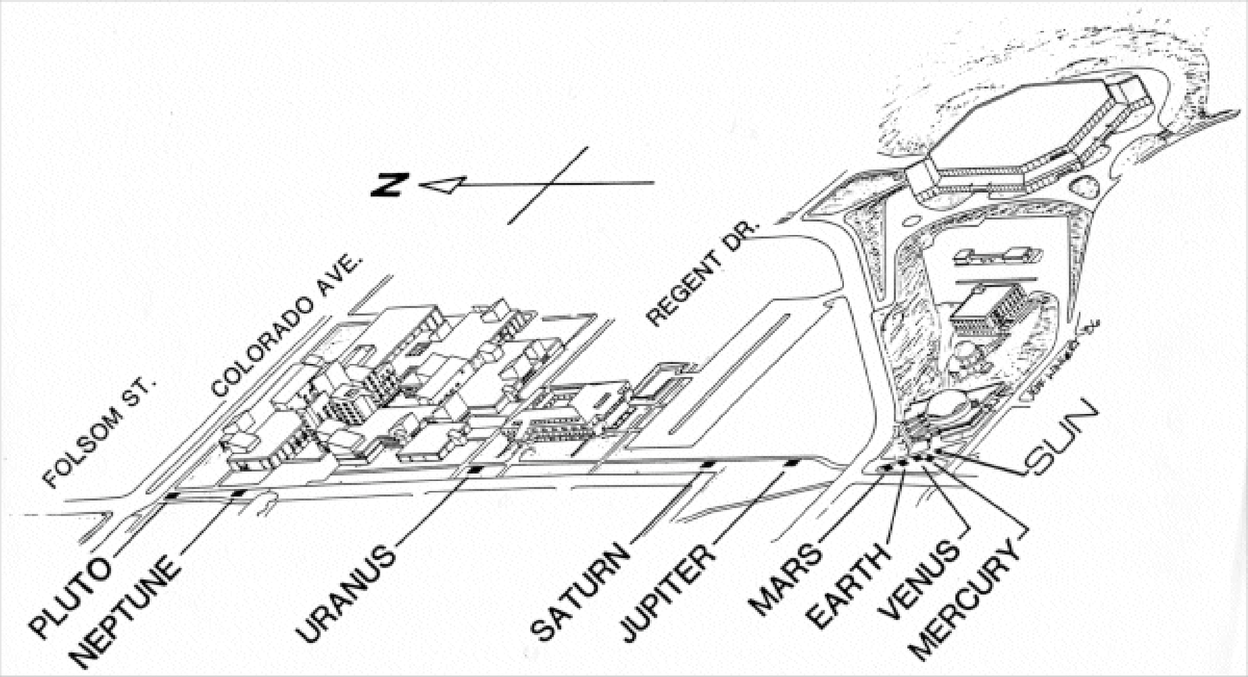
THE COLORADO MODEL SOLAR SYSTEM

SYNOPSIS: A walk through a model of our own solar system will give you an appreciation of the immense size of our own local neighborhood and a "feel" for astronomical distances.

EQUIPMENT: This lab write-up, tape measure, a pencil, perhaps a calculator, and walking shoes.

LENGTH: One lab period.

Astronomy students and faculty have worked with CU to lay out a scale model solar system along the walkway from Fiske Planetarium northward to the Engineering complex (see figure below). The model is a memorial to astronaut Ellison Onizuka, a CU graduate who died in the explosion of the space shuttle Challenger in January 1986.



The Colorado Scale Model Solar System is on a scale of 1 to 10 billion (10^{10})!!! That is, for every meter (or foot) in the scale model, there are 10 billion meters (or feet) in the real solar system.

Note: A review of scientific notation can be found on page 15 of this manual.

All of the *sizes* of the objects within the solar system (where possible), as well as the distances between them, have been reduced by this same scale factor. As a result, the apparent *angular sizes* and separations of objects in the model are accurate representations of how things truly appear in the real solar system.

The model is unrealistic in one respect, however. All of the planets have been arranged roughly in a straight line on the same side of the Sun, and hence the separation from one planet to the next is as small as it can possibly be. The last time all nine planets were lined up this well in the *real* solar system, the year was 1596 BC!

