ASTR 121 – Spring 2016

Lab 2 – Stellar Parallax

Important dates:

- Prelab due: Monday, [Date TBA]
- Rough draft due: Monday, [Date TBA]
- Final draft due: Friday, [Date TBA]

Science Goals:

At the end of this lab, you should be able to…

- Use stellar parallax to calculate the distance to stars

MATLAB Goals:

In this lab, you will apply MATLAB knowledge to….

- Create a function in a program file
- Create and use arrays
- Plot data with error bars

Background

Of all the techniques astronomers use measure the distance to objects, the most fundamental is parallax. Parallax is the apparent shift of an object as compared to a more distant object as the perspective of the observer changes. This phenomenon can be observed simply by looking at your thumb in comparison to a distant object while closing your left, then your right eye. Depending on the distance of your thumb to your eyes, it will appear to move a different amount.

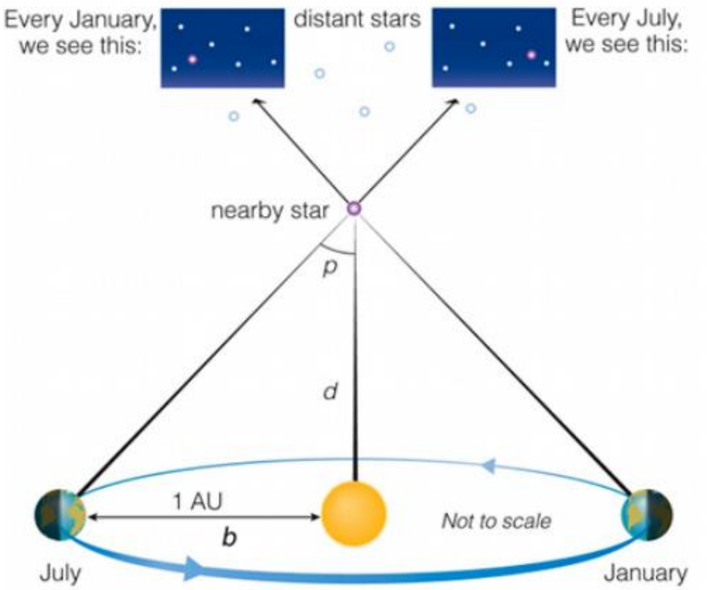

Figure 1: Parallax using Earth's orbit as the baseline. Adapted from *The Cosmic Perspective, Sixth Edition*

Similarly, as the Earth moves around the sun, we observe distant stars from different angles, as illustrated in Figure 1. If stars are close enough, our change in position is enough to create an apparent change in the position of the star. By measuring the amount that a star appears to move, one can calculate the distance to the star.

The distance is found using the simple trigonometry of a right triangle. From the tangent of the angle p, we get:

$$\tan p = \frac{b}{d}$$

where d is the distance to the object of interest, and b is the baseline. Note that the parallax angle p is only half of the total angular displacement of the star.

In astronomical cases, the angles are typically small enough that the small angle approximation ($\tan p \sim p$) can be used. Then the equation can be written as:

$$p = \frac{b}{d}$$

where p must be in radians, and the units of the baseline b and distance d need to cancel out in order to achieve appropriate units for p. For this lab, we will be restricting ourselves to small angles.

A useful unit to use in measurements of parallax is the parsec, which is defined as the distance to an object with a parallax angle of one arcsecond, as observed from Earth's orbit (a baseline distance b of 1 AU). By this definition, the parallax equation becomes:

$$p_{\text{arcsec}} = \frac{b_{\text{AU}}}{d_{\text{pc}}}$$

Where p must be in arcseconds and d in parsecs. For Earth-based observations of stars, this becomes:

$$p_{\text{arcsec}} = \frac{1}{d_{\text{pc}}}$$

About the Data

You will be given 10 sets of data for this lab. Each set of data will include two images of the same field of view, taken six months apart. Look at the different data sets, and take notes on any differences you see and how these differences might affect the way you take measurements.

In each set of images, two stars are circled in red: these are <u>not</u> the stars to be used for the parallax calculation. The circled stars will be used for calibration.

Each data set has one star that is a good candidate for a stellar parallax calculation, that is, one star that visibly changes in position. This is the star you will calculate the distance to. Note that the maximum angular displacement of the star is shown in these images; they were carefully timed as to show the full parallax shift.

