Purpose of the Experiment

- To introduce you to some basic ideas of observational astronomy, including coordinate systems, celestial navigation, the magnitude scale and calculating distances to stars.
- To understand what light pollution is, the problems it causes, and its solutions.
Background Information

This lab will explore concepts of the Celestial Sphere by performing celestial navigation calculations based on data obtained from a meridian transit observation of a single star. With this exercise, you will be able to calculate your position on Earth with relative accuracy. Additionally, you will learn about the stellar magnitude system with which the brightness of stars are categorized.

The Celestial Sphere and Celestial Coordinates

While the use of the Horizon coordinate system is convenient for measuring the position of a celestial body at a particular point in time, it is limited in the sense that a star’s Horizon coordinates will change within a short amount of time. Thus, a system in which a star has fixed coordinates is more useful in providing an actual map of the sky. Astronomers use a grid of **Celestial coordinates** in order to provide just that. This coordinate system maps the night sky according to a grid, called the **Celestial Sphere**, which is an extension of the longitude and latitude system on Earth, but projected onto the sky. See Figure 1 for a labeled diagram of this system.

![Figure 1](davidpratt.info/earth)

**Figure 1:** The Celestial Sphere, showing example right ascensions and declination lines. Image credit: davidpratt.info/earth
Instead of making use of the terms longitude and latitude, the Celestial Sphere uses **right ascension** and **declination**, respectively. Declination, the Celestial Sphere’s latitude, spans from -90° (or 90°S) at the South Celestial Pole, to 0° at the Celestial Equator, to +90° (or 90°N) at the North Celestial Pole. Right ascension, the Celestial Sphere’s longitude, increases Eastward from a location on the Celestial Sphere known as the Vernal Equinox. This is the point at which the Celestial Equator is intersected by the Ecliptic (the path of the Sun mapped on the Celestial Sphere), where the Sun would move Northward past this point during the month of March. Unlike longitude, however, right ascension is measured in hours instead of degrees. Historically, this convention was conceived due to the importance of measuring a star’s position in the sky at a specific point in time, as the diurnal motion of the Celestial Sphere causes the stars to appear to move with respect to one’s point of observation on Earth. Because the Earth rotates at a rate of about 360° in 24 hours, right ascension is measured from 0 to 24 hours.

It is important to remember the co-alignment between Earth and the Celestial Sphere, as indicated previously. This means that a coordinate in Earth latitude is equal to a coordinate of declination, and an “hour angle” in right ascension corresponds to a 15° angle of longitude on Earth (since Earth rotates at 15°/hour). Figure 2 demonstrates this co-alignment.

![Figure 2: Depiction of the Celestial Sphere surrounding the Earth, showing coord reference lines for both the Celestial coordinate system and Earth latitude and longitude. Image credit: jrjohnson.net/wp-content](image-url)
A useful way to demonstrate the link between the Celestial Sphere and Earth coordinates is to practice a celestial navigation technique similar to that used by sailors, explorers, and anyone in need of finding their position on Earth, throughout history. The basis of this method involves calculating your longitude and latitude coordinates by finding the local time that a star transits (or crosses) your local meridian (a reference coordinate line passing from North to South in the sky, directly overhead), and measuring that star’s altitude in the sky during this event. To do this accurately you will need a clear night sky, a clock, an astrolabe, knowledge of your local time zone, and some ability to correct for factors that affect accurate time calculations regarding transit measurements.

To find your latitude, the simplest method is to measure the altitude of the Celestial Pole relevant to the hemisphere on Earth (North or South) encompassing your location. In the Northern hemisphere, the star Polaris can be used as it is very close in position to the North Celestial Pole. Because of this, it is also known as the North Star: if you stood at Earth’s North Pole (90°N latitude), Polaris would be directly overhead (90° altitude). Were you to travel South from that position, Polaris would decrease in altitude until you reached Earth’s Equator (0° latitude), where it would basically be on the horizon (0° altitude). Therefore, the altitude of Polaris as seen from anywhere in the Northern Hemisphere is equal to the latitude of that location.

However, Polaris does not provide a useful means of determining one’s longitude. Thus, observing other stars during their meridian transit provides better data with which to calculate your position on Earth. The altitude of a star during its transit, while not equal to your latitude, can be used to derive your latitude with some extra calculation. Figure 3 demonstrates the arrangement of angles that provide this relationship, which you will use later in the lab.

