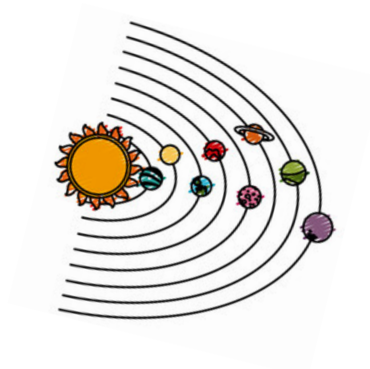
Saturday Morning Astrophysics at Purdue

Scaling Our Solar System

Relative Size and Distance Between Our Planets

Introduction



In 2003, the planet Mars was closer to Earth than it had been in over 50,000 years. Yet it was still 35,000,000 miles away! If you wanted to travel to Mars, in the same jet you might fly to Europe or Asia, you would have fly continuously for over *six years*!

It is impossible to show the relative sizes of our planets on the same scale as the distances between them in a single image on a page. Textbook illustrations can be misleading, confusing and even confirm our misconceptions.

For example, illustrating the distances between the planets, based on an accurate and visible representation of their relative size, would require a page larger than a football field. If you tried to show the relative distances on a single page, the sizes of the planets would be too small to see, even with a microscope.

In this lesson, you will create three dimensional scale models of the planets. Then, you will go outside and model the distances between them ***on the same scale***!

Learning goals

1. Devise a scale and construct models that accurately represent the relative sizes of the sun and the planets in our solar system.
2. Create a model that represents the relative distances among the sun and planets in the same scale as their relative sizes.

Materials (per group)

Play-Doh (small 2 oz jar) or modeling clay
Long measuring tape [1]
String or yarn (about 1 m)
Ruler (cm/mm)
Calculator
Transparent plastic tape
Planet orbit markers[2]
Masking tape
Planet images[3]
Spherical balloon (10-12 inch)
Internet Access
Steps Between Planets (data table)

(1) You will need to measure a distance of 50 feet. You can use a yardstick, or measuring tape of any length to get to 50 feet.
(2) Planet orbit markers will locate the position of the planetary orbits relative to your sun (long bamboo skewers, driveway or sidewalk markers, PVC pipes) or 2 L bottles half full of water to keep them in place, or other markers). Tape the planet images or names to your markers before you go out into the field.
(3) Electronic PDF images of the will be provided. If you do not wish to print the files, a simple paper label with the name of the planet will be fine.

Procedure

Take a look at the helpful tips in the **Notes** section near the end of this lesson.

Activity 1 – Setting the scale

The largest object in our solar system is our sun. The sun has a diameter of 1,391,900 km. That's over 850,000 miles! Our sun is the Earth's nearest star. Let's start with the sun.

1. Blow up a medium sized spherical balloon to a diameter of about 10 inches. This will be your scale model "sun". (If you do not have a balloon, a paper disk will be fine.)
2. Measure and record the **circumference** of your sun with a string and ruler. (Wrap a string around the widest part of the balloon, mark the ends and measure the length of the string with a ruler.)

   Circumference of your sun = ______________ in
3. Calculate the **diameter** of your sun to the nearest 0.1 inch and record that value. (π = 3.14)

$$Diameter\ of\ your\ sun\ = \frac{Circumference\ (in)}{\pi} = \underline{\hspace{3cm}}in$$

4. Then, determine the diameters of each of the planets, scaled to the size of your sun.
   a. Use the link, http://www.exploratorium.edu/ronh/solar_system/, or just search, "*exploratorium solar system*" to find the link.
   b. Enter the value for the measured diameter of your sun under ***Body Diameter*** (in **inches**).
   c. Click ***Calculate***.

   Write the diameter pf each planet in the table (***use the mm values***):

Object	**inches**	**mm**
Sun	________	
Mercury		________
Venus		________
Earth		________
Mars		________
Jupiter		________
Saturn		________
Uranus		________
Neptune		________

5. Take a look at your data.
    a. What is the largest planet in our solar system?
    b. Which is the smallest planet?
    c. Which planet is Earth's nearest neighbor?
    d. What is the largest object in our solar system?

Activity 2 – Scale model planets

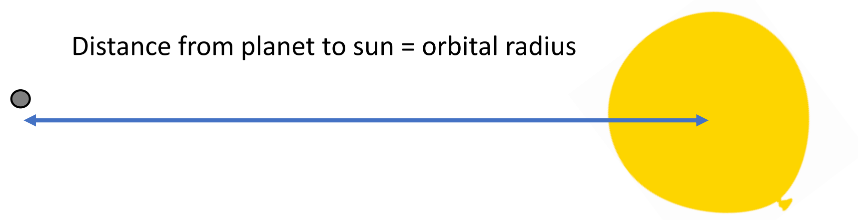
Your goal will be to create a clay model of each of the eight planets, *all to the same scale*. Work as a team if you can, it will be more fun. You will need some Play-Doh and a ruler.

