Astronomy 102 Lab: Stellar Parallax and Proper Motion

If you own a laptop, please bring it to class. You will use Stellarium again. The Stellarium shortcuts you used in the first lab are on the inside cover of your lab packet and on the website.

Pre-Lab Assignment: When we look up at the night sky night after night, we see that stars rise and set regularly. Over the course of the year, we see different constellations. However, we notice that the constellations look exactly the same every time we see them; stars seem to be absolutely fixed relative to each other. We know now that the positions of stars in the sky do actually change. In this lab, you will be studying these changing star position over the course of the year and over the course of many years. Answer these questions before coming to lab.

A) What is "parallax?"

B) Can you measure the parallax of a star 1,000 light-years away? Why or why not?

C) If Star A has a parallax of 0.15 arcseconds and Star B has a parallax of 0.18 arcseconds, which star is closer?

D) If stars are moving around at hundreds of kilometers per second, why don't we see their positions change relative to each other within a few nights or even a few hours of time?

A. Parallax: Astronomers have been studying stars for thousands of years, but the first accurate measurements of their distances were not made until the 19th century. Here we examine the most direct method for determining distances to stars.

We'll start with some basic observations using parallax. Place two white board markers in a line on the table. Stand approximately one meter from the markers and move to where the markers are exactly in line with each other. Now, move one small step to either side.

1. Which marker appeared to move more?

Move back so the markers are in line and take two steps in the same direction as before.

2. Do the markers appear to move more than or less than they did in Question 1?
Now, move to a distance of approximately two meters from the markers and stand at a position such that the markers are in line. Move one small step to either side.

3. **Do the markers appear to move more than or less than they did in Question 1?**

You are observing parallax at work. Astronomically, we talk about the shift in the apparent position of a nearby star with respect to background stars (stars which are much farther away). This occurs as the Earth orbits around the Sun. The position from which we view the star changes slightly, just as your position changed slightly relative to the markers as you took steps to one side or the other.

Now, turn your attention back to the light table. You will find two star fields from January 1 and July 1. The pages show photographs of the same part of the sky, taken 6 months apart when the Earth was at opposite sides of its orbit. Careful observations will reveal that four stars on the photographs move from one picture to the next. To find these stars, overlay the images on the light table, making sure that the star images are on top of one another. Be sure to align the images carefully!

4. **The star field included on the next page is strictly for recording your answers; don’t try to line it up with any of the fields on your light table. Find the four stars which move on your star field and circle them on the image on the next page. (Do not write on the star fields on the light tables!)** Label the stars with the numbers 1–4.

5. **For each of the four stars, measure, in centimeters, how far the star has moved over a period of six months and record this in the data table. Note the scale of the photographs is 1 cm = 1'' (arcsecond)! Make all your measurements from the center of the black dots. Divide this distance by two to get the parallax in arcseconds and then use the following formula to acquire the star’s distance in parsecs (pc):**

\[
\text{distance (pc)} = \frac{1}{\text{parallax (')}}
\]

<table>
<thead>
<tr>
<th>Star</th>
<th>Measured Distance (cm)</th>
<th>Parallax (')</th>
<th>Distance (pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td>2</td>
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<td>3</td>
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<td></td>
<td></td>
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<tr>
<td>4</td>
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</tbody>
</table>

6. **One of these objects shows too great a parallax to be a star. Which object is it? Where do you think this object is located if it is not a star?**

7. **Although the use of parallax measurements to determine distances is a very powerful technique, the method has a major drawback. Why is this the case?**

8. **We are not seeing the motion of the stars through space in these images. Why do the stars appear to move?**
9. Why do you divide the measured distance by two to get the parallax? If you aren't sure, consult the diagram to the right from Wikipedia.

10. Imagine that we were on Mars instead of Earth, which has a larger orbit. Would it be easier or harder to detect parallax angles for nearby stars as Mars orbits the Sun? Explain your answer.
**B. Proper motion:** Thus far in class, we've dealt with the stars as if they were fixed relative to each other. They rise and set during the day and they change their positions as the seasons change, but they always appear to be in the same place relative to each other. That is what has allowed astronomers to set up maps of the night sky, celestial spheres; they know that the maps they create will be accurate for years to come.

However, the Sun and every other star in the Galaxy are moving in orbits around the center of the Galaxy. Beyond this ordered motion in the Galaxy, stars also have a unique velocity specific to themselves. When observing the stars in the night sky, these two motions of the stars combine and after many years of careful observations, we can see some stars shift positions relative to other stars. This change in position of the stars on the celestial sphere is called *proper motion*.