The local time that a transit occurs actually contains information about your longitude on Earth, due to Earth’s known rotation rate and the layout of the Celestial Sphere with respect to Earth coordinates. The simplest way to think about this is that your time zone standards have a known difference in hours from the global time zone standard, Universal Time (UT, also known as Greenwich Mean Time), corresponding to 0° Earth longitude which runs through Greenwich in the United Kingdom. For a
transiting star, its right ascension coordinate, now aligned with your local meridian, can also be thought having a difference in hours from the right ascension aligned with the local meridian over Greenwich, UK. Because the Earth longitude system is linked to the Celestial Sphere’s right ascension system by design, determining the Precise time that a star transits therefore provides you with a difference in hours which can be converted to degrees of longitude, allowing you to calculate your longitude coordinate on Earth. However, navigators must take care to provide a correction to this time difference; clocks we use record Solar Time whereas the Celestial Sphere rotates according to Sidereal Time, and the coordinates of stars on the Celestial Sphere change slowly with time due to imperfections in Earth’s motion of spin. You will become more familiar with this process through the steps in the Analysis section of this lab.

![Figure 3: A cross-section of the Celestial Sphere according to an observation of a transiting star from one’s local horizon. With careful consideration of this geometry and knowledge of the star’s declination coordinate, one can demonstrate that their latitude on Earth can be calculated from a measurement of the altitude of the star when it transits.](image)
The magnitude scale is a scale for indicating the brightness of objects in the night sky. The key features of the scale are:

- The zero point on the scale is roughly based on the star Vega, which has a magnitude close to zero of -0.03.

- More negative values on the scale indicate brighter objects. Thus, an object with a magnitude +1 is dimmer than an object with a -1. Similarly, +3 is dimmer than +1. This is somewhat counterintuitive. The reason for this is that when the scale was first created around 2000 years ago by the Greek astronomer Hipparchus, he gave the 1\textsuperscript{st} brightest group of stars in the sky a magnitude 1, the 2\textsuperscript{nd} brightest group were given a magnitude 2, etc. Later, when more accurate measurements of the brightness of stars became feasible, it was discovered that some stars are brighter than first magnitude and thus were assigned negative numbers (i.e. 0 being brighter than +1, and -1 being brighter than 0, etc.).

- The differences in brightness on the scale are based on a change of 5 magnitudes corresponding to 100 times the brightness. Thus, a change of 1 magnitude on the scale is \( \sqrt[5]{100} = 2.512 \). Thus, it is a logarithmic scale.
With these key features in mind, the magnitude scale looks like this:

![Diagram of the magnitude scale]

Figure 4: The astronomical magnitude scale.

Using this scale, it is easy to determine how much brighter or dimmer one object is compared to another if you know their magnitudes. For example, a magnitude +4 object is brighter than a magnitude +6 object by a factor of:

$$2.512^{(6-4)} = 2.512^2 = 2.512 \times 2.512 = 6.310 \text{ times brighter}$$

In general, if you know the two magnitudes, the number of times brighter $N$ is given by:

$$N = 2.512^{\Delta M}$$

where $\Delta M$ is the difference between the two magnitudes.
We need to define three basic types of magnitude that are useful in astronomy: *apparent magnitude, absolute magnitude* and *limiting magnitude*. 

**Apparent Magnitude,** \( m \)  
The apparent brightness of an object as seen from Earth.

**Absolute Magnitude,** \( M \)  
A measure of the brightness of an object (either intrinsic brightness or due to reflected light in the case of planets). For stars, the absolute magnitude is equal to the apparent magnitude of an object if it were viewed from a distance of 10 parsecs (32.62 light-years or \( 1.917 \times 10^{14} \) miles).

**Limiting Magnitude**  
The faintest apparent magnitude detectable by a given instrument. This term usually refers to the magnitude of the faintest stars that can be seen with the unaided human eye. On a good, reasonably clear night this value is around +6.

There is a connection between an object’s apparent magnitude and its absolute magnitude: a bright object that is farther away will appear dimmer. Conversely, a dim object that is close by will appear brighter. This is why absolute magnitude is equal to a star’s apparent magnitude when viewed at a distance of 10 parsecs. If you could place all of the stars in the sky at a distance of 10 parsecs from the Earth, you could compare their intrinsic brightness directly to each other without having to account for differences in distance. It might occur to you that if you know a star’s apparent magnitude (which is relatively easy to measure) and a star’s absolute magnitude (which can be determined if you know something about how stars work), you can figure out how far away the star is. In fact, this is an easy calculation to perform:

\[
d = 10^{0.2(m-M+5)}
\]

where \( d \) is the distance to the star in parsecs, \( m \) is the apparent magnitude, and \( M \) is the absolute magnitude. Solving for the absolute magnitude in terms of distance, we have:

\[
M = m - 5[log_{10}(d) - 1]
\]
The Lab

Purpose of the Experiment:

To introduce you to some basic ideas of observational astronomy, including the magnitude scale and calculating distances to stars. To understand what light pollution is, the problems it causes, and its solutions. To give you a brief overview of *Starry Night College*.

