Laboratory 6: Parallax

Astronomy 120. The Copernican Revolution

Name	Full	Partial	None

Purpose

The student will explore parallax, a primary distance measuring technique used by astronomers. The image above shows the effect of parallax. Notice how in the main part of the image the Sun is clearly above the lamppost. But in the reflection seen in the water that lamppost is partially blocking the Sun. By viewing the reflection you are effectively viewing the scene from a different location and this changes the relative positions of the Sun and the lamppost.

Background and Theory

One of the most difficult problems in astronomy is determining the distances to objects in the sky. Parallax was used by the ancients to estimate the distance to the Moon, and by Tycho Brahe and others to show that comets resided beyond the sublunary realm. Tycho also attempted for most of his professional career to measure the parallax of Mars, which he was not able to do (although he thought he had measured it); this negative result had implications for his own model of the universe. It was also understood by astronomers both before and after Copernicus that the lack of parallax displayed by the stars indicated a great distance to the celestial sphere.

You can see the parallax effect by holding your thumb out at arm's length. View your thumb relative to a distant background while you alternate opening and closing each eye. Does your thumb seem to jump back and forth relative to this background? This is because the centers of your eyes are a few centimeters apart, so each eye has a different point of view.

Understanding Parallax

Do the following activities and record your answers on this sheet.

1. Let's test how the parallax of an object varies with distance.

   (a) One partner takes a meter stick and places a pen upright at the 50 cm mark, centering the pen on the meter stick. The other partner places the "zero" end of the meter stick against her/his chin, holding it out horizontally. This partner then alternates opening and closing each eye, noting how the pen moves against specific background objects. When you do this, you should choose a distant reference object, like the wall on the opposite side of the room. Do not use people as a reference object. Make rough sketches of the left-eye view and the right-eye view below.

   (b) Have your partner move the pen to half of the original distance (to 25 cm). When you alternate opening and closing each eye does the pen appear to move more or less than before? Using your original reference object, make rough sketches of the left-eye view and the right-eye view below. Try to quantify how much more or less the pencil moves against the background. (Twice as much? half as much? three times as much?, etc.)

(c) Now, have your lab partner move the pen twice the original distance to you, to approximately the end of the meter stick. When you alternate opening and closing each eye does the pen appear to move more or less than before? Using your original reference object, make rough sketches of the left-eye view and the right-eye view below. Try to quantify how much more or less the pen moves against the background. (Twice as much? Half as much? Three times as much?, etc.)

(d) Repeat, switching places with your lab partner so that (s)he can get a sense of the parallax also. See if s/he confirms your results. (There is no need to do a new set of drawings, so long as both of you agree on them.)

Parallax in Astronomy

2. Now let's see how this works in astronomy. Let's start by thinking about looking at an astronomical object from opposite sides of Earth. To get a sense of the geometry of this situation, run the `AstronomicalParallax2D` program. The top window shows the Earth, with the location of an observer (on the equator) marked in green. The green line shows the line of sight to the (red) astronomical object. Red lines mark the extreme points of view from opposite sides of Earth. Controls let the user adjust the baseline (Earth's diameter, in this case), the distance to the astronomical object, and the location of the observer on Earth. The bottom window shows the observer's view from Earth. Hit play and watch as the observer moves around Earth (due to Earth's rotation). What happens to the location of the object relative to the stars, as seen by the observer?

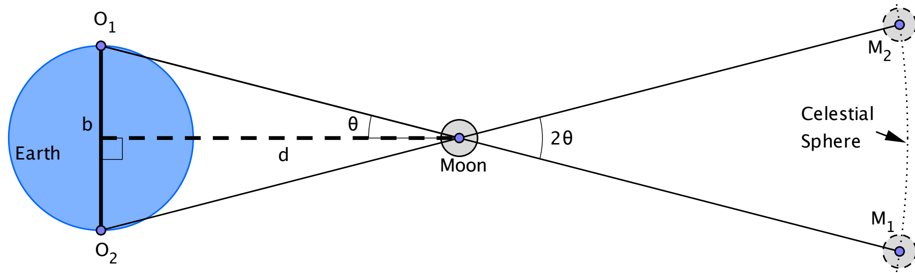
3. The simulation displays the *parallax angle* for observations made from opposite sides of Earth. The parallax angle is half of the angle between the two extreme apparent positions of the object relative to the stars. Let's see how this angle depends on the distance to the object. If you double the distance, what happens to the parallax angle? Be precise.

4. If you double the baseline, what happens to the parallax angle? Be precise.

5. I'm going to claim that for small parallax angles θ, the parallax angle is given by

$$\theta = \frac{90° b}{\pi d}$$

where b is the length of the baseline and d is the distance to the object, as shown in the diagram below.



Does this formula fit with your answers to the last two questions?

6. What is the parallax if the baseline is 4 units and the distance to the object is 24 units? Compute the parallax using the formula and record your result below. Then check your answer using the simulation. Do the results match?

7. Suppose you measure the parallax of an object to be $27''$ when it is viewed from opposite sides of Earth (a baseline of $b \approx 8000$ miles). [Recall that $1° = 60'$ and $1' = 60''$, so $1° = 3600''$.] Convert this parallax to degrees and then use our parallax formula to find the distance to this object.

8. Tycho Brahe claimed that he could measure parallaxes as small as $1'$. How far away must an object be such that its parallax (when viewed from opposite sides of Earth) would be too small to see?