In a more accurate representation, the planets would be scattered in all different directions (but still at their properly-scaled distances) from the Sun. For example, rather than along the sidewalk to our north, Jupiter could be placed in Kittridge Commons to the south; Uranus might be found on the steps of Regent Hall, Neptune in the Police Building, and Pluto in Folsom Stadium. Of course, the inner planets (Mercury, Venus, Earth, and Mars) will still be in the vicinity of Fiske Planetarium, but could be in any direction from the model of the Sun.

<u>Before you begin take a look at Tables 1 and 2 at the end of this lab</u>. As you walk through the model solar system you will need to fill in the tables in addition to answering the questions below.

I. The Inner Solar System

Read the information on the pyramid holding the model Sun in front of Fiske Planetarium. Note that the actual Sun is 1.4 million km (840,000 miles) in diameter – but on a one-ten-billionth scale, it's only 14 cm (5.5 inches) across.

I.1 Designate one person in your group to count paces between the planets and another person to time the trip. Walk at a normal pace between the Sun and Mercury and record your paces and time values in columns 1 and 2 of Table 1. Use the information given on the plaque to fill in columns 3-8 of Table 1 and all columns of Table 2. Repeat these steps for Venus and the Earth.

The *real* Earth orbits about 150 million km (93 million miles) from the Sun - a distance known as an *astronomical unit*, or *AU* for short. The AU is very convenient for comparing relative distances in the solar system by using the Earth-Sun separation as a "yardstick".

I.2 Use the tape measure provided to measure the distance from the Sun to the Earth. Is this distance an accurate representation of the scale of the model solar system? Explain!

I.3 What fraction of an AU does one of your paces correspond to in the model?

I.4 For the remainder of the lab you will use the fraction you calculated for I.3 to determine the distance in AU between the <u>**Sun**</u> and each of the planets and record it in column 9 of Table 1. It will not be necessary to pace from the Sun to each planet, only to keep track of the cumulative distance traveled in a <u>straight line</u> (i.e. after pacing from the Sun to the Earth, pace from the Earth to Mars and add the two values together to get the proper distance).

I.5 Convert your measured values for the distance to each planet from AU to km and record them in column 10 of Table 1. Show your conversion in your lab report for one of the values in this column.

Another way to describe distance is to use "light-time" - the time it takes light, traveling at 300,000 km/second (186,000 miles/sec, or 670 million mph!) to get from one object to another. Since light travels at the fastest speed possible in the universe, light-time represents the shortest time-interval in which information can be sent from one location to another.

Sunlight takes 500 seconds, or 8 1/3 minutes, to reach the Earth; we say that the Earth is 8.33 light-minutes from the Sun. Remember, *the light-minute is a measure of distance!*

I.6 (a) Since light takes 500 seconds to travel that same distance in the *real* solar system, how many times "faster than light" do you walk through the model? Explain.

(b) As you travel through the solar system, record (column 11 of Table 1) the distance from the Sun in light minutes for each planet by keeping track of the cumulative time it has taken to reach each planet.

Finally, take a closer look at Earth's own satellite, the Moon - the furthest object to which mankind has traveled "in person". It took three days for Apollo astronauts to cross this "vast" gulf of empty space between the Earth and the Moon.

I.7 (a) How many years has it been since mankind first walked there?

(b) At the scale of this model, estimate how far (in cm or inches) mankind has ventured into space.

I.8 Assuming that we could make the trip in a straight line over the smallest possible separation (neither of which are feasible), roughly how many times farther would astronauts have to travel to reach even the *nearest* planet to the Earth?

Stand next to the model Earth and take a look at how the rest of the solar system appears from our vantage point (remember, since everything is scaled identically, the apparent sizes of things in the model are the same as they appear in the real solar system).

I.9 Stretch out your hand at arm's length, close one eye, and use your index finger to estimate the angle, in degrees, of the diameter of the model Sun as seen from Earth.

Note: see page 28 of this manual for a "handy" way to estimate angles.

I.10 If it's not cloudy, use the same technique to cover the real Sun with your outstretched index finger. Verify that the apparent size of the *real* Sun as seen from the *real* Earth is the same as the apparent size of the model Sun as seen from the model Earth.

Caution! Staring at the Sun can injure your eyes - be sure the disk of the Sun is covered!

Off in the distance to the north, along the walkway leading to the Engineering Building, you can just see the pedestals for the next two planets, Jupiter and Saturn.

