1. Introduction

1.1 Motions in the Sky Background

To be updated

1.2. Goals

1. To become familiar with the night-sky simulation software Stellarium.
2. To gain practical experience using spreadsheets for data entry and analysis: a marketable skill
3. To connect local sky vocabulary, horizontal coordinates (azimuth & altitude), and equatorial coordinates (right ascension & declination) to a simulated view of the sky.
4. Become more deeply familiar with the diurnal motion of the Sun and stars
5. Observe and collect data on the Sun’s noon-time altitude, and rise and set locations as a function of season and latitude
6. Observe and understand the connection between the celestial sphere, celestial equator, and the Sun’s position on the ecliptic and relate that to Earth’s seasons.

1.3 Materials

All online materials for this lab can be found at the University of Tennessee Astronomy Lab Exercises Website: http://astrolab.phys.utk.edu/LabExercises.php and the NMSU GEAS Project Lab Exercises Website: http://astronomy.nmsu.edu/geas/labs/html/home.shtml

To complete this lab, you will need the following:
• Access to a computer to run Stellarium
• The Night-Sky Simulation software Stellarium
  ○ Downloaded for Windows, Mac OSX, and Linux from stellarium.org.
  ○ A web version at https://stellarium-web.org/. The web version should be sufficient for this lab, but its limitations make it much more difficult.

1.4 Primary Tasks

This lab is built on four primary activities that make use of Stellarium’s ability to simulate the night sky, provide overlay displays of coordinate systems, control the flow of time, and display observational information for celestial objects. Some of these tasks have you collecting observational data to generate xy plots using the NMSU GEAS Labs xy plotting tool and/or a Google Sheet spreadsheet.

The four primary tasks are:

1. Use Stellarium to see the local sky overlain with the celestial meridian, horizontal coordinates, and equatorial coordinates. Each coordinate system will be observed as time changes.
2. Explore what stars are observable as a function of latitude and time of year.
3. Examine the observational differences between the solar and sidereal days using the Sun and stars.
4. Collect data on the Sun’s altitude (observed from Knoxville, TN), its rise/set times & location as a function of time of the year/season.

1.5 Grading Scheme

To be determined after the questions have been written

1.6 Lab Reports

You will write a laboratory report for each laboratory exercise using the Google Documents application, an online tool which allows you to write reports and share your work with others. Your University of Tennessee email address comes with a linked Google Account that is already set up for you. The Lab Report Template is available on the UTK Astronomy Lab Website. The filename for your lab report should be defined by your last name and first initial followed by “_02” to indicate this is Lab 2 (Carl Sagan’s lab report would be called saganc_02).
1.7 Timeline

This lab is a **1-Week Long Lab.** Astronomy 153 has a follow-up lab to this called Phases of the Moon that lumped together makes up the entire *Motions in the Sky Lab.*

**Week 1 (ASTR 153 & 154): The Local Sky, Celestial Coordinates, and Solar Altitude.** Read all sections and complete all activities. Enter all data into your Lab Report, which will be shared with your instructor before leaving your lab session.

2 Celestial Coordinates & the Local Sky

**Astronomy** has long been considered the first science. Early humans surely looked to the skies and were able to detect and predict patterns. Ancient Mesopotamians recorded their astronomical observations of the night sky starting 5000 years ago. Though modern astronomy is far more than mapping the positions of stars and planets on the celestial sphere, accurate measurement in the night sky is crucial to answering some of the biggest questions under study today. Two frequently used systems for specifying locations on the celestial sphere are horizontal and equatorial coordinates.

2.1 - Horizontal Coordinate System

A simple system uses the target object’s angular distance above the horizon and heading. These two parameters are called **altitude** and **azimuth,** respectively, and shown in Figure 1. Beginning by facing north, azimuth is the number of