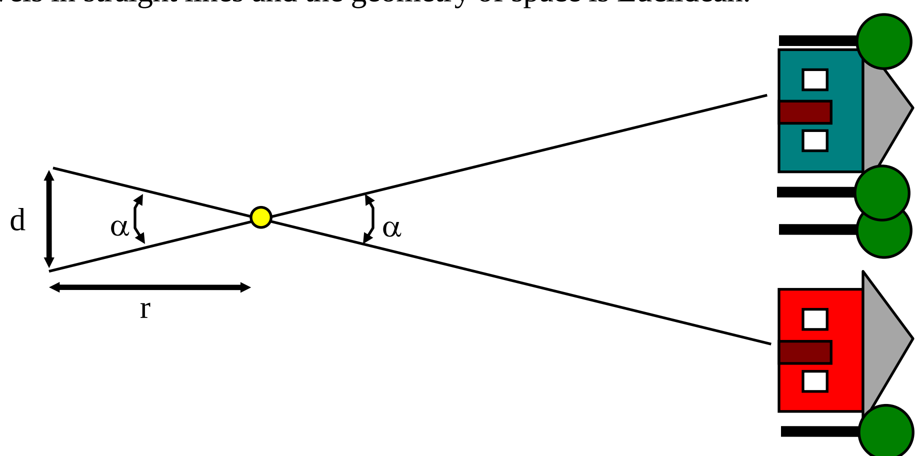
OUTSIDE LAB 4: Finding the Distances and Sizes of Remote Objects

OBJECTIVE: *To use the principles of trigonometry to find the distances to remote objects and then to find their dimensions.*

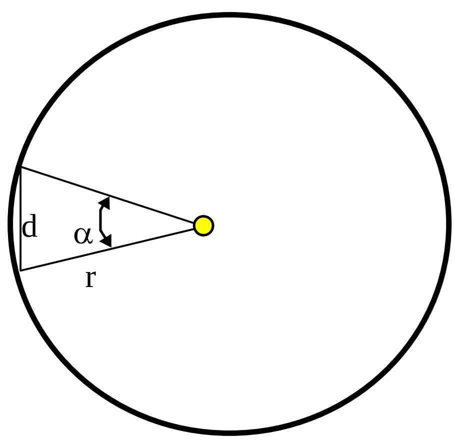
DISCUSSION:

The most accurate method of measuring distances within the solar system is through radar ranging. A radar signal is bounced off an object and the time t it takes for the signal to make a round trip is recorded. The signal travels at the speed of light c so the distance to the object can be determined by the simple equation $2r = ct$. The light signal travels twice the distance to the object since it makes a round trip. The distance to objects can also be determined by sending spacecraft to them and sending radio signals to and from the spacecraft.

The most reliable method for measuring distances to objects outside of the solar system is through trigonometry. Unless gravity is very strong, as it is near a black hole, light travels in straight lines and the geometry of space is Euclidean.



As shown in the diagram, the background objects that an object is aligned with depend on the position of the observer. To determine the distance to an object one first determines which background objects it is aligned with as seen from one position. One then chooses a second position and does the same thing. The distance is obtained by measuring the angle α between the two background objects and the distance *d* between the two observation points. To see how this works draw an imaginary circle of radius *r* centered on the object as shown to the right.



For a small angle α it is can be seen that the ratio of the angle to the angle of the entire circle is the same as the ratio of the distance *d* to the circumference of the circle. Thus if α is measured in degrees, the following formula is approximately correct:

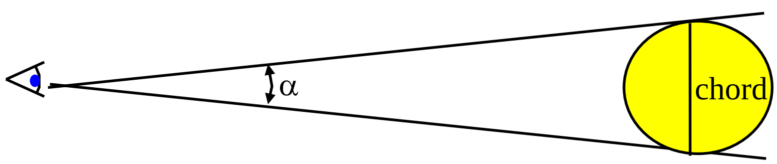
$$\frac{\alpha}{360} = \frac{d}{2\pi r} \ .$$

If α is measured in radians, the equation is even simpler:

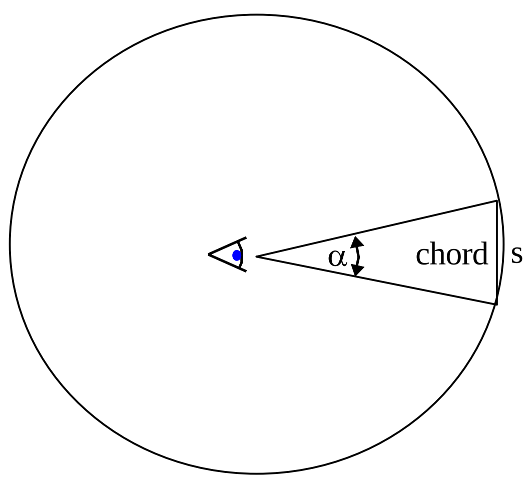
$$\alpha = d/r \ .$$

For celestial objects the angle α can be measured directly by comparing the positions of the heavenly body as seen from the two locations against a background of very distant stars that appear the same from both locations since they are so far away. The largest baseline possible from the Earth is the diameter of the Earth's orbit that is 2 AU. In this case the measurements of the positions of the star are made six months apart. This method of measuring distances is called the method of **parallax**.

Once the distance to an object is known, whether by the above method or some other method, its dimensions can be determined from its angular dimensions. By angular dimension, we mean the angles subtended at the eye by two points on the edge of the object as shown in the following diagram.



The actual size can be determined as shown below by drawing an imaginary circle with a radius *r* that is centered at the observer's eye.



Then the arc length *s* is given by

$$\frac{\alpha}{360} = \frac{s}{2\pi} \ .$$

For an object with a small angular diameter, its actual size, which is represented by the length of the chord in the diagram, is approximately equal to the arc length *s*. Again, if α is measured in radians, then the formula is simpler:

$$\alpha = \frac{s}{r}$$

EXERCISES:

Your TA will point out two objects whose distances and widths you are to measure. Begin with the more distant object and complete Exercises 1–3 below.

EXERCISE 1:

a) For the first more distant object, pick two points to observe it from. At each point, line up the object with some distant object such as the edge of a window or a streetlight. The distance between these points is your **baseline**. Measure the distance between the two observation points.

Baseline = ____________

b) Standing in the middle of the baseline, close one eye, hold the caliper at arm's length and adjust its width so that the two distant objects are each at one edge of the caliper. Have your lab partner measure the distance from your open eye to the caliper. Divide these to get the angle (in radians)

Object 1	**Object 2**

c) Divide the baseline by the angle to get the distance to the object. You have now measured the distance to the object without ever going there!

EXERCISE 2:

a) Next measure the angular size of the object.

b) Now you can calculate the diameter of the object! Multiply the distance by the angle to get the size.

EXERCISE 3:

Using the meter stick, directly measure the distance to the object and its diameter. Calculate the percent differences between your parallax measurements and your direct measurements. These are computed using the formula:

$$\frac{|\text{Direct Value} - \text{Parallax Value}|}{\text{Direct Value}} \times 100$$

Now repeat Exercises 1–3 on the second, closer object. **You must use the same baseline**.

Which measurements that you made (object 1 or object 2) were the most accurate? Which were the least accurate? What does this tell you about the uses of this method in astronomy? In other words, under what conditions would it be most useful?

Reading the Vernier Caliper