1. Roll bits of Play-Doh or clay to make each planet to the correct size (in mm) according to the table above.
2. Assemble the 8 planets in order, on a sheet of paper. You may want to tape them to the paper to keep them in place.
3. Compare your models and describe what you find. What do you find interesting?

Mercury	**Venus**	**Earth**	**Mars**
Jupiter	**Saturn**	**Uranus**	**Neptune**

Activity 3 – Scaling the distances between the planets – orbital radii

Before you go outside to arrange your solar system, you need to know how far each planet should be from your sun. In other words you need to know the **orbital radius**.



Refer back to the same ***Exploratoriun calculator*** page you used previously to locate the diameters of the planets.

Using the distances from the sun to each planet, complete **Column 1** (**Scaled Orbit Radius**) on the **Steps Between Planets** table (supplemental sheet).

However…, you need to know ***how many steps*** you have to take for the distances between the planets.

1. In an open space, lay a piece of tape on the floor to mark a starting point (0 feet).
2. Measure a distance of 50 feet and mark that spot with another piece of tape.
3. With an even and **consistent** stride, count the number of steps you take, between the pieces of tape and record this number in the table below. (Don't walk heel to toe, it will take forever! Walk like you normally would).
4. Repeat two more times and calculate (to the nearest foot) the average of your trials. Your average value is the number of steps you will use when you set up your model outside.

Trial	# Steps for 50 feet
1	
2	
3	
Average	

5. Now, calculate the number of steps you need to take to reach each of the planets.

   For example, if the distance, **Sun to Mercury is 34 feet**, and your average is

   21 steps per 50 feet,

$$34\ feet\ to\ Mercury \times \frac{21\ steps}{50\ feet} = 15\ \ steps\ to\ Mercury$$

6. Calculate and enter the values for each planet in **Column 2** (Scaled Orbit Radius # of Steps). You will need to know the number of steps for yourself, since everyone's steps are different.
7. Complete **Column 3** (Number of Steps to NEXT Planet), to find out how many steps you will take from one planet to the next. Knowing this, you do not have to start at the sun from zero every time.

Activity 4 – Arranging the planets in order outside

Now, you can head outside. Your goal will be to create an actual scale model of the solar system, accurately spacing as many planets as you can, to the correct distances between them. You will need:

- Your Steps Between Planets data table
- Planet orbit markers
- Your sheet of planets (This is optional, but it does give a proper perspective to actually tape your planets to the orbit markers you are using. Bring some clear tape.)

Think about safety (and other people's space and property)….

- You will need a large area to do this (the length of 3-4 football fields); be mindful of your surroundings.
- Respect other people's property.
- Don't go alone. Find a responsible adult to accompany you. Better yet, do this part with friends or classmates.

And then head outside.

1. Place the sun on a stand at the far end of the space you have available.
2. Staying as a group, step off the correct distance to the first planet (Mercury).
3. Place Mercury in position, and then walk to place Venus in position.
4. Continue placing as many planets as you can, given the space you have available.

5. Get a picture! Before you go back inside, get your friends to go back and stand at each of the planets with their arms outstretched so you can see them, and have someone take a picture from the viewpoint of the sun.

(Optional) Activity 5 – Defining the AU

Scientists often create and define units of measurements as a matter of convenience.

One convenient unit of measurement in astronomy is the **Astronomical Unit** (AU). An AU represents the mean distance between the Sun and the Earth. This is a useful measure for distances between objects relative to the scale of our solar system. Other arbitrary units of measurement in astrophysics are the light year, and the parsec (pc), used to measure distances at scales far beyond our solar system.

You will need to devise a method to easily approximate "**one AU**," based on the scale you have established. You'll need some masking tape and a long measuring tape.

Refer back to your **Distances Between the Planets** table. Using the distances from the sun given for each of the planets (Column 1), calculate the distance from the sun (in AUs) for each of the planets, based on defining the Earth's distance as 1 AU. Write these values in **Column 4** (Distance from the Sun in AU)

$$AU\ distance\ of\ planet\ to\ sun = \frac{scaled\ orbit\ of\ the\ planet\ (feet)}{scaled\ orbit\ of\ Earth\ (feet)}$$

Wrapping up – Some things to think about

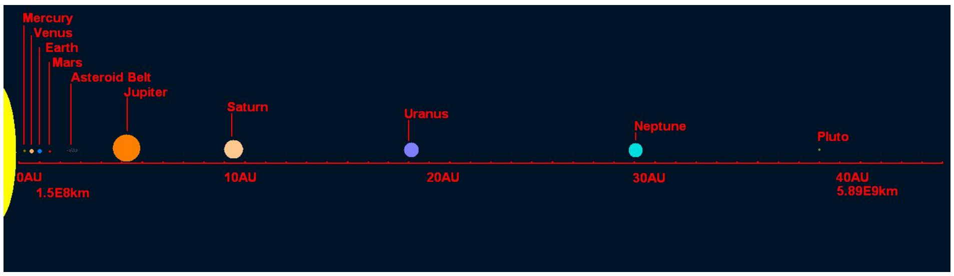
1. The planets at this scale are pretty small. Why do you think we don't just adjust the scale of the sun to make them bigger?