Apparatus

- Windows PC (Indoors)
- *Starry Night College* (Indoors)
- Astrolabe
- Tripod
- Adhesive
- Bull’s-eye level
- Flashlight/headlamp with red cellophane
Part Ia: Celestial Navigation (OUTDOOR-ONLY)

*Skip to Part Ib if performing the lab indoors (page 17)*

In order to observe the transit of a star and accurately record its time, you must have an instrument calibrated to the Cardinal directions. Thus, an astrolabe will make a suitable instrument for this measurement, once calibrated so that the 0° mark on its azimuth dial points towards North. Consult the **Ready Time** listed for your night of observation in Table 1. **BEFORE** this time, you must complete the setup and calibration of your astrolabe as describe in the instructions below (through Step 9)

<table>
<thead>
<tr>
<th>Date</th>
<th>Ready Time (hh:mm, pm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 7</td>
<td>7:50</td>
</tr>
<tr>
<td>November 8</td>
<td>7:45</td>
</tr>
<tr>
<td>November 9</td>
<td>7:40</td>
</tr>
</tbody>
</table>

*Table 1: Your lab group must complete setting up and calibrating your astrolabe by the time listed for you date of observation.*

The *astrolabes* used in this lab (shown in Figure 5) are simplified versions of ones used throughout history to make measurements of stellar positions. While historical astrolabes were designed to measure both the Horizon and Celestial coordinates of stars, as well as provide a simple map of the sky for any time of the year, the ones used in this lab only provide Horizon coordinate measurements, but do so in a very simple and robust way. Each astrolabe has two rotational axes and two dials that provide angular measurements on the planes associated with those rotations. Acquiring any star through the astrolabe's sights will allow you to read the azimuth (the base's scale) and altitude (the tilting scale) coordinates of the star simply by looking at where the indicators are pointed with respect to the dials on both parts of the astrolabe. However, the astrolabe must be *calibrated* for these measurements to be true. For true altitude, the astrolabe must be level with the ground, and for true azimuth, the base align such that its 0° mark is pointed due North (or an azimuth offset from North must be known for data calibration later).
The tripods you’ll be using are fairly simple. Each tripod has adjustable legs (in length and separation from each other) that can be locked in place using the three leg-locks on each leg. These leg-locks are indicated in Figure 6. Additionally, the camera mount on the top of the tripod can be locked in its orientation using an altitude lock, azimuth lock, and tilt lock. Each of these locks are indicated in Figure 7.
While the directions for using the astrolabe is printed on the instrument itself, acquiring stars with its sights can be somewhat tricky, due to the narrow field of view of the instrument. Additionally, the plastic that the instrument is made out of is flexible, and if you aren't careful in keeping the instrument straight and stable, your readings will be imprecise. Use the following directions to ensure you collect good data during your observations.

1.) Once at Observatory Park, begin by finding the directions of North, South, East, and West (hint: the University of Denver is due West of Observatory Park). Once you've oriented yourself with the cardinal directions, set up your tripod with one leg pointing approximately North. You can set up your tripod either on the ground, with the legs fully extended, or on a nearby table if you have access to one. Note that you can adjust the length of the tripod’s legs by clipping or unclipping the three locks along the legs and extending or collapsing the legs to the desired length. Remember to re-lock each leg lock once you are satisfied with your tripod setup.

2.) Next, using a double-sided adhesive pad, attach the astrolabe to the camera mount atop the tripod (see Figure 8 for an example of this setup).
3.) Then place the bull's eye level on top of the astrolabe’s azimuth dial. Adjust the length of the tripod legs and make the surface of the mount level by observing the bubble inside the level until it is within its circle marking. Lock down the tripod's legs at this point and try not to bump the tripod for the rest of the observing session. If you do, you will have to double-check that the tripod is level and re-level it if necessary.

4.) To calibrate the astrolabe's azimuth dial, you will need to acquire Polaris (α UMi, the North Star) in the astrolabe's sights. In order to find Polaris, first find The Big Dipper, the asterism depicted in Figure 9. This asterism is located slightly West of North. If you cannot find it on your own, ask your TA for assistance. The portion of The Big Dipper that is currently lowest in the sky may be hard to see due to Denver's light pollution.

5.) Once you can identify The Big Dipper, note the two stars that form the edge of the “cup” portion of the dipper. The lower of these two stars will be the lowest star in the asterism. Facing the asterism, the upper of the two, called Dubhe, will be brighter, a
little higher and to the right of the lower. These two stars are referred to as the
“pointer stars”, as you can use them to envision a line that points approximately to
Polaris, which will be the next obviously bright stars along that line. Use this method
to find Polaris now.

6.) **Polaris** is referred to as the North Star since it is at a point in the sky nearly in-line
with where the Earth's North Pole points, if the North Pole were considered to be an
imaginary line pointing from its location on Earth into space. In other words, finding
**Polaris** allows you to find due North form your location. At this time, sight **Polaris**
by crouch or kneel behind the astrolabe and begin tilting the altitude axis of the
instrument toward the star's position in the sky. Once at the approximately correct
altitude, use both your eyes, looking along the astrolabe's sights, and adjust the
astrolabe so it is pointed directly towards the star you wish to measure.

