Celestial Motion II Lab Guide *Experiment A03*

Part A: Eclipses

1.) **(10 points)** First off – if you are doing this on the computer the best way to do this is to use the 'Draw' program in Word. If you do not have this option, then you can insert different shapes to represent the sun, moon, and Earth. Just make sure to label them in a way so I know which is which.

Looking at the two words, *solar* eclipse and *lunar* eclipse, tells us immediately which each one is describing. A *solar* eclipse describes the case where the *sun (sol)* is blocked by the moon from our point of view here on Earth; the MOONS shadow is casted onto the surface of the Earth. A *lunar* eclipse describes when, from the *moon's* perspective, the sun is blocked by the Earth; the moon (being smaller than the Earth) moves into the shadow of the Earth, shading it from the sun. Knowing this, question 1 asks you to draw diagrams of both of these phenomena – making sure to include the sun, moon, and Earth in each diagram.

2.) Angular size describes the *apparent* sizes of objects we look at without considering how far away they are from us. For example, if you hold up a pencil out in front of you, you can see that this pencil *appears* larger than some person standing off in the distance. You *know* the person is larger than this pencil when you compare their exact sizes, but because of how far that person is from you they *appear* to look smaller to you than the pencil does. Thus, to you the pencil has a larger *angular size.* In this exercise, we have a definition of angular size in terms of the objects *exact (physical) size* and the *distance* the object is away from the observer:

$$Angular\ Size\ =\ Physical\ Size\ \times \frac{360°}{2\pi \times Distance}$$

In this equation, the "Physical Size" and the "Distance" MUST be measured in the same units! This, then, makes sure our "Angular Size" has units of degrees(°).

For **PART A (2 points)**, we are given the "Physical Size" of the moon (its diameter) and the "Distance" from it to the Earth – each in km! We are also given the same info about the Sun. Here you need to use the equation above to calculate the angular size of both the sun and moon as we see them in our sky. What do you notice here? If your math is correct, the answer you get for both of them should be nearly the same!

PART B (2 points): So we found that the *angular sizes* of the Sun and moon as seen by us here on Earth are the SAME! However, as we see by looking at the actual diameters of the two, the Sun is clearly a lot bigger than the moon. How is it that the moon, then, can block out the entirety of the sun during a full solar eclipse? Its all about *angular sizes* and what the two objects *look like to us* in the sky!

For **PART C (2 points)** you'll be doing some easy math again. You'll be finding two ratios:

$$Size\ Ratio = \frac{Sun\ Diameter}{Moon\ Diameter}$$

$$Distance\ Ratio = \frac{Distance\ Earth\ to\ Sun}{Distance\ Earth\ to\ Moon}$$

Once you find these two numbers, you need to compare them. Are they the same? Different?

PART D (4 points): What IS an *Annular Eclipse?* According to Googles definition, an Annular Eclipse is "an eclipse of the sun in which the edge of the sun remains visible as a bright ring around the moon." This comes form the word *annulus,* which basically is just a ring. In this case, the moon does NOT completely cover the moon during a solar eclipse. But why? We just finished talking about how the angular sizes are the same, what is different about an annular eclipse? The answer to that lies in the fact that the moon's orbit around the Earth is not completely circular and the Earth's orbit around the Sun is not either. There arise times in which the Earth is its closest to the sun (i.e., closer to the sun than its mean distance stated above), resulting in the apparent size of the sun in the sky *increasing.* At this same time, the moon can cross between the sun and the Earth (resulting in a solar eclipse) when it is furthest away in its orbit (i.e., further away from the Earth than its mean distance stated above), resulting in the apparent size of the moon *decreasing*. Thus, if the angular size of the Sun *increases* at the same time the angular size of the moon *decreases*, the moon will appear to be much too small to be able to cover the entire Sun in this instance resulting in part of the sun (in the shape of an *annulus*) peeking through from around the moon.

Part B: Stellar Parallax

1.) **PART A:** Here it is asking you to use the diagram at the beginning of this section to draw a straight line from Earth (the one labeled October) through the "nearby star" all the way towards the group of stars to the right. This arrow will point to a specific location in this group of stars. Now notice how this group of stars is copy-and-pasted below this question. What you need to do is insert some kind of image or shape in this copied group of stars that represents the location in which the arrow you drew up above points to. This point coincides with the apparent location of the "nearby star" in relation to these distant stars during this month on Earth!

In **PART B** and **PART C,** you will do the same procedure as above, but now you are going to start drawing your arrow from different positions of Earth around the sun (January and July, respectively). You will see that all three of these arrows you've drawn all point to different locations in this group of stars. This tells us that as the Earth revolves around the sun, this "nearby star" appears to move in relation to these distant stars (which are so far away they don't look to move at all). In **PART D**, you need to describe to me what the motion of this "nearby star" would appear to be like in the sky to you and I here on Earth as the year goes on.

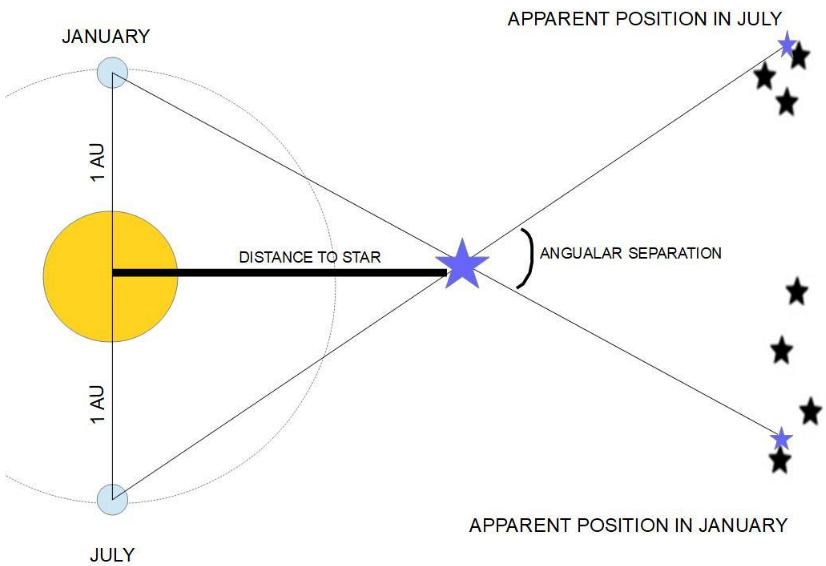
In **PART E** you can actually see for yourself if you put a new star in between Earth and the "nearby star" and then redraw the lines in parts A-C with this new star. In the months January and July, are the new arrows pointed further apart at the group of stars (to the right) or are they closer together? If they are further apart, this would mean that the NEW "nearby star" would appear to be moving MORE in comparison to the original "nearby star" (with the opposite being true if they are closer together).

In **PART F** you'll do the exact same thing as part E, except now you are considering a new star in between the original "nearby star" and the distant stars (those to the right). Again, draw your lines from January/July through this new star and towards the distant stars and do the same analysis as before.

You should see that as you get to stars that are further and further away, they tend to seem to move *less* in our sky until we get to stars that are so far away they don't seem to move *at all* (i.e., these kind of stars ARE the "distant stars" here).

In **PART G**, we actually need to do a little bit of geometry; lets look at parts A-C together and see what there is to work with. Below I've included a diagram that I will be referring to.

A hint in the problem reminds us that *the distance between two positions in the night sky is measured in angular separation*. In the diagram, this gives us a reasonable value for the bisection angle (labeled here). If you remember from geometry, *opposite* angles in a bisection like this are equal. Thus, we have the right-most angle in the large triangle to the left (the one that consists of the sun as its base). Now we know the *height* of this triangle is the "distance to the star" as labeled below, and THIS is the value we'd like to know. Since we know that the base of this triangle is just twice the distance from the Earth to the sun, and we know one of the angles of this triangle, we can use trigonometry to find this distance!



In **PART H,** we need to think about what differentiates ancient Greek astronomers from modern day astronomers. Parallax is something we can observe with an outstretched thumb, but how could they have not seen this phenomenon with the stars? What objects have helped modern astronomers peer into the cosmos that the Greeks did NOT have? Evolution of *what* made it easier to see these phenomena today than it was thousands of years ago.

For **PART I**, think about our work in parts A-C but now considering the SUNS point of view. Does the Sun see any parallax phenomena in this case? *No*, the sun in this case is stationary and thus there is no relative motion between it and these (assumed motionless) distant stars. Now think about what the Greeks would have thought not seeing this phenomenon – they'd come to the same conclusion about the Earth as we just did about the Sun in this example, i.e., it is *stationary* and thus all the things we DO see moving in our sky everyday *must be revolving around the Earth!* Now, we obviously know today this is incorrect due to what was discussed in part H.

Part C: Kepler's Laws

KEPLERS FIRST LAW: *The orbital paths of the planets are elliptical with the Sun at one focus of the ellipse.*

1.) Make sure you click "ok" after selecting from the drop-down arrow!

2.) Remember *perihelion* is the point along the planets orbit in which it is CLOSEST to its star. The opposite location being *aphelion*.

3.) Note that every time you move the planet around its orbit, the value for r1 and r2 change – this is because r1 is ALWAYS the distance from the planet to the star (one of the foci) and r2 is ALWAYS the distance from the star to the other foci. Putting the planet at its furthest point along the orbit here then makes r1 the *aphelion* distance, while in 2) it was the *perihelion* distance.

4.) In the **first table (6 points, 0.5 each)** you will follow steps 1-3 for Mercury, Earth, and Pluto (while remembering to click "ok" every time you go to another planet). *Eccentricity* and the *semi-major axis* can be found in the upper right-hand box "Orbit Settings" once you click "ok" on the planet you want.

You found both the *perihelion* and *aphelion* distances in the previous table- here you will write those again. However, now you will need to find the difference between the two:

$$Difference = Aphelion\ distance\ (AU) - Perihelion\ distance\ (AU)$$

Note that since the *aphelion* represents the point in which the Earth is FURTHEST away, it is a larger number than the *perihelion*. Thus, this difference will be a positive number.

In the **second table (4 points, 0.5 each)**, using the distances given to you in the program you will have them in AU (astronomical units) already. So, for the last column in this table you will have to take the difference you found in the previous column and convert it into miles. Remember we can use dimensional analysis that we reviewed in lab 1 to do this conversion:

$$Distance\ (AU) \times \left(\frac{9.296 \times 10^7 miles}{1\ AU}\right) = Distance\ (miles)$$

Plug in the difference you found into the left-hand side, do the conversion above, and you should have a result in miles!

5.) **(3 points)** The difference you found in the previous question IS how many miles closer the sun is at perihelion, so did you make sure your math was correct?
6.) **(3 points)** This is a quick Google search!

7.) **(3 points)** Starting with any planet, you can increase the *eccentricity* slider in the top right box. What happens to the orbit when you increase it? It should look like its going further and further AWAY from a perfect circle! Now click the "start animation" button in the "Animation Controls" box on the right while the *eccentricity* is large. Observe how fast the planet is moving at both the *perihelion* and *aphelion* locations – at which point is it moving FASTER, and which point is it moving SLOWER (you may have to increase the "animation rate" in the same box to see the effect better)?

8.) **(1 point)** Now move the *eccentricity* slider all the way into the other direction (so that it reads "0"), what shape is this?

KEPLERS SECOND LAW: *An imaginary line connecting the Sun to any planet sweeps out equal areas of the ellipse in equal amounts of time.*

1.) These tabs are located in the bottom left-hand corner

2.) The best way is to just highlight the values in the boxes here and type "1.0" (or "0.5") and then press ENTER.

3.) See that clicking "start sweeping" will give you a different color sweep area for every click. Try to generate two sweep areas by clicking once around the *perihelion* location and another time around the *aphelion* location.

4.) In the "Animation Controls" box on the right, once you click for the first time "start animation" it will give you the option to "pause animation."

5.) **(4 points)** Once you "pause animation," you can click on these sweep areas. Do you notice how the sweep areas DO NOT change as you click between them?

6.) **(4 points)** Go ahead and click and drag one of your created sweep areas all around the orbit. You'll notice at one point of the orbit the sweep area will be its THINNEST; what is the name of this location (i.e., what is the name of this location when the PLANET is at this point in its orbit)? Now what about the opposite, where is it the WIDEST? Again, what is the name of this position?

KEPLERS THIRD LAW: *The square of a planet's orbital period is proportional to the cube of its semi-major axis.*

1.) **Planet Table (8 points, 0.5 each)** Here you can just Google search 4 different planets; Wikipedia will work fine for this section. For each of these planets you need to find its *period* (in Earth years) and its semi-major axis (in AU's). Usually good sources online will have these parameters listed for you in these units already so you shouldn't need to look very hard or do any conversions.

2.) Using the equation in your lab manual for *k:*

$$k = \frac{P^2}{a^3}$$

You will now take the *period* (P in YEARS) and the *semi-major axis* (a in AU's) and plug them into this equation. Remember P in the numerator is SQUARED while a in the denominator is CUBED – use the skills we developed in the first lab to make sure your result is correct.

3.) **(4 points)** If you're getting pretty much the SAME value for k in each instance then you are on the right track. What IS this value for k?