Parallax of the Moon

Now let's see how Tycho Brahe was able to use measurements of parallax to determine the distance to the Moon (and to attempt to determine the distance to other astronomical objects).

1. Go to a computer and open Stellarium. In the Locations window (compass rose on left) set the Latitude to "N 0" and hit return. Then set the longitude to "E 0" and hit return. You should also set the altitude to 0 and hit return. This puts you at the intersection of the Equator and then Prime Meridian. Stop the flow of time (7) and turn off the atmosphere (a) and fog (f). Set the date and time to 5 PM on 15 August, 2011. Find the Moon. Turn on the celestial equator (.) and you should notice that the Moon is very close to it (this makes the geometry easier). Now record the RA and Dec (use the J2000 values) for the Moon. Be as precise as possible.

   RA = ______________________________

   Dec = ______________________________

2. Now we are going to change our viewing location by moving 140° eastward around the Earth.[1] In the Locations window, set the Longitude to "E 140" and hit return. Find the Moon again if necessary (it should be in the west now). MAKE SURE TO NOT THE LET THE SIMULATION PLAY DURING THIS TIME. Record the (J2000) values for the right ascension and declination of the Moon as seen from this location.

   RA = ______________________________

   Dec = ______________________________

3. You should have found that the coordinates of the Moon changed when you changed location, even though the Moon itself did not move (because we kept the time fixed). The change in coordinates is due to parallax: we are seeing the Moon from two different locations on Earth and therefore it appears to have a different location relative to the background stars. Find the difference in RA between these two locations. Calculate this first in minutes of *time* (recall that 1 second is 1/60 of a minute), then convert to degrees of arc by multiplying by the appropriate conversion factor, (360°)/(1440 m).

   change in RA (m) = ______________________________

   change in RA (°) = ______________________________

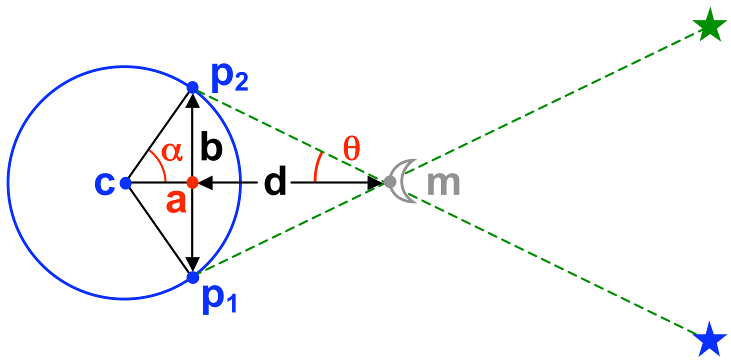
4. Now compute the change in Dec in degrees (convert ″ to ′ and then ′ to degrees):

   change in Dec (°) = ______________________________

5. How does the change in Declination compare to the change in RA? Explain why we can ignore the change in declination and, therefore, why the change in RA is equal to twice the parallax.

[1] The geometry is easier if we move 180° eastward, but then we wouldn't be able to see the Moon any more.

6. The diagram below depicts the relationship between your two Moon observations. The diagram is NOT TO SCALE!



The angle θ is the parallax angle. Record the value of θ below.

$\theta =$ ____

7. The angle α is half of the difference in longitude (Earth longitude, not ecliptic longitude) between our two viewing locations on the Equator. Record the value of α below.

$\alpha =$ ____

8. Note that the triangle $\mathbf{cap_2}$ is a right triangle. The length of the side opposite α is $b/2$. The length of the hypotenuse of this triangle is the radius of Earth (which we previously found to be about 4000 miles). In the space below, determine the value of b. Show your work.

9. Now that we know the baseline and the parallax angle, we can use our parallax formula to compute the distance to the Moon. Show your work in the space below.

10. Look at the diagram above. The distance from the center of the Earth to the center of the Moon is _____________ the distance you found above (d). Recall that the diagram is not drawn to scale, so you need to think about the distances involved.

    (a) much less than
    (b) slightly less than
    (c) slightly greater than
    (d) much greater than

Parallax of the Sun

11. Now let's try to find the parallax of the Sun. In the Locations window set the Longitude to "E 0" and hit return. Set the date and time to 3 AM, 21 March, 2011. This is the vernal equinox, so the sun should be on the celestial equator. Find the Sun, which should be low on the eastern horizon. Record the RA and Dec of the Sun in the space below. Use J2000 values. Be as precise as possible.

RA = ______________________________________

Dec = ______________________________________

12. In the Locations window set the Longitude to "E 140" and hit return. Find the Sun, which should now be low on the western horizon. Record the RA and Dec of the Sun in the space below.

RA = ______________________________________

Dec = ______________________________________

13. Find the difference in RA between these two locations. Calculate this first in minutes of *time*, then convert to degrees of arc by multiplying by the appropriate conversion factor, $(360°)/(1440\text{ m})$.

change in RA (m) = ______________________________________

change in RA (°) = ______________________________________

14. Can we still ignore the change in Dec? Explain why or why not.

15. Record the parallax for your two observations of the sun (in degrees) in the space below.

16. Convert this solar parallax to minutes of arc and show the result in the space below. Would Tycho have been able to measure the parallax of the Sun?

17. Use the same procedure you used for the Moon to determine the distance to the Sun. Show all of your work below.