7.) Have a group member make sure that the astrolabe is stable and that it's vertical
portion is straight up and down during this next step. Close one eye and with the
other, look through the astrolabe's sights and try to acquire the target star in the
instrument's field of view. A good methodology for this is to look through the sight
closest to your eye at an angle so that you can see the star you wish to acquire, but
outside of the sight farthest from your eye. Next, while continuing to look through the
sight closest to your eye, move the astrolabe in small amounts so that you begin to
eclipse the target star with the sight farthest from your eye. Once the star is eclipsed
by the other sight, keep moving the astrolabe in the correct direction to get the star
exactly in the field of view of the further sight.

8.) Once sighted on **Polaris**, rotate the base of the astrolabe (or the head of the tripod by
loosening the azimuth lock **slightly**) until the azimuth dial reads 0° while Polaris is
sighted. Record the altitude reading of the astrolabe to the nearest 0.5° in the field
provided below.

| Altitude of Polaris (°) |

**NOTE:** If the tripod or Astrolabe get knocked out of alignment during the lab, you
record a new azimuth offset by re-sighting **Polaris** using the procedure above. **Be
sure to make note of what measurements the re-recorded offset corresponds to.**
9.) Once your astrolabe is North-aligned, make sure the azimuth-lock of the tripod is re-tightened (if you used it), and rotate the astrolabe so that the azimuth dial reads exactly 180°, while remaining North-aligned.

10.) Find the star, α Peg (Markab) in Pegasus using the star map in Figure 10. Pegasus is currently high above the Southern horizon (the square pattern will be between altitudes of 60° to 70°). Note that the diagram in the figure is tilted with respect to how you will see the constellation in the sky this evening.

Figure 9: The Big Dipper (asterism) portion of the constellation Ursa Major.

Figure 10: The constellation Pegasus. Markab is the α star that is labeled.
11.) Once you’ve found \( \alpha \) Peg, use the Astrolabe to check to see if the star has transited: keep the astrolabe pointed at 180° azimuth but adjust the altitude to see if the star is in its field of view. By definition, transit will be when you can see the star through the astrolabe while the astrolabe reads 180° azimuth. The transit will occur a short time after the Ready Times listed in Table 1. So, if you are set up well before the ready time, you can leave your astrolabe alone and wait until then before taking any measurements (you may start Part II of the lab if this is the case, but don’t forget to start checking for \( \alpha \) Peg’s transit once your clock reads that night’s Ready Time).

12.) Once your clock reads the Ready time, start checking to see if \( \alpha \) Peg has reached transit. Keep checking approximately every 30 seconds until you can see the star through your astrolabe, while the astrolabe’s azimuth dial reads 180°. Once transit has occurred, immediately record the time, and the altitude of \( \alpha \) Peg into the fields provided below.

<table>
<thead>
<tr>
<th>Time of Transit for ( \alpha ) Peg (hh:mm)</th>
<th>Altitude of ( \alpha ) Peg at Transit (°)</th>
</tr>
</thead>
</table>

Proceed to Part IIa of this lab, on page 18.

**Part Ib: Celestial Navigation (INDOOR-ONLY)**

Due to the unpredictable nature of weather, it is an unfortunate reality that your GTA may have decided to take you to the lab room to perform your measurements indoors using the *Starry Night College* software.

1.) At a lab computer, open the *Starry Night College 6*. Click on the File menu, then click “Open”. Find and open the file “Markab Transit”, found in the Celestial Navigation & Stellar Magnitudes folder via the 21st Cen shortcut on the desktop of the computer you are using. Once open, you will see a view of the night sky in the software for the current date, with the local meridian already displayed.

2.) Use the “Stop Time” button to stop the flow of time in the software. Next, change the time listed in the upper-left of the screen to the “Ready Time” listed in Table 1 for the night your lab is meeting.

3.) Press CTRL+F to open the “Find” pane in the software and type in “Markab”, then press enter. This will show you the star on-screen and should center your view. If your view is not centered, right-click the star and left-click “Center” in the pop-up menu.

4.) Change the “Time Flow Rate” to 300x and press play in order to observe Markab approaching the local meridian. Once Markab is exactly on the meridian, press “Stop Time” to pause the software. Record the time of day listed in the upper-left (including hours, minutes, AND seconds), and approximate the latitude of the star using the
markings shown on the meridian. Write these two values down in their respective fields in Table 1.

<table>
<thead>
<tr>
<th>Time of Transit for α Peg (hh:mm:ss)</th>
<th>Altitude of α Peg at Transit (°)</th>
</tr>
</thead>
</table>

Proceed to the indoor Magnitudes portion of this lab, Part IIb (page 21).

Part IIa: The Magnitude Scale (OUTDOOR-ONLY)

*Skip to Part IIb (page 21) if doing this lab indoors.*

In Table 2, you will find a list of stars and magnitudes for the stars in the constellations Lyra and Cygnus. The first 6 stars in this list have their approximate apparent magnitudes marked with an X under the number corresponding to that magnitude. **These stars will serve as calibration stars for the evening**, and you will use the given magnitudes of these stars to characterize the brightness of each other star in the list.