I.11 Use your hand to measure the angle between Jupiter and Saturn, as seen from the model Earth. (Remember, if this were the *real* solar system, 10 billion times bigger in all directions, the angle between them would still be the same!)

Now proceed to Mars. From now on you do not need to start at the Sun to count your paces, but remember that the paces and times recorded in Table 1 are measured **from the Sun**.

I.12 (a) Mars is depicted in the model at its closest approach to Earth (that is, both the Earth and Mars are on the same side of the Sun). In this configuration, what is the distance, in *astronomical units*, between Earth and Mars?

(b) What is this distance expressed in *light-minutes*?

On July 4th, 1997, the Pathfinder spacecraft landed a rover named Sojourner on the surface of Mars. The vehicle was equipped with a camera and an on-board computer that enables it to recognize obstacles and to drive around them.

I.13 Explain why Sojourner was not steered remotely by an operator back on the Earth.

II. Journey to the Outer Planets

As you cross Regent Drive heading for Jupiter, you'll also be crossing the region of the *asteroid belt*, where thousands of "planetoids" or "minor planets" can be found crossing your path. The very largest of these is Ceres, which is 760 km (450 miles) in diameter.

II.1 If the asteroids are scaled like the rest of the solar system model, would you be able to see Ceres as you passed by it? Show a calculation to support your answer.

II.2 Use your hand measurement to compare the apparent size of the Sun as seen from Jupiter with your earlier measurement (in I.9) from the Earth. (You'll have to walk a few paces to the west to avoid the intervening evergreen, which plays no useful role in our model.) Hint: How much further away from the Sun are you now than you were when you were at the Earth.

Next stop, the Ringed Planet Saturn - the most distant object in the solar system that you can see from Earth without a telescope.

II.3 (a) Earlier (in II.11) you found that Jupiter and Saturn *appeared* to be very close to each other as seen from Earth. How far apart are they *really*, expressed in astronomical units?

(b) Compare the size of the entire inner solar system (from the Sun out to Mars) with the empty space between the orbits of Jupiter and Saturn. Give your answer as a ratio.

II.4 Compare the diameter of Jupiter to the diameter of Saturn's rings (Be careful! The value listed on the plaque is the width of the rings, **NOT** the diameter). Which do you think would appear wider (through a telescope) from Earth: the ball of Jupiter, or the rings of Saturn? (Hint - consider distance from Earth as well as actual size). Support your answer with numbers.

Now continue the journey onward to Uranus.

II.5 William Herschel discovered Uranus in 1781 (all of the planets interior to Uranus could be easily seen by the naked eye). How many complete orbits has it made around the Sun since its discovery?

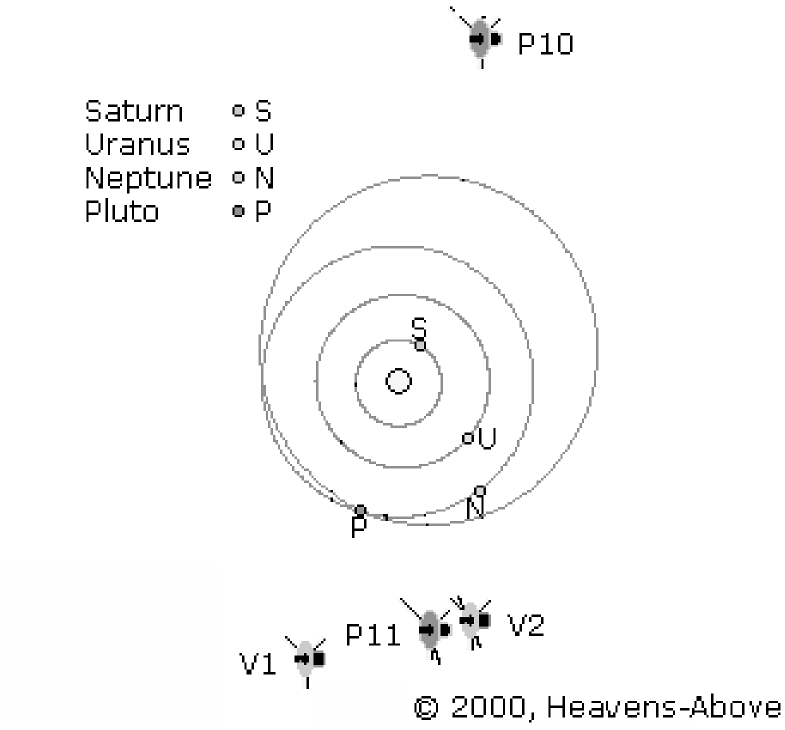
Proceed to Neptune.

