Name: ____________________________ Section: ________

Lab 1 - The Scale of the Solar System

"*All models are wrong, but some are useful.*" - George Box

We have all seen diagrams of our solar system showing the planets and their orbits around the Sun. But did you know that virtually all of these diagrams are incorrect in some way? It is difficult to depict each planet's relative sizes and distances in a single diagram. The consequence is that nearly all of us (including astronomers) have a poor idea of the true scale of the solar system.

In this lab, you will develop an appreciation of the immense size of our local neighborhood and a sense of astronomical distances. Astronomy students and faculty have worked with CU to lay out the Colorado Scale Model Solar System along the walkway from Fiske Planetarium northward to the Engineering complex. You will walk through this model solar system and answer questions along the way.

Materials

- Printout of this lab
- Clipboard or something hard to write on
- Pencil
- Calculator (a phone app is fine)
- Eclipse glasses
- Ruler

Instructions

- While you should each complete your own observations, we encourage you to consult with at least one other student along the way and throughout (that is, we encourage you to work in at least pairs as you complete this lab activity).
- Complete your work directly following the instructions provided by your TA. Make sure to include your name and section number.
- Hand in the lab following the instruction provided by your TA and LA at the end of the lab session, along with your ruler, the clipboard, and eclipse glasses

Part 1: Inside the Observatory

Skim the entire lab since some later parts require paying attention to certain details during your walk-through of the model. Then, before you go outside:

1. (2 pts) Make some estimates. You won't be graded on accuracy - just completion.

   a. Which planet do you think is most similar to Earth in size?

   b. Which planet do you think is most similar to Earth in the length of day (rotation period)?

   c. Jupiter is the largest planet in our Solar System. If the Sun is the size of a grapefruit in the model, what common object do you think could be used to represent Jupiter?

   d. How long (in Earth-hours or Earth-days) do you think it takes Neptune to rotate once (i.e., experience one complete Neptune-day)?

   e. Which planet has the most moons? Which has the least?

2. If you have a phone running iOS (not Android yet, unfortunately), consider downloading the Wanderers CU App, which adds a sound component to your walk through the solar system! The experience is even more immersive using earphones.

Part 2: The Inner Solar System

1. Go outside and find the Sun in front of Fiske Planetarium. Look northward.

   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. All the *sizes* of the objects within the solar system (where possible), and 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.

2. (4 pts) Walk from the Sun to Mars, stopping at each planet to **jot down** some of the important properties of each planet **AND record** the number of steps you took between each planet. Look ahead to Question 3 to see what things you should be writing down.

Mercury (Steps from the Sun: _____) Notes:	**Venus** (Steps from Mercury: _____) Notes:

Earth (Steps from Venus: _____) Notes:	**Mars** (Steps from Earth: _____) Notes:

3. (3 pts) Answer the following questions based on your walk from the Sun to Mars:

    a. Which planet is most like the Earth in temperature?

    b. Which planet is most similar to Earth in size?

    c. Which of these is the smallest planet?

    d. Which planet has a period of rotation (i.e. a day) very much like Earth's?

    e. Which planet has the fewest moons?

4. (2 pts) The real Earth orbits about 150 million km (93 million miles) from the Sun. This distance is 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 average Earth-Sun separation as a standard distance.

   What fraction of an AU does one of your steps correspond to in the model? Show your work.

   How many km do you cover in each step? Show your work.

5. (2 pts) Stand next to the model Earth and look at how the rest of the solar system appears from our vantage point. (Remember, because everything is scaled identically, the apparent angular sizes of objects in the model are the same as they appear in the real solar system).

   a. Stretch out your hand at arm's length, close one eye, and see if you can cover the model Sun with your index finger. Are you able to completely block it from your view?

   b. The width of your index finger at arm's length is about 1 degree. Estimate the angle, in degrees, of the diameter of the model Sun as seen from Earth.

> ***Caution! Staring at the Sun with unprotected eyes can injure your eyes.***
> *For the next question, be sure your finger covers the disk of the Sun!*
> *You may also use the eclipse glasses available from SBO.*

c. <u>If it is not cloudy</u>, you can use the same technique to cover the real Sun with your outstretched index finger. Is the apparent size of the *real* Sun as seen from the *real* Earth the same as the apparent size of the *model* Sun as seen from the distance of *model* Earth? Why or why not?

Part 3: The Outer Solar System

1. (1 pt) Continue walking northward. As you cross under Regent Drive heading for Jupiter, you will also be crossing the region of the *main belt asteroids*, where we estimate there are 1-2 million "minor planets" larger than 1 km in diameter. The largest of these is Ceres, which is 760 km (450 miles) in diameter (slightly larger than 1/10th the size of Mars).