1.) Start by finding the constellations Lyra and Cygnus. Figure 11 on the next page provides a star map as an aid, with the stars you will “measure” labeled clearly. Lyra can be found easily by finding the brightest star in the sky at this time of night, Vega. Cygnus represents a cross (swan)-shaped star pattern in the sky with the brightest star in the constellation, Deneb, at the tip of this cross (the Swan’s tail). This pattern will be in the Western portion of the sky, about 20° to 40° below zenith (the point straight-up in the sky). From Vega, Deneb is the next brightest star in the sky, following a path towards zenith. If you cannot find the constellations based on these clues, ask a TA for assistance.

2.) Once you’ve found the constellations, familiarize yourself with the layout of the labeled stars and where they appear in the sky.
3.) Using Table 2 on the next page, estimate the magnitude of each unmeasured star, based on the given magnitudes for the calibration stars. Remember: Stars that are less bright have higher numerical magnitudes. This is a pseudo-quantitative method, so high accuracy is not required. Simply pick a star in the unknown portion of the list and find it in the sky. Use the given calibration star magnitudes to and compare how bright you think the star you chose is compared to those values, and place an X in the appropriate column of Table 2. **If you cannot see a star for whatever reason, place an X in the “Not Seen” column.**

4.) Perform these measurements again, but now with respect to the first values you estimated. Here, you are comparing the stars you measured between each other in order to see if you need to adjust your first estimates (this will make your measurements internally-consistent).

5.) Limiting magnitude: Could you see the star φ Cyg? If you can see stars fainter than this star, write > 4.7 in the corresponding field on the next page. Write 4.65 in the field if you could see this star but no fainter stars. Write < 4.6 if you could not see φ Cyg.
<table>
<thead>
<tr>
<th>Star</th>
<th>Not Seen</th>
<th>Limiting Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vega</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>ε Cyg</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>β Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ι Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ν Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>σ Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>α Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>γ Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ζ Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>η Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>κ Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ω Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>τ Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>φ Cyg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>β Lyr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>γ Lyr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ Lyr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Stars in Cygnus and Lyra
Part IIb: The Magnitude Scale (INDOOR-ONLY)

1.) Open *Starry Night*. Make sure that the time and date are set to September 25, 2014 at exactly 9:00:00 PM, and that the ‘Stop Time’ button in *Starry Night* is pressed.

2.) The stars in the following list are all members of the 30 brightest stars in the night sky. Of those 30, the stars below are the ones that are prominent when viewed from Denver in the fall evening sky.

<table>
<thead>
<tr>
<th>Star</th>
<th>Constellation</th>
<th>Apparent Magnitude $m$</th>
<th>Rank</th>
<th>Absolute Magnitude $M$</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fomalhaut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deneb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capella</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vega</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Altair</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a.) Using the ‘Find’ tab, locate the first star on the list.
b.) Determine what constellation it is in, and record that in the table above.
c.) First, right click on the star and choose ‘Deselect <star name>’ from the pop up menu (there is a bug in *Starry Night* that prevents some information from being displayed unless the star is deselected). Next, right click the star again and select ‘Show Info’ from the pop up menu. Expand the ‘Other Data’ layer and record the star’s apparent and absolute magnitudes in the table above.
d.) Repeat Steps (a) through (d) for the remaining stars.
e.) Rank the stars in terms of both their absolute and apparent magnitudes (1 = brightest, 5 = dimmest).
3.) The absolute magnitude is equal to the apparent magnitude of a star if it were located 10 parsecs (32.62 light-years) from the observer. Thus, if a star’s apparent magnitude is brighter than its absolute magnitude, it is closer than 10 parsecs. Conversely, if a star’s apparent magnitude is dimmer than its absolute magnitude, it is further than 10 parsecs. With that in mind, complete the following table:

<table>
<thead>
<tr>
<th>Star</th>
<th>Further Than 10 parsecs?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fomalhaut</td>
<td></td>
</tr>
<tr>
<td>Deneb</td>
<td></td>
</tr>
<tr>
<td>Capella</td>
<td></td>
</tr>
<tr>
<td>Vega</td>
<td></td>
</tr>
<tr>
<td>Altair</td>
<td></td>
</tr>
</tbody>
</table>

4.) Determine the distance in light-years to the star using:

\[ d = 3.262 \cdot 10^{0.2(m-M+5)} \]

Then, rank the 5 stars by distance (1 = closest, 5 = furthest). Check your answers to Step 3 against your answers here. (Hint: 10 parsecs = 32.62 light-years.)
5.) Using your answers to Step 4 above, indicate the positions of each star on the apparent magnitude, absolute magnitude and distance scales shown below. Label each position with the star’s name. If a star does not lie on the scale, briefly state why not.
6.) Pick a star whose rank for apparent magnitude is low (i.e. closer to 5), but whose rank for absolute magnitude is high (i.e. closer to 1). State which star you picked. Explain this discrepancy in rank. Is this star one of the thirty brightest stars in the sky because it is actually bright or just because it is relatively close to the Earth?

