Astro 101 Parallax Lab: Instructor Notes

1. The Parallax Lab at Bucknell University

Bucknell University has run the parallax lab in its introductory astronomy course since 2012. It is part of a semester-long course that discusses extrasolar astronomy in three 50-minute lectures and one three-hour lab section per week. Lab sections average approximately twenty students. The following statements refer to the way that the lab is regularly run at Bucknell.

- Students complete a pre-lab reading assignment and quiz before the lab period. The reading assignment is approximately a page and a half long and discusses the concept and geometry of parallax. The quiz consists of four questions based on the reading.
- In lab, students typically work in groups of two. For the parallax lab, students work in pairs for the WWT component and in groups of four to six for the outdoor component and subsequent calculations.
- At the end of the lab period, students complete a quiz that is based on components of the WWT tour, measurements and calculations, and conclusions they've reached during the lab. The quiz is four questions long, and depending on the preference of the instructor, the students will either work individually or with their partner.
- The lab staffing usually consists of one instructor and one undergraduate TA who is not necessarily (and not usually) a physics and astronomy major.

Lab Activity	Approximate Time for Students to Complete
Pre-lab reading and quiz	20 minutes (typically done before the lab period)
WWT tour	30-40 minutes
Outdoor measurements and calculations	60 - 90 minutes (see notes on shortening)
Post-lab quiz	20-30 minutes

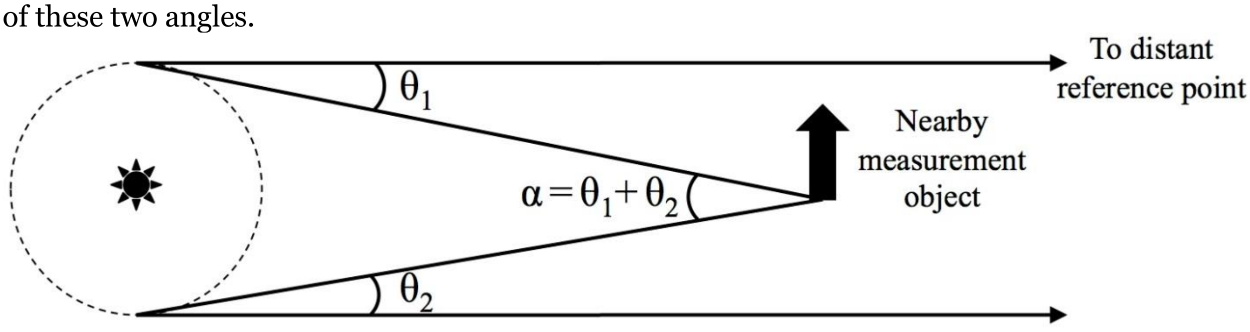
2. Location Criteria and Selection

When choosing the measurement object for this lab, here are some guidelines to keep in mind.

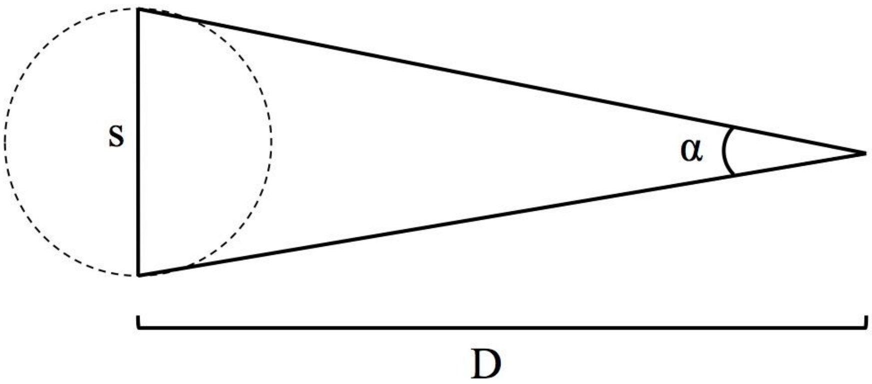
At Bucknell, the location used is in a quad toward the edge of campus. Lampposts are used as the measurement objects (i.e., those objects for which parallax distance measurements will be obtained), and distant electrical towers or smokestacks are used as reference objects.

Measurement Object Distances

The distances to the objects the students will measure are determined by two factors: angle measurement uncertainties and the string length (which determines the maximum baseline). Below is a diagram of an example setup for this lab using a simple geometry where the nearby measurement object and the distant reference point are located in nearly the same direction. The star shape on the left indicates the position of the "Sun," and the dotted circle denotes the "Earth's orbit." Here, $\boldsymbol{\theta_1}$ and $\boldsymbol{\theta_2}$ are the angles between the nearby object and the distant reference point, measured from the two sides of the "Earth's orbit." The angle $\boldsymbol{\alpha}$ is then the sum of these two angles.



