We now take it for granted that the Moon orbits the Earth and Earth-Moon system orbits the Sun. But this was not always the case. Trying to determine the paths of celestial bodies while on a spinning, tilted Earth that's orbiting the Sun is an extremely difficult task. Imagine trying to draw a map of your own hometown while riding the Tilt-a-Whirl at the amusement park!

Throughout the 17th century, scholars advanced several different explanations for the motions of the Sun, planets, and stars. In the absence of unambiguous scientific data, theories were often justified on aesthetic, religious, or philosophical grounds. By 1632, the controversy surrounding the many explanations of celestial motions had become so intense that Galileo was summoned before the Roman Inquisition for publishing a book describing a *heliocentric* model. At the time, a geocentric theory was the accepted explanation for the motions of objects seen in the night sky and was the model taught by the [Roman Catholic] Church. But Galileo based his argument on careful observations that he made with a newly invented tool: the telescope.

Four centuries of increasingly sophisticated astronomical observations later, we now know that Galileo's heliocentric theory was correct. But it wasn't until Isaac Newton's 1687 theory of universal gravitation that the last piece of the puzzle fell into place.

Even before Newton, Johannes Kepler was able to show that all the planets orbit the Sun and the Moon orbits the Earth along elliptical paths. The data also showed that the farther a moon or planet is from the body it is orbiting, the longer it takes to complete one orbit. For example, the Moon is 3.8×10^5 km from the Earth and it completes one round trip every 27.3 days. The Earth is 1.5×10^8 km from the Sun and it makes a complete orbit in about 365.25 days. We now know this is because of gravitational interactions. But despite the apparent simplicity of this description, the Sun, Moon, and stars follow relatively complicated paths across the sky.

You may have previously observed the motion of a planet (or the Moon) over a very short time. In this exercise, you will see the motion of the Sun over an *extended* period of time. As you watch the Sun and Moon (and planets and stars) travel through the sky, try to keep in mind that their paths are the combined result of four relatively simple facts: (1) the positions of the stars relative to each other are nearly constant; (2) the planets orbit the Sun; (3) the Moon orbits the Earth; (4) the Earth spins.

MOTION OF THE SUN

Find a safe place outside (or out of a window if that is necessary because of your schedule) to observe where you can see either the eastern or western horizon. Note that you do not need an unobstructed view of the horizon and in fact, you actually need at least one "obstacle" in the way along your horizon to measure from. You must commit to one or the other – either sunrises or sunsets; you cannot combine the observations. Make sure you can access this *exact* location each time you want to observe. You may find it helpful to mark your spot with some kind of temporary mark. ***It is critical that you make the solar observations from exactly the same location each time!*** Draw a representation of your horizon by hand (not electronic), making sure to label the <u>three</u> cardinal directions visible (you cannot see all four at once!) and sketching in major obstacles or landmarks such as buildings, trees, microwave towers, etc. You will use this map to chart the location of the sunrise or sunset (not both!) over an extended period of time.

Go to your particular observing spot several minutes before sunrise/sunset and make sure you can orient yourself with your own drawing (remember you will have to adjust the time accordingly throughout the term). Watch carefully until the Sun just appears <u>*on the horizon*</u>. <u>*At that instant*</u>, use your hands to measure the angular separation between the position of the sunrise/sunset and a

Figure 1. Fist is roughly 10 degrees at arm's length.

stationary object to one side of that location along the horizon. Your fist, extended at arm's length, subtends about 10° on the sky (Figure 1; turn your fist 90 degrees from the orientation in the picture so you can measure horizontally along the horizon instead of vertically like in the picture). No app can give you these measurements. They depend on your very specific view of the horizon, your local topography, and the object you choose as the stationary reference point so only you can make these measurements. Record the angular separation to the nearest whole degree (finer resolutions are not realistic), whether the position of the Sun is north or south of your stationary object (because it may cross over), and the time you make the measurement. You must keep your measurements in a table similar to Table 1. Astronomical observations are dependent upon very specific locations, dates, times, and observing conditions. You must include all of this information in your observations!

Observations taken from Murfreesboro ,TN, USA (35.8° N, 86.4° W)				
Obs #	**Weather & Notes**	**Date**	**Time (CST)**	**Angular Separation (deg)**
1	low cloud layer; hard to tell spot	2001 Feb 16	17:07	41.0 S
2				
3				
...				
10				

Table 1. Sample data table for solar observations.

Sketch the positions of your sunsets (or sunrises) on your horizon drawing and number them with the correct sequence numbers from your data table. ***Put all the data on one drawing!*** The point is to observe changes. Thus, having separate drawings makes no sense! Make sure to indicate and label the stationary object from which you measured the angular separations.

You must make **a minimum of 10 observations** of either the sunrise or sunset (remember you cannot mix the two) **over the course of at least three weeks**. *If your observations do not span a time period of at least three weeks, you will not earn credit.* Do not wait until the last three weeks of the assignment to take your measurements – bad weather is not an excuse. The motion of the Sun along the horizon is *very* slow so making observations each day will not be very rewarding and can sometimes seem confusing (if you get the same position two or three days in a row, or if the Sun seems to have moved in the wrong direction compared to its previous motion). Thus, it is recommended to skip several days between observations. Note that this is not a requirement; it is simply a suggestion that may help avoid confusion.

You will find this exercise both easier and more rewarding if you start early and come to one or more help sessions to check your work after making one or two observations. You'd hate to go the entire term, make ten observations, turn it in at the last opportunity, and then earn very little to no credit because you did it incorrectly and made errors that could have been corrected if only you'd been asking for help and checking your work all along. Successful students start early, ask for help often, get feedback, and check their work multiple times before turning it in.

ANSWER THE FOLLOWING QUESTIONS. YOUR OBSERVATIONS MUST SUPPORT YOUR ANSWERS!

1. **Did the Sun move along the horizon over the course of your observations? If so, which direction did it move (N-to-S or S-to-N)?**
2. **Roughly how many degrees per week did the Sun appear to move? You must use the FULL dataset (final – initial), quote your answer to the nearest tenth of a degree, and show your work.** ***Do NOT take an average for any individual week! That is not what the instructions indicate!***
3. **Based on what you know about celestial motions and the time of year, do your observations support this knowledge? Explain why or why not.** ***You must refer back to the many specific ideas we learned about with respect to seasons and their cause, as well as the motions of planets with respect to their parent stars.***