7.) The \textit{limiting magnitude} is the dimmest magnitude visible to the unaided human eye. The limiting magnitude is +6 under good, dark sky conditions.

a.) In \textit{Starry Night}, select ‘Viewing Location>>Denver, United States (with Reset)’ from drop down menu on the toolbar. Make sure that that the ‘Stop Time’ button in Starry Night is pressed, and the time and date are set to September 25, 2014 at exactly 9:00:00 PM.

b.) Right click on any “empty” part of the sky. Make sure the options ‘Local Light Pollution’ and ‘Distant Light Pollution’ are NOT selected.

c.) Find and center on Ursa Minor, and then right click on it to ‘Deselect Ursa Minor’. Next, right click on the sky and select ‘Show Constellations’. With no light pollution, there should be 7 main stars clearly visible in the stick figure. Right click and select ‘Hide Constellations’.

d.) Open the ‘Options’ tab and expand the ‘Local View’ layer. Click on the ‘Local Light Pollution’ label (it will become a button when you hover the cursor over it). In the ‘Local View Options’ dialog box that pops up, select ‘Local Light Pollution’, ‘Distant Light Pollution’, ‘Large city in North’, ‘Smaller city in South’ and slide the bar all the way over to ‘More’. Then click ‘OK’. These settings will mimic the light pollution conditions on the South edge of Denver with Colorado Springs’ light dome visible to the South, and Denver’s in the North.
e.) Toggle both ‘Local Light Pollution’ and ‘Distant Light Pollution’ on and off. Explain what each setting does to the view of the night sky.

f.) Turn both types of light pollution back on. Of the stars still visible of the original 7, locate the dimmest one. (You may wish to alternately ‘Show Constellations’ and ‘Hide Constellations’ to outline Ursa Minor, but make your determination of the dimmest still-visible star with the constellations hidden.) **What is the name of this star and what is its apparent magnitude?** The apparent magnitude of this star is a reasonable estimate of the limiting magnitude in Denver.

<table>
<thead>
<tr>
<th>Star</th>
<th>Name</th>
<th>Apparent Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>Polaris</td>
<td>+1.96</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Kochab</td>
<td>+2.06</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Pherkad</td>
<td>+3.00</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Delta Ursae Minoris</td>
<td>+4.34</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>Epsilon Ursae Minoris</td>
<td>+4.18</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>Zeta Ursae Minoris</td>
<td>+4.28</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Eta Ursae Minoris</td>
<td>+4.93</td>
</tr>
</tbody>
</table>

**Figure 5:** Bayer designations for the 7 brightest stars in Ursa Minor.

How many times brighter is this magnitude than the +6 quoted for dark skies?
Part I Analysis:

1.) Use the altitude of a Polaris that you recorded during your observations to infer your latitude. Remember, since you are in the Northern Hemisphere, the altitude of the North Celestial Pole is equal to your latitude on Earth. Indicate whether this is North latitude or South latitude.

<table>
<thead>
<tr>
<th>Latitude from Polaris Altitude</th>
</tr>
</thead>
</table>

2.) Use the altitude, $\alpha$, you recorded for the transit star you observed ($\alpha$ Peg), along with its declination $\delta$ (in this case, $+15\degree 12\arcmin 18.96\arc''$), to calculate your latitude on Earth a different way. The relationship between latitude and these values is shown in the equation below. You will need to convert the value for declination into degrees-only units before doing the calculation. Remember, there are $60\arc''$ in $1\arcmin$, and $60\arcmin$ in $1\degree$. Indicate whether this is North latitude or South latitude.

\[
Latitude = 90\degree - (\alpha - \delta)
\]

<table>
<thead>
<tr>
<th>Latitude from $\alpha$ Peg Transit Altitude</th>
</tr>
</thead>
</table>

3.) Which of the results from steps 1.) and 2.) is closer to the correct value for the latitude of Denver, $39.7392\degree$? You will use whichever is closest for the rest of your analysis. Note that the uncertainty corresponding to this result is +/- 0.5°. Record this value, with “+/-0.5°” next to it, in the “Latitude” field of Table 3. Writing your answer this way indicates that you only know that your location is between your closest value MINUS 0.5°, and your closest value PLUS 0.5°.