The triangle that the students then use to determine distance is shown in the figure below. Students at Bucknell use a relationship called the Observer's Triangle, shown to the right of the figure. Here, **D** is the distance to the object, **s** is the total separation of the two angular measurements, and **k** = 57.3 degrees = 206265 arcsec (for a more complete description of this relationship, please refer to the following page: http://www.eg.bucknell.edu/physics/astronomy/as102-spr99/specials/obstri.html).



$$\frac{\alpha}{k} = \frac{s}{D}$$

a. Measurement Uncertainties

The distances to the objects that the students measure in this lab are limited in the extremes by the minimum and maximum angles that can be measured. When using the transits, the smallest angle that students can measure with reasonable certainty is two degrees. Below this value, the uncertainty in their measurements is on the order of their measured value. Regardless of measuring device used, the small angle approximation requires that the measurement angles not exceed ten degrees.

For the Bucknell string length of 2 meters (**s** = 4 m) and the minimum angle measurement of 2 degrees (**α** = 4 degrees), the observer's triangle equation yields a maximum distance of 57.3 m. For the same string length and the maximum angle measurement of 10 degrees (**α** = 20 degrees), the observer's triangle equation gives a minimum distance of 11.5 m.

b. String Length

The string length also determines the range of measurement object distances because it affects the maximum separation that the students can achieve. Using the minimum and maximum angle restrictions described above, a string length of 1 m (**s** = 2 m) gives a distance range of 5.73 to 38.7 m. A string length of 3 m (**s** = 6 m) will allow for a distance range of 17.2 to 86 m.

A string length of 1 m allows students to measure very close objects, but the total distance range is limited. Using a string with a length of 3 m gives a very large range of distances over which to measure, but has the downside that the range might be too large for the average campus. A string length of 2 m is a desirable middle ground between these two options. Bucknell students tend to measure objects that are approximately 30-40 m away.

Reference Object Distances

The reference object being used must be much farther away from the observer than the measurement objects, so that its apparent position does not change as the observer moves between the two measurement positions. Practically, this means that the reference object should be distant enough that the change in apparent position is smaller than the transits' ability to measure. When using the transits, the smallest angle that can be determined is half of a degree, which can be used to determine a minimum reference object distance. Assuming then that $\alpha = 1$ degree ($\theta_1 = \theta_2 = 0.5$ degrees), the minimum distance to the reference object is 229 m (assuming a string length of 2 m).

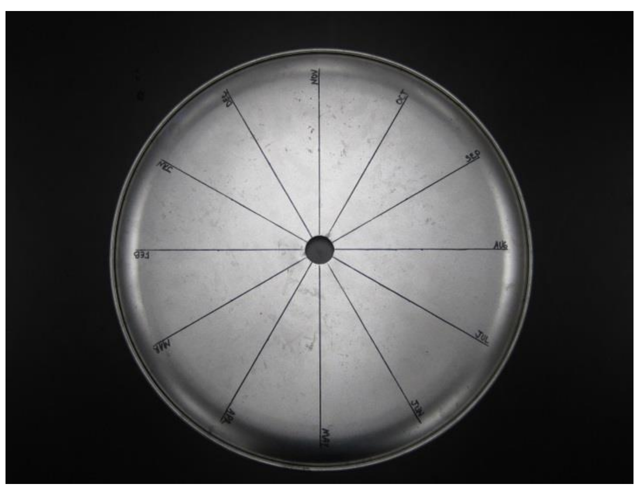
3. Equipment List and Suggestions

Surveyor's transit

Bucknell students use surveyor's transits in lab to make precise measurements of angular separations for this lab. They are mounted on tripods and have built-in levels.

Month tracker

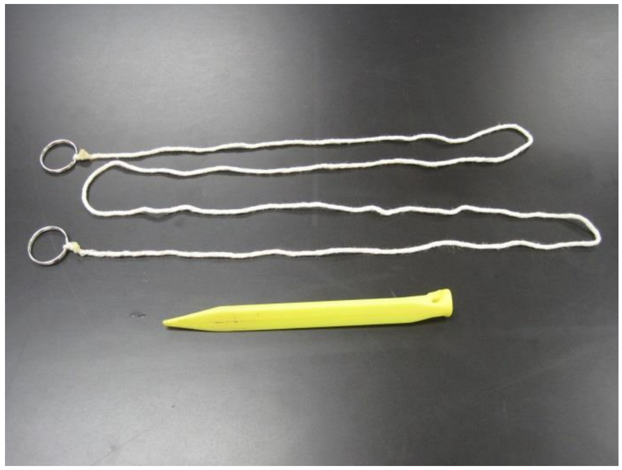
Pizza tins with the months of the year written on them are used to mimic the Earth's motion about the Sun. Students place a plastic stake in the ground to denote the position of the Sun and use a string originating from the stake and lined up along the markers on the pizza tin to trace out the Earth's orbit.

