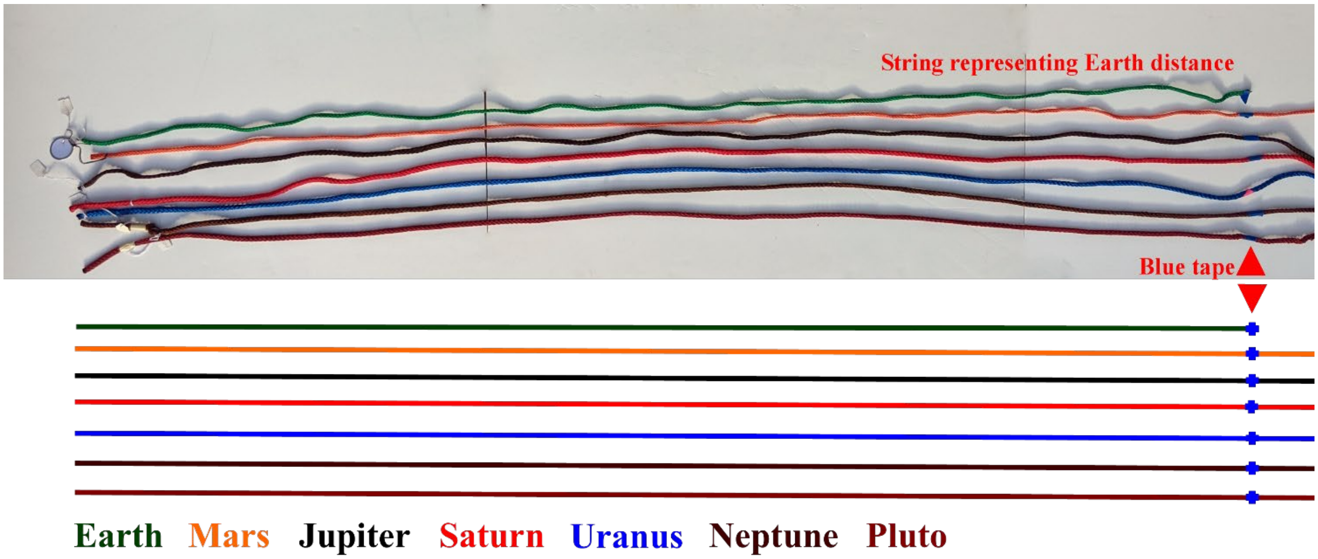
Procedure:

In preparation for the activity, roll out and line up all the macramé strings in parallel lines as straight as possible. You may want to hold the near ends of all the strings with a rock to keep them from moving. At the end of the Earth string, put strips of tape around the Mars, Jupiter, Saturn, etc. strings. Move on to the end of the Mars string and put strips of tape at this distance around the Jupiter, Saturn, etc. strings. Continue this until you have put a strip of tape around the Pluto string to mark the distance of Neptune. **Note:** when you do this activity, you may find that the distances may not align perfectly from one planet to another. String stretches and when strung out, may not be perfectly straight or may stretch out a little. Assume that distances are accurate to about 6 inches to a foot. This is fine as the orbits of the planets are not circular and we are using only the mean distances of the planets from the Sun.

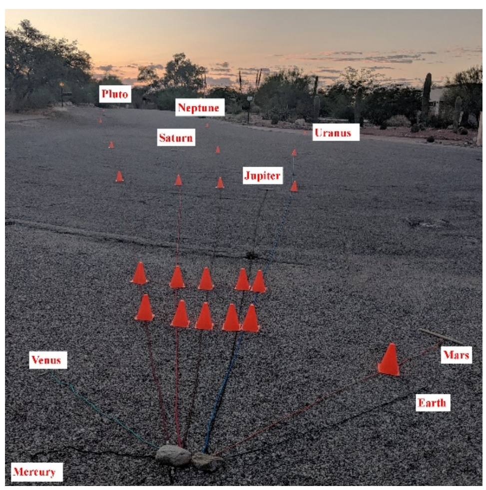
Explain to the girls that, once they get to their final locations, the girl who is Pluto will "send a signal" (start walking back along the string) toward the Earth. Proceed with the activity as you would in the previous section. Once the girls have unrolled their strings, have two or three other girls put the cones out at the locations of the tape marks.

Once the cones are in place, tell the girl who is Pluto to send her signal (walk back along the string). When she gets to the first cone, Neptune's distance, the Neptune girl should send her signal (start walking). They should continue doing this for Uranus, Saturn, etc. They should try as best as they can to keep the same pace (this is not a race) so that they arrive at the last cones at the same time and stop there. For most of them, they will only be at the distance of the orbit of the Earth and the Earth may be on the far side of the Sun. In reality, they would have to walk a little more to reach the Earth.

If there are enough girls, two of them (or an adult) can time how long it takes for the messages from each of the planets to reach the Earth. You or the girls can calculate how fast they are going in this model Solar System relative to a real message going at the speed of light. We have done this twice and it took both Pluto walkers almost exactly a minute to walk from Pluto to the Earth. If you compare this to the light time in Table II, the walkers were going 320 times the speed of sound (328 minutes minus 8 minutes)!



Showing the blue tape marks for planet distances



All of the planets, with sports training traffic cones marking planet distances

Closure:

There are several things that the girls will learn from the two scale models of the Solar System and then the activity of sending a message to the Earth.

- The diameters of the planets are much smaller than the distances between them.
- A reinforcement of the fact that the planets all orbit the Sun and do not all line up in one direction.
- When you are communicating with a spacecraft in orbit or on the surface of another planet, there may be a delay of minutes to hours before a signal gets to or from the spacecraft. As described in the Background section. Sending a command to a Mars rover would take anywhere from 3 minutes up to 22 minutes (when Mars is on the far side of the Sun).