<table>
<thead>
<tr>
<th>Results</th>
<th>$MST_{\text{transit}}$</th>
<th>UT</th>
<th>GAST</th>
<th>Longitude</th>
<th>Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Transit measurement results

4.) It will be more useful to state your recorded transit time according to your time zone’s (Mountain time, in this case) standards. Using your recorded Transit Time from your observations, convert this value to 24 hour-scaled Mountain Standard Time ($MST_{\text{transit}}$), using the equation,

\[
MST_{\text{transit}} = \text{Transit Time} + 12\text{hr}
\]

where the Transit Time is the time you recorded for $\alpha$ Peg’s transit in your observations. Record this value in the appropriate field of Table 3, to the nearest 0.0001 hour. Be Careful: When you calculate values using time, and your time is recorded in hours:minutes:seconds (or hours:minutes for the outdoor instructions) format, you must convert BOTH the stated minutes and seconds into units of hours before adding them to the stated hours. Once they are converted, you may then add them to the stated hour measurement in order to obtain your final answer, in units of hours only.
5.) Using your value of $MST_{\text{transit}}$, calculate the transit’s corresponding Universal Time (UT) using the following equation. Keep this value to the nearest 0.0001 hours, and record it in Table 3. For an explanation of Universal Time, and why this step must be performed, consult the Celestial Navigation portion of the Background Information in this document.

$$UT = MST_{\text{transit}} + 7\text{hr} - 24\text{hr}$$

6.) Next, you will need to find the Greenwich Apparent Sidereal Time (GAST) of the transit. This is Universal Time summed with an applied correction for your date of observation. These corrections must be date-specific, so use the correction for your date of observation. Their values are: November 7: -10.8231 hrs, November 8: -10.7584 hrs, November 9: -10.6920 hrs (note the minus signs). Add this value to your measured UT, and record the result to the nearest 0.0001 hours in Table 3, under the “GAST” field. This is done for several reasons: 1) the second measured in sidereal time is shorter than that of UT (essentially the difference between solar and sidereal time), and 2) there are small changes in the positions of stars themselves over time, due to imperfections in the Earth’s rotation. These corrections are provided to allow you to skip over some of the more complicated math involved in this process, which is beyond the scope of this lab.

7.) We can now begin to link your recorded transit measurement to your position on Earth. First find $\alpha$ Peg’s Hour Angle (essentially a time-dependent version of right ascension, useful for things like celestial navigation); this can be calculated with

$$\text{Hour Angle} = RA - GAST$$

where RA is the right ascension of $\alpha$ Peg (23hr : 04min : 45.65sec). Remember to convert RA to hours-only units, to the nearest 0.0001, before doing the calculation. GAST is the value you recorded in Table 3 in Step 6. Now calculate your longitude using the equation,

$$\text{Longitude} = 360^\circ - (\text{Hour Angle} \times 15^\circ/\text{hr})$$

Record your result, indicating whether this is E(ast, positive) longitude or W(est, negative) longitude, in Table 3 under the appropriate field. Similar to your latitude measurement, your result is uncertain based on the accuracy of the device used to make the measurement. Optimistically, this value is 2.5°; write “+/- 2.5°” with your longitude result in Table 3.

8.) Produce a map of your latitude and longitude results with respect to Denver. To do this, use a computer and internet browser to go to the website maps.google.com. In the search field, type in your latitude and longitude results from Table 3 in the format “[latitude value]X, [longitude value]Y”, where the bracketed statements should be the corresponding results from Table 3 (without the brackets or “+/-” uncertainty statements), and X and Y should indicate whether your results for latitude and
longitude were N or S (North or South), and E or W (East or West), respectively. Pressing “Enter” on the keyboard should then show you the location on Earth that corresponds to these coordinates. Hopefully your result shows that you performed your observation in, or at least very near to, Denver, CO!

Additionally, you can search for the upper-and-lower-bounds of both your latitude and longitude results based on the measurement uncertainties you wrote. Simply take your direct results for either, add or subtract the corresponding uncertainty (for upper or lower bounds, respectively), and re-enter these new coordinates in Google Maps to get a sense of how far off these uncertainties are on Earth compared to your direct results. Essentially, your result is defined by an area subtended by these upper and lower bounds based on the uncertainty in your measurement.

9.) Using the methods described in Step 8, your lab group will need to print off a Google Map that indicates the following locations simultaneously (as in, on the same map, and not separate maps):

- The location corresponding to the central, direct values (without uncertainty offsets) of your latitude and longitude results
- The location of your upper bounds of both latitude and longitude
- The location of your lower bounds of both latitude and longitude
- The location of your upper bound of latitude but lower bound of longitude
- The location of your lower bound of latitude but upper bound of longitude

This map is to be turned in with the rest of your results from the lab.

10.) Comment on your results. Does the area defined by the uncertainties in your measurement, centered on your direct result, place you in Denver (in other words, were you successful in your attempt at celestial navigation)? If not, describe where on Earth your results indicate that you are, and comment on what might have caused you to be imprecise in determining your location. **A few things to note:** If you are sure your observational measurements are of good quality, you may want to double-check your calculations if your results indicate you are significantly far from Denver, CO. **If your results indicate you are in Colorado at all, then you did a good job!**
Part II Analysis (OUTDOOR-ONLY):

Note: The calculations in this part of the lab are significantly faster to complete using spreadsheet software like Microsoft Excel. It is recommended that you use such software to calculate your results.