II.6 How many complete orbits has Neptune made around the Sun since its discovery?

Now begin the final walk to Pluto. When you get there, you'll be standing three-tenths of a mile, or **one-half of a kilometer**, from where you started your journey. You'll also be standing about 33 times further away from the Sun than when you left the Earth.

II.7 You may have been surprised by how soon you arrived at Pluto after leaving Neptune. Read the plaque, and then explain why the walk was so short.

II.8 Although you can't actually see the model Sun from this location, use what you learned in questions I.8 and II.2 to determine the angular size of the Sun as it would be seen from the surface of Pluto.



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III. Beyond Pluto

Although we've reached the edge of the solar system visible through a telescope, that doesn't mean that the solar system actually ends here - nor does it mean that mankind's exploration of the solar system ends here, either.

Down by Boulder Creek to your north, at 63 AU from the Sun, Voyager II is still travelling outwards towards the stars, and still sending back data to Earth.

III.1 Voyager II uses a nuclear power cell instead of solar panels to provide electricity for its instruments. Why do you think this is necessary? (Hint: Use your answers from questions I.8, II.2, and II.8 to support your position)

In 2000 years, Comet Hale-Bopp will reach its furthest distance from the Sun (*aphelion*), just north of the city of Boulder at our scale. Comet Hyakutake, the Great Comet of 1996, will require 23,000 years more to reach *its* aphelion distance - 15 miles to the north near the town of Lyons.

Beyond Hyakutake's orbit is a great repository of comets-yet-to-be: the *Oort cloud*, a collection of a billion or more microscopic (at our scale) "dirty snowballs" scattered over the space between Wyoming and the Canadian border. Each of these is slowly orbiting our grapefruit-sized model of the Sun, waiting for a passing star to jog it into a million-year plunge into the inner solar system.

And *there* is where our solar system really ends. Beyond *that*, you'll find nothing but empty space until you encounter Proxima Centauri, a tiny star the size of a cherry, 4,000 km (2,400 miles) from our model Sun! At this scale, Proxima orbits 160 kilometers (100 miles) around two *other* stars collectively called Alpha Centauri - one the size and brightness of the Sun and the other only half as big (the size of an orange) and one-fourth as bright. The two scale model stars of Alpha Centauri orbit each other at a distance of only 1000 feet (0.3 km).

III.2 At the scale of the model solar system, where on Earth would you find Proxima Centauri? (Hint: Try http://www.indo.com/distance/ to find the distance between any two cities.)

III.3 How does the distance between the two stars called Alpha Centauri compare to the size of our solar system? Calculate. How do you think our solar system would be different if the sun had a companion at this distance?

III.4 In the movie *Contact*, Jodie Foster's character received signals from Vega, a star in the constellation Lyra. Vega is located at a distance of 25 light-years from Earth (1 light-year = 9.46×10^{12}km). At the scale of our model solar system, could we still put a plaque for Vega on this planet? Support your answer with a calculation.

III.5 Now think about the largest galaxy in our Local Group, the Andromeda galaxy, located at a distance of about 2.4 million light-years from the Milky Way galaxy. Roughly where would we need to locate the plaque for the Andromeda galaxy at the scale of our model solar system? Since the Andromeda galaxy has a diameter of about 100,000 light-years, how big would the plaque need to be?

IV. Follow-up Questions

Now that you have finished your tour of the solar system let's consider a few additional questions.

IV.1 Determine the percent error between the distances you calculated (in km) from the Sun to each planet with the distances listed on the plaques. Record your answers in column 12 of Table 1. Now calculate an average percent error and explain why it is there and whether it is significant. Show your work.

IV.2 What is the general trend in planetary temperatures as you move through the solar system? What planets (if any) don't fit this trend? *Extra Credit:* Why?

IV.3 The total mass of the solar system (including the Sun, planets, and all other material) is 2.002 x 10^{30} kg. Use the appendix in the back of your book to find the mass of the Sun. What percentage of the mass of the solar system is contained within the Sun? Of the remaining mass, what percent is taken up by Jupiter? by Earth? Show your work.

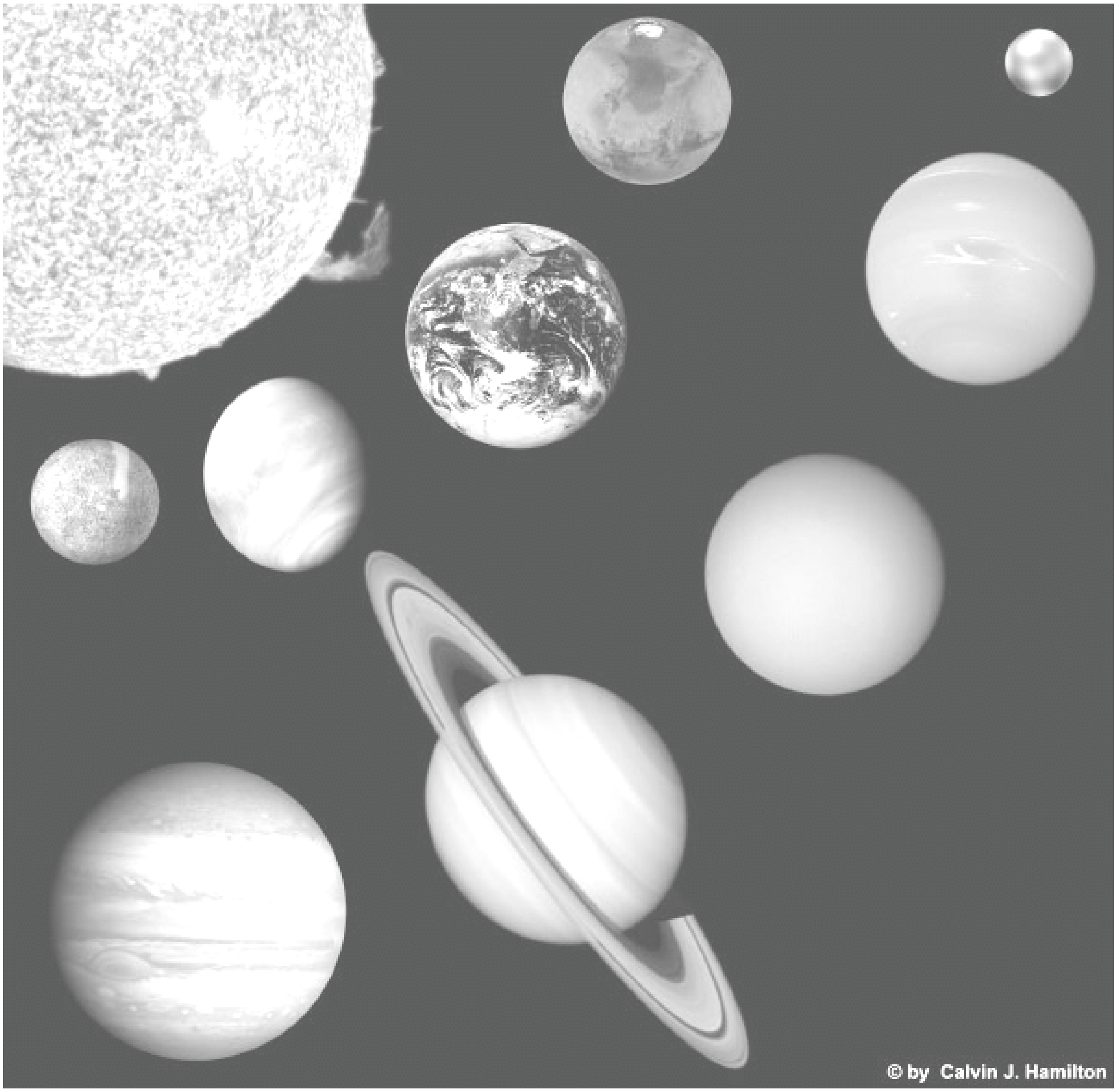
During the formation of our solar system, the Sun accreted most of the material available to it (mostly Hydrogen and Helium, with trace amounts of other gasses) and the rest of the material was spread uniformly in a disk spanning the extent of the solar system.

IV.4 *Extra Credit:* If the original mass of the solar system was distributed uniformly, why do you think there is such a difference between the masses of Jupiter and Earth?

Table 1

*For some planets it may be more appropriate to give the rotation period in days. Be sure to indicate your units if they differ from those in the column header.

Table 2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