   Assuming the asteroids were to be scaled like the rest of the solar system model, would you likely be able to see most of the asteroids as you passed by them? Why or why not?

2. (4 pts) Continue walking northward, visiting Jupiter, Saturn, Uranus, and Neptune. As you did for the inner solar system, jot down important properties of the planets and the distances (in steps) between them.

Jupiter (Steps from Mars: _____)	**Saturn** (Steps from Jupiter: _____)
Notes:	Notes:

Uranus (Steps from Saturn: _____) Notes:	**Neptune** (Steps from Uranus: _____) Notes:

3. (1 pt) While at Jupiter, position yourself so that you can look back and see the grapefruit sized Sun. Notice that while the Sun has not change in actual size, the angular size of the Sun from Jupiter is smaller than from Earth. Because this is a scale model, the Sun would appear this large in the sky as viewed from Jupiter. Using either a physical estimate or a conceptual estimate, how much smaller in the sky would the Sun appear from Jupiter than from Earth? Show your work or explain your process.

4. (3 pts) Answer the following questions based on your walk from Jupiter to Neptune:

   a. Were you right in your estimate for what object you could use to represent Jupiter? If not, pick a new object now.

b. How many times larger (in radius or diameter) is Jupiter than Earth? Show your work.

c. How many times more massive is Jupiter than Earth? Show your work.

d. How does the distance between Saturn and Jupiter compare to the entire inner solar system? *(We're not looking for exact answers here, just make a general comparison.)*

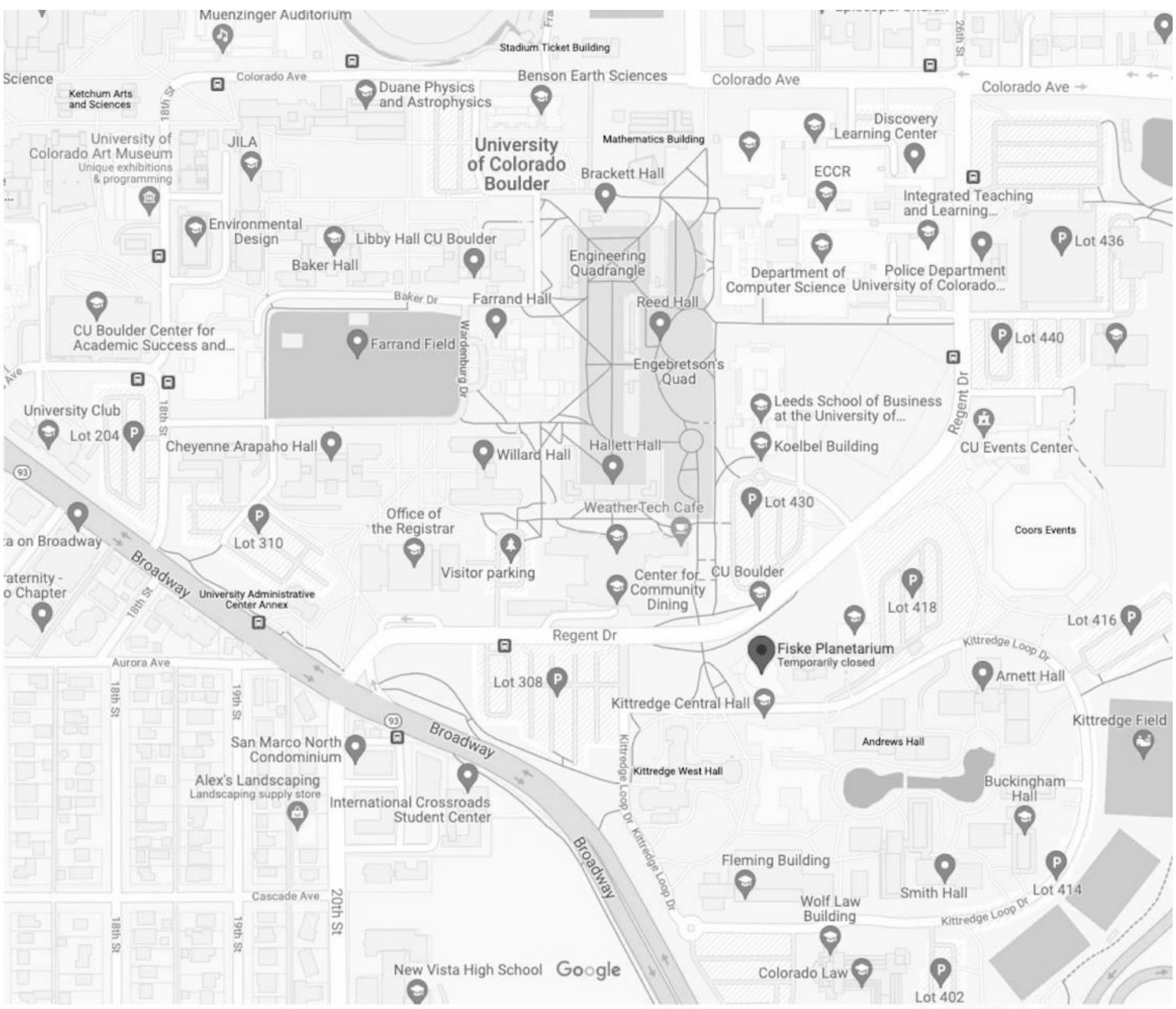
e. Which planet has the most moons?