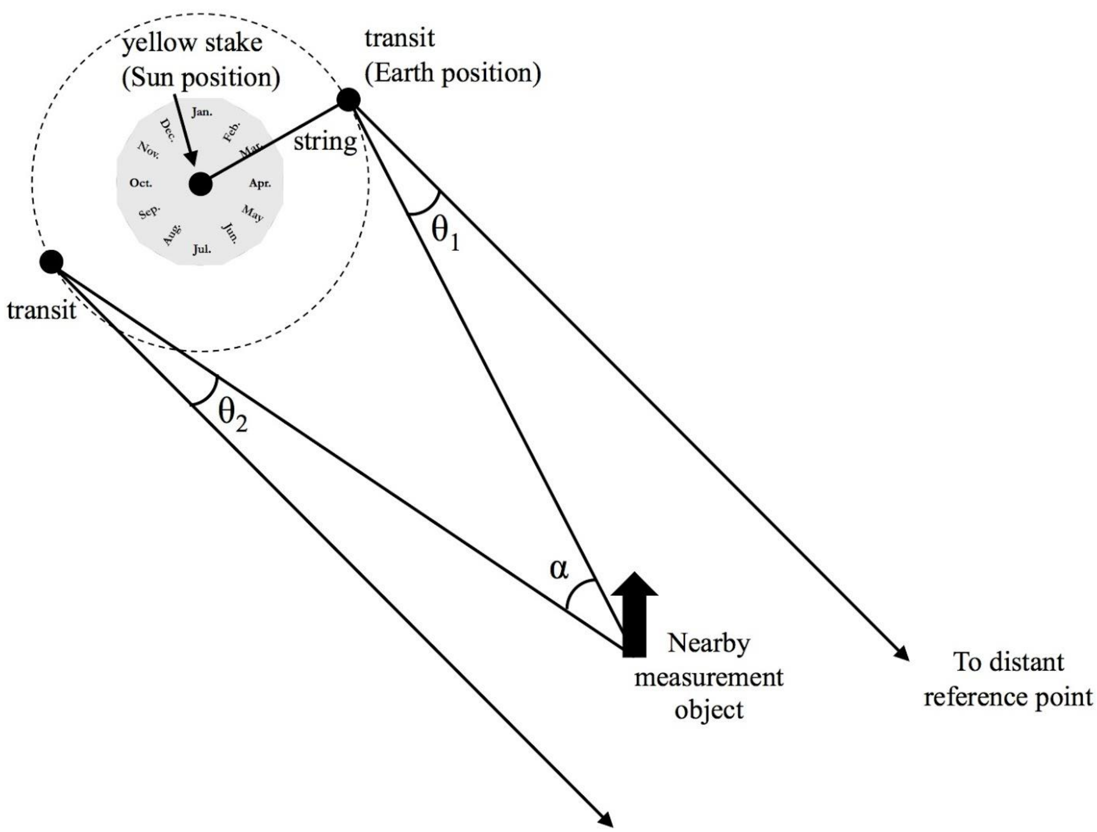


The size or material of the month tracker is not important, as long as the months are clearly marked on the face of it in such a way that students can make a straight line from the center to a point on the edge. Having a way for the students to secure a string to the center, such as a hole or hook, would be ideal.

Sun/String/Earth location marker

Bucknell uses a yellow stake to represent the Sun, which sits at the center of the month tracker. A 2 m string with loops on the ends is used to help students mark the position of the Earth around the Sun.





4. Software Requirements and Suggestions

- WorldWide Telescope must be installed on the Windows PCs being used for the lab, in order for the tour to run. WWT can be downloaded here: http://worldwidetelescope.org/Download/ .
- The WWT Ambassadors page has resources for learning how to install and use WWT here: http://wwtambassadors.org/learn-how-use-worldwide-telescope .
- Bucknell stores the tour on a campus server that all students can access, instead of putting a copy of the tour on each lab computer.
- Bucknell also found it helpful to have the students access a link to the tour itself, instead of opening WWT and then loading the tour.

5. Suggestions for Shortening and Modularizing the Lab

This lab can be shortened by skipping the last page, which has the students use the Observer's Triangle to calculate the height of the measured objects using the distances they determine. There are also two distance measurements in the lab: one for a closer object and one for a farther object. Students could find the distance to only one of these objects in order to shorten the lab.

If a three hour time slot for this lab is not possible, it can be split up into three parts that would each take approximately one hour to complete. Considering the time estimations given in the description of Bucknell's lab at the beginning of this document, the first hour of the lab would consist of the pre-lab reading assignment and quiz and the WWT tour. The second hour would be used to have the students take the outdoor measurements and calculations. The last hour could be spent concluding any remaining calculations and analysis, discussing the results, and doing the post-lab quiz.