You will also be given a list of distances to the same ten stars. Imagine these were calculated from the Hipparcos satellite. You will use your data to refute or verify the 'Hipparcos data'.

Measurements

For each pair of images, you will determine the plate scale s and the apparent separation a of a star between the two images.

1. You will be making your measurements with a ruler. Determine the precision with which you will be able to make measurements with it.

2. The plate scale relates the angular distance in an astronomical image to a length across that image (e.g., an image may have a plate scale of 75 arcseconds per millimeter). In order to determine the plate scale, measure the distance between the circled calibration stars and assign an uncertainty to this measurement. Using the given angular separation of the calibration stars, calculate the plate scale s and its uncertainty for each data sat.

3. Measure the apparent distance a each star appears to move. This may be more difficult for certain images; measure them however you see fit, but justify your methods. What is σ_a?

Calculations and Analysis

1. Create an array in MATLAB of the measured apparent distances a. Create a second array of the determined plate scales s. Make sure the order is the same (e.g., the first element of both arrays refers to the same image pair, etc.).

2. Both the determined plate scale and the measured distances have uncertainties. Therefore, any calculation done with these values will have a propagated uncertainty. Remembering that parallax angle is half of the angular separation (refer to Figure 1), determine equations to calculate parallax angle p and its uncertainty σ_p, using the formulae for propagation of uncertainty. Does σ_p change for differ different measurements of p? What about σ_s and σ_a?

3. Write a function to convert apparent distance into parallax angle. There should be four inputs: an array of apparent distances, an array of corresponding plate scales, and the errors in these sets of values. It should have two outputs: parallax angle and uncertainty.

4. Once the initial function is operational (it's always a good habit to check for bugs before making your code more complicated), add to it so that it also outputs the distance to the object *d* and its uncertainty σ_d. Note that error propagation for division is the same as that for multiplication (e.g., f=xy has the same error propagation equation as f=x/y or f=1/xy)

5. You should now be able to use your function to calculate object distances from apparent separation and plate scale. To check for errors, calculate the object distance of the first image pair—as well as its uncertainty, of course—and compare it to the output of your function. Once you're sure it's bug-free, record your values for *a*, *s, p*, and *d* for star 1 on the whiteboard.

6. Once you have the calculations complete for all ten data sets, compare your results to those from the Hipparcos data (given in this lab, not from the Astrobites article). For each star, calculate the difference between your result and the distance measured from Hipparcos, and plot this. The plot should have the ten data sets on the x axis and the difference between your data and the Hipparcos data on the y axis. On the y axis, include error bars, using your propagated uncertainties for the distances. This plot is called a residual.

7. For data set 1, use the class's collective data to calculate the average distance to the star. Determine a method of assigning an uncertainty to this average. Plot the data in a histogram.

Report

Your report should contain the following:

1. *Cover page*: Follow the model and guidelines in the rubric.
2. *Abstract:* In a paragraph or two, summarize the scientific purpose of the lab, what was done, the results, and your conclusions.
3. *Introduction:* In several paragraphs, discuss the background information regarding the purpose of the lab and its goals.
4. *Methodology:* Explain the procedure you used to take measurements and collect data from the given images. Additionally, describe the data you were given to do the lab. Make sure to state any decisions made in how you made your measurements. Another scientist should be able to repeat your data collection based off of your methodology and obtain similar results. Show and explain any equations used to calculate values.
5. *Analysis:* Present your data both for your own calculations of the entire data set as well as the class's collection of data for data set one. Include a table of parallax angles and distances to all stars (with uncertainties), a plot showing the residuals of your data and the Hipparcos data, and a chart and plot showing the class's measurements for image pair 1 Show and explain any equations used for calculation of uncertainties.
6. *Discussion:* Discuss the quality of your results, comparing them to the given distances. Discuss the sources of error in your measurements and calculations, and distinguish them as random or systematic. Consider both accuracy and precision, citing your uncertainties in your discussion. Additionally, answer any other questions asked in this hand-out.
7. *Appendix:* Include the function you wrote for your calculations and the inputs you used in it. I should be able to run your script function with the inputs you give and get the same results.

Remember to upload any functions and scripts as .m files on ELMS, as well as a PDF of your lab report.