Part 4: Planetary Alignment

While the Colorado Scale Model Solar System is accurate in terms of the relative sizes and distances of the planets, it is unrealistic in one respect. All the planets have been arranged roughly in a straight line on the same side of the Sun; hence, the separation from one planet to the next is as small as possible. The last time all nine planets were lined up this well in the *real* solar system, the year was 1596 BC!

1. (1 pt) Mark and label the model locations of the Sun and Solar System planets on the map below.

2. (2 pts) Make use of your ruler to select and mark and label *new* locations on the map for Jupiter, Saturn, Uranus, and Neptune if the model had a more realistic layout for the planets. Keep the Sun in the same location. Make sure all locations are on campus. Put at least one planet inside the Kittredge loop. Try to pick interesting/accessible locations.



Part 5: Pluto and Beyond

1. (1 pt) Continue walking northward to Pluto, a well-known dwarf planet in our solar system. How many steps did it take you to get from Neptune to Pluto?

2. (1 pt) Is Pluto larger or smaller than Mercury? How many times larger or smaller? Show your work.

3. (3 pt) Based on the *total* steps you took from the Sun to Pluto, how long (in seconds) would it take to walk the scale model Solar System from the Sun to Pluto if you took 1 step per second? Show your work.

   What is the actual distance from the Sun to Pluto in km? How long (in seconds) would it take a particle of light to travel from the Sun to Pluto at the speed of light (3.0×10^5 km/sec)? Show your work.

   How many times faster than the speed of light would you be traveling through this scale model solar system 1 step per second? Show your work.

4. (BONUS: 3 pts) Now pick any two outer solar system planets in your 'more realistic SS layout' from Part 4. Traveling at the speed of light, how long would it take to travel between the two planets in the physical scale model and how long would it take to travel between their positions shown on the map in Part 4? How many times farther away are the two planets on your diagram than in the physical model? Show your work.

Although we have reached the solar system's edge, as we typically describe it, the solar system doesn't end here.

- Spacecraft have traveled beyond the orbit of Pluto. The New Horizons spacecraft, which flew by Pluto in 2015, is now more than 52 AU from the Sun. This would place it at the intersection of University Heights Ave and Folsom St. Over on Pearl Street Mall, about 155 AU from the Sun, Voyager 1 is still traveling outwards towards the stars and is still sending back data to Earth.
- In 2000 years, Comet Hale-Bopp (which was visible from Earth in 1997) will reach its farthest distance from the Sun (*aphelion*), just north of the city of Boulder at our scale. Comet Hyakutake, which was visible from Earth in 1996, will require 23,000 years more to reach *its* aphelion distance, which is 15 miles to the north in our scale model, 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 across the space between Wyoming and the Canadian border. Each of these icy worldlets is slowly orbiting our grapefruit-sized model of the Sun, waiting for a passing star to gravitationally jostle it into a million-year plunge into the inner solar system.

And *this region (the Oort Cloud)* 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 (still staying at our 1-to-10 billion scale)! You'll be asked in class where on Earth this might correspond to in our model. We now know that Proxima Centauri hosts a planet! At this scale, Proxima orbits 160 kilometers (100 miles) around *two other stars* collectively called Alpha Centauri. One is similar in size and brightness to the Sun; the other is only half as big (the size of an orange) and one-fourth as bright. The two stars of Alpha Centauri orbit each other at a distance of only 300 meters (1000 feet) in our scale model (so close that they appear to the naked eye as a single star in our night sky).

Now you know why we call it SPACE!