In this section of the lab, you'll be analyzing the proper motions of several stars using Stellarium and figuring out what the relationship is between the distance to the star and the proper motion we are likely to see for it. Start by opening up the Stellarium program. You can take the software out of full-screen mode.

The Stellarium shortcuts you used in the first lab are on the inside cover of your lab packet and at this URL. http://natsci.parkland.edu/ast/101/shortcuts2.pdf

Open the Configuration window and select the Information tab. **Uncheck** every box for the "Displayed fields" except the following: Name, Right ascension/Declination (J2000), and Distance. Close the Configuration window.

Remove the atmosphere and the ground. You are now able to see the entire night sky without any interference. In order to keep the view relatively stable, we need to switch the view from an azimuthal mount to an equatorial mount. Click the button to the right of the Saturn button or type "**Ctrl+M**" ("**Command+M**" for Macs). When it is in equatorial mode, the button is lit. You are now ready to start looking for proper motion.

Let's start with the star that has the largest proper motion: a star called Barnard's Star. Use the Search window to find this star. You should now be centered on the star and its information should be displayed.

**11. What is the distance to Barnard's Star in light-years (ly)?**

Turn on the constellation boundaries and the constellation labels.

**12. Which constellation is Barnard's Star currently located in?**

Magnify your field of view (FOV) until it is just less than 0.5°. There should be only about five stars in the field, including HIP 87901. Select and center on HIP 87901. If Barnard's Star has left the view, increase your field of view. Select Barnard's Star again. This will allow HIP 87901 and other stars to remain stationary and you can easily track Barnard's Star.

The spreadsheet at the following URLs includes right ascension and declination (J2000) for Procyon. In the line for the current year, replace the RA/Dec (J2000) values with those for Barnard's Star. Type only the numbers and include any negative signs.

**Excel:** http://natsci.parkland.edu/ast/102/labs/propermotion.xls
**OpenOffice:** http://natsci.parkland.edu/ast/102/labs/propermotion.ods
Open the Date and Time window. Make sure this inset window isn't blocking your view of either HIP 87901 or Barnard's Star. Move forward in time by 25 years. For the later date, record the new right ascension and declination (J2000) for Barnard's Star in the next line on the spreadsheet. The formulae saved in the spreadsheet will automatically calculate the change in position for Barnard's Star.

13. How far has Barnard's Star traveled? This is the "total change" listed in bold. Include units.

Proper motion is generally expressed in arcseconds per year ("/yr). Since we used a 25-year time step to make it easier to measure the angle, we now need to divide our previous answer by 25 years to get Barnard's Star's proper motion in arcseconds per year.


The human eye can only distinguish angles that are larger than 1 arcminute (1') or 60".

15. If you are observing Barnard's Star strictly with the naked eye, how many years would you need to watch the star until you noticed that it has moved relative to the other stars?

We would now like to convert the proper motion of Barnard's Star to its actual velocity in space, or at least the part of its velocity which is in the plane of the sky. The relationship between proper motion and distance is given by the equation:

\[ \text{velocity (km/s)} = 1.45 \times \text{proper motion ("/yr) \times distance (ly)} \]

16. Using the equation given above, calculate the velocity of Barnard's Star.

For reference, the velocity of the Sun around the center of the Galaxy is roughly 220 km/s.

17. Compare the velocity of Barnard's Star to that of the Sun. Calculate the ratio by dividing Barnard's Star's velocity by the velocity of the Sun.

Center on Barnard's Star again. Increase the field of view to about 4°. In the Date and Time window, we are going to advance time by decades. Click on the year and hold down the "Page Up" key (Fn+down arrow for Macs). Continue to do so and watch Barnard's Star until it crosses over into another constellation. This should give you the idea that the constellations we see change only on very long time scales.

18. What constellation did Barnard's Star move into? Around what year did this happen?

To finish the lab, we'll explore the relationship between a star's distance and its proper motion. To do so, let's look at some bright stars in the night sky.
Return the time to the present day. Find the star Sirius and select it. Record its distance from the Solar System. Repeat the procedure you followed to determine the proper motion of Barnard's Star using the spreadsheet.

19. Record the distance to Sirius from the Solar System and its proper motion which you calculated in the table below. Do the same for the remaining the stars in the table below. Include units.

<table>
<thead>
<tr>
<th>Star</th>
<th>Distance</th>
<th>Proper Motion</th>
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</thead>
<tbody>
<tr>
<td>Sirius</td>
<td></td>
<td></td>
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<tr>
<td>Altair</td>
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<td>Vega</td>
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<td>Aldebaran</td>
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<td>Polaris</td>
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<td>Deneb</td>
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</table>

20. Based on the table you've just completed, describe the relationship between a star's distance and its proper motion.

21. Explain how stars can have large velocities and yet have small proper motion values.