2. What's wrong with our model? In what ways do you think our model of the solar system is not a very accurate representation of reality?

3. In what ways do you think our solar system model reasonable accurate?

Challenge Yourself – How Small Are We, Really?

An astronomical unit (AU) is a convenient unit of measurement for comparing distances among planets. The distance from the Sun to Earth is 1 AU. For convenience, let's assume that in the following drawing 1 AU is 1 mm.



On this scale, (where 1 AU = 1 mm), how far away would Neptune be? Think about creating a model using a roll of cash register tape. Would one 30 m roll of paper be enough?

How many meters of paper would Alpha Centauri (the nearest star) require? The black hole at the center of our galaxy? The Andromeda Galaxy?

You will find the following information useful:

Alpha Centauri is 4.3 light years away

The center of our galaxy is 26,000 light years away

The Andromeda Galaxy is 2.54 x 10^6 light years away

1 light year is 63,200 AU

For the Teacher - Wrapping up (Doing this lesson in the classroom)

What's wrong with our model?

Models are limited representations of reality. In this case, while the sizes and distances between the planets might be reasonably accurate, the planets are not all in the same plane (ecliptic). Nor are they ever all lined up.

Pedagogy

- Work in teams of 3 or 4, each team doing each activity; or, divide the activities among the teams, each team responsible for an activity.
- Don't spend too much time making the clay models; do it "quick and dirty"; students will tend to be too elaborate in detail (color, etc.)
- Explain the data table. the "nearest foot" is accurate enough.
- Have the student teams work together in setting the planets outside; move from one planet to the other as a group.
- When students go to the Exploratorium site, fill in both the diameters and the distances at the same time. That would save having to go back to the website again.
- Students will be taking 1000+ steps. Demonstrate normal consistent, walking, not foot to foot measures. If students have a measure that is in gross disagreement with the others, they can discard and repeat that measurement.
- Before going outside, talk about safety; what to do if you run out of room; stay together as a group.
- Cover expectations, and what to do when finished.
- Back at the room; disassemble the stands (TAs can help) and return to tubs.
- Have students do Activity 5 (Defining the AU) or the Challenge Yourself activity as an optional activity when they return to the room, until all groups return.

Further thoughts:

1. You will need lots of space.

   Typically, with a 10 - 11 inch sun, you will reach Saturn at 1000 – 1200 feet. You can make the sun slightly smaller, but the planets will be really, really tiny.

2. Circumference and diameter of your sun.

   Your balloon is a "model" of the sun for your solar system. It will not be a true sphere, but it will serve the purpose for our solar system model. Spheres have an infinite number of cross sections, each with a different circumference. You should find the cross section with the largest area (and the greatest circumference), what mathematicians would refer to as the "great circle" of a sphere, the cross section that goes through the center of the sphere.

3. Calculating diameter of the sun.

   You need to know the diameter of your sun in order to determine the relative diameters of the planets in your model solar system. We will use the constant, pi (π) to do that. Actually though, pi is no magic number. It is just the ratio of the circumference of a circle, divided by the diameter of the circle, two easily measured quantities. Try it for yourself. Use a string and ruler to measure the circumference around common round objects (jar lids, food cans, etc.), or different size circles you draw with a compass. Measure the diameters and divide. Repeat this multiple times for different objects, take the average and see what you get. Are your answers approximately the same? Do you think your answer would be more accurate if you averaged 100 measurements? Or, 1000?

4. Have a strategy in advance for getting back the sticks/planet stands when students return to the classroom.
5. Get the balloons before coming back into the building!

Note on the Challenge Yourself activity:

Initial thoughts might be to use a roll of cash register tape, or a line on the board. However, even if we take 1 AU to be 1 mm, the nearest star would be 270 m away; the center of our galaxy, a mere 1.6 x 10^6 m out there!

Additional resources

https://en.wikipedia.org/wiki/Pale_Blue_Dot

https://www.youtube.com/watch?v=wupToqz1e2g

Carl Sagan's Pale Blue Dot (the whole story) https://vimeo.com/240133809

If the Moon Were Only One Pixel;
https://www.google.com/search?q=if+the+moon+were+only+one+pixel&oq=if+the+moon+were+onl&aqs=chrome.0.0j69i57j0l2.5694j0j4&sourceid=chrome&ie=UTF-8