1.) As mentioned in the Background Information, magnitudes can help determine distances to stars if a star’s absolute magnitude, $M$, is known. You will calculate the distances to each of the stars you measured in Part II (outdoor version) by using the values for Absolute Magnitude given in Table 4. First, calculate the distance modulus, $\mu$, using the following equation, for each star.

\[
\mu = m - M
\]

$m$ are the magnitudes you measured for each star, recorded in Table 2.

2.) Now find the distances, $d$, to each star using the next equation. This distance is in units of parsecs (or pc). This unit is used because it represents one of the primary methods scientists use to determine the distances to star. Another useful unit, the light year, is sometimes more commonly heard of, though you will not use it in this lab (these units are related with the following conversion: 1 pc = 3.26 light years).

\[
d = 10^{0.2(\mu+1)}
\]

Be careful: This equation indicates that you are raising the number 10 to the power $0.2(\mu+1)$. Make sure you use the correct mathematical operations on your calculator (i.e., don’t multiply 10 by $0.2(\mu+1)$).

3.) Calculate the percent difference for each star you observed (but NOT those with the provided magnitudes in Table 2) using the equation below and the Actual Apparent Magnitudes values given in Table 4. Remember that if your result is negative, you should ignore the minus sign, as the difference that you take in the equation is the absolute value of the difference.

\[
\% \text{ Difference} = \left| \frac{\text{Measured } m - \text{Actual } m}{\text{Actual } m} \right| \times 100\%
\]

4.) Recall the weather (and moonlight) conditions of your observation, and reflect on the % Difference values you calculated in Table 4. Did the weather or moon phase affect your ability to determine the apparent magnitudes of stars you observed? If so, describe how.
<table>
<thead>
<tr>
<th>Star</th>
<th>M</th>
<th>μ (mags)</th>
<th>d (pc)</th>
<th>Actual m</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vega</td>
<td>-8.75</td>
<td></td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ε Cyg</td>
<td>0.74</td>
<td></td>
<td>2.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>β Cyg</td>
<td>-2.23</td>
<td></td>
<td>3.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>τ Cyg</td>
<td>0.87</td>
<td></td>
<td>3.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ν Cyg</td>
<td>-1.26</td>
<td></td>
<td>3.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>σ Cyg</td>
<td>-6.56</td>
<td></td>
<td>4.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>α Cyg</td>
<td>-8.75</td>
<td></td>
<td>1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>γ Cyg</td>
<td>-6.18</td>
<td></td>
<td>4.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ Cyg</td>
<td>-0.76</td>
<td></td>
<td>3.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ζ Cyg</td>
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</tr>
<tr>
<td>η Cyg</td>
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</tr>
<tr>
<td>κ Cyg</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ξ Cyg</td>
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</tr>
<tr>
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<tr>
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<tr>
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</tr>
<tr>
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</tr>
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<td>γ Lyr</td>
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</tr>
<tr>
<td>δ Lyr</td>
<td></td>
<td></td>
<td>4.30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Part II stellar distances results.

5.) What was the limiting magnitude you listed in Part II? Note that humans can normally see out to a magnitude of 6 on a clear night. Based on this, how much do you think Denver’s light pollution affects the darkness of the sky that you observed? Or, were there other factors that evening that you believe impacted your ability to see fainter stars?

6.) The Sun has an apparent magnitude of -26.74, but an absolute magnitude of 4.83. Calculate how many times brighter the Sun’s apparent magnitude is compared to Vega, using the actual apparent magnitude $m$ listed in Table 4 and the equation below. Do the same to compare their absolute magnitudes $M$. Based on these comparisons, and how the Magnitude System is defined in the Background Information of this document, do you think that these two stars are similar types of stars, or different? Whatever answer you give, describe why.

$$\text{Times Brighter} = 2.512^{m_{\text{sun}} - m_{\text{vega}}}$$
7.) Be creative: suggest some potential improvements that can be made to light pollution issues in city areas such as Denver.

Extra Credit questions are on the next page.
Extra Credit:

1.) (10 pts) Use the geometry of the Celestial Sphere shown in Figure 3 to prove the relationship you used in Part I Analysis, regarding an observer’s latitude is given by the measured *altitude* of a star, if it’s *declination* is known:

\[
\text{Latitude} = 90° - (\alpha - \delta)
\]

Note that Figure 3 shows a star with negative declination, whereas the declination of \(\alpha\) Peg, the star you observed, is positive. You should still be able to derive this relationship generally (full extra credit points awarded for a *full* derivation, showing or reasoning each step explicitly).

2.) (5 pts) Provide some feedback about this lab: What did you like about it? Was it effective in teaching you some basic observational astronomy tools and techniques? What criticisms of this lab do you have, if any?
Calculations Page: