Names: _____

Laboratory 7: The Sizes of Stars

Astronomy 120. The Copernican Revolution

Purpose

In this lab you will examine conclusions that can be drawn about the distance to the nearest stars from the failure to detect (daily or annual) parallax. You will also examine how these distance estimates, combined with measurements of the angular size of stars, leads to conclusions about the size of stars. These estimates for the sizes of stars were considered by some astronomers to constitute strong evidence against the Copernican system. Finally, you will examine some evidence indicating that the measured angular size of a star might not be directly related to the star's true size, and thus might not constitute an argument against Copernicus.

Background and Theory

There are two relationships we will use in this lab. The first is the relationship between the parallax θ of an object viewed from two locations, the baseline distance b between the two locations, and the distance d of the object from the observer. We found in the previous lab that this relation was:

$$\theta = \frac{90^\circ b}{\pi d}. \tag{1}$$

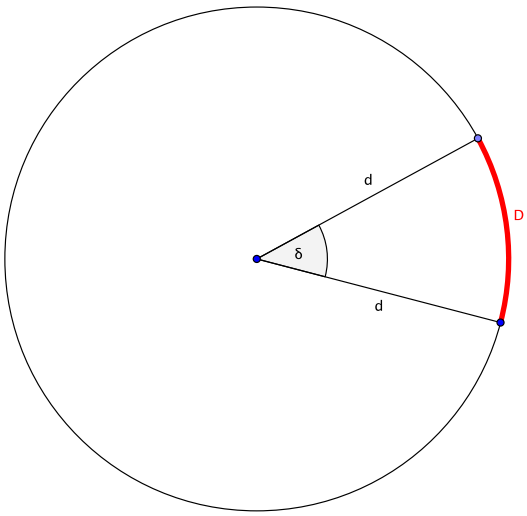
The other important relation is one that relates the angular diameter δ of an object (ie how many degrees of arc the object occupies in the observer's field of view), the physical diameter D of the object (how big across the object is), and the distance d of the object from the observer. This relation is given by:

$$\delta = \frac{180^\circ D}{\pi d} \tag{2}$$

We will verify this relation in the first part of this lab.

Angular Diameter

Take a look at the figure below and then answer the questions that follow.



1. What is the perimeter of the circle shown above?

2. If you travel along the arc of length D, what fraction of the circle have you traveled along? (Note: your answer should be in terms of D and d.)

3. If you went all the way around the circle you would have gone through an angle of 360° (as measured from the center). If you travel the distance D along the circle, you have only gone through the angle δ. So what fraction of the circle have you traveled along? (Note: your answer should be in terms of δ.)

4. Take a look at the previous two questions. Make sure you understand why the answers to these two questions must be the same. In the space below, use this fact to write an equation that relates D, d, and δ.

5. Show that this equation is the same as Equation **??** above.

6. You may be concerned that D is a circular arc, while in Equation **??** it is supposed to stand for the physical diameter of an object. A diameter is a straight line, while a circular arc is curved. Explain why we don't have to worry about this as long as $D << d$.

7. The Sun has an angular diameter of about 0.5°. We know that the Sun is 1 AU from Earth (by definition). What is the physical diameter of the Sun in AU?

Parallax and the Distance to the Stars

8. Tycho Brahe attempted to measure the parallax of stars by observing stars from opposite sides of Earth (well, not quite, but almost). He was certain that he could have detected this parallax if it was larger than $2'$, but he was unable to detect any parallax. So the closest a star could be would be the distance at which its parallax (viewed from opposite sides of Earth) would be $2'$. Convert this parallax to degrees and then use Eq. **??** to find the minimum distance to a star. (Recall that Earth's diameter is about 8000 miles.)

9. Tycho had determined (on the basis of Ancient Greek estimates of the distance to the sun, as well as his measurements based on his own system - which was identical to that of Copernicus in this respect) that Saturn was about 38 million miles from the Sun. How does the minimum distance to the stars that you found above compare to the distance to Saturn? Does this make sense in the context of the Tychonic system? Why or why not? (Note: the distance you found is the *minimum* distance to a star. Stars could all be *much* farther away than this minimum distance.)

10. Now let's consider parallax in the Copernican system. To help with this, run the `Parallax2D` program. In the Options Menu, select Earth Orbit Mode. This now displays the Earth orbiting around the Sun. Play the simulation. What is the maximum possible baseline for parallax measurements taken from Earth? Give your answer in AU.

11. How far apart (in time) must the measurements be taken in order to make use of this largest possible baseline?

12. Tycho took these kind of measurements and was still unable to detect a parallax. Let's continue to assume that the maximum parallax of a star is $2'$ (just beyond what Tycho could measure). Calculate the distance to the star using the maximum possible baseline for the Copernican system. Give your answer in AU.

13. In Copernicus' system, Saturn is 7.9 AU from the Sun. How does the distance to the stars compare with that to Saturn? Does this seem reasonable? Would a 16th century astronomer think it was reasonable?

The Sizes of Stars

14. Tycho measured the angular diameter of several bright stars and found that the brightest of these had angular diameters of a few minutes of arc. Let's say a star has an angular diameter of $2'$. Convert this value to degrees and then use Eq. **??** to find the physical diameter of a star if it lies just beyond the orbit of Saturn (say, at a distance of 10 AU) as Tycho thought.

15. How does this size compare to that of the Sun? Does this seem reasonable?

16. Now calculate the physical diameter of the star if it is at the minimum distance for the Copernican system.

17. How does this compare to the size of the Sun? How does it compare to the size of Earth's orbit? Does this seem reasonable?

18. Alcyone is a third magnitude star in the Pleiades star cluster that is occasionally occulted by the Moon, which means the Moon passes in front of Alcyone. We know that the Moon moves relative to the stars at about 13° per day, or about $0.54''$ per second of time. Tycho measured stars of the third magnitude to have angular sizes of about one minute of arc. If Tycho's measurement is correct, how long should it take for Alcyone to dim and disappear as the Moon moves in front of it (i.e. how long does it take between the time the edge of the Moon first reaches the edge of Alcyone and the time when the Moon fully covers Alcyone)?

19. Jeremiah Horrocks and William Crabtree observed an occultation of the stars in the Plieades in 1637. They found that the stars appeared to vanish instantly, at most taking only a fraction of a second to dim and disappear. How does this compare with the time you calculated above? Do you think the angular size of a star measured by Tycho really gives an indication of the star's physical size? Explain.

20. Prior to Horrocks and Crabtree's measurement it seemed as though the angular sizes of stars, combined with their lack of parallax, argued against the Copernican system. But if the measured angular sizes aren't really related to the physical size of the stars, then does this really serve as evidence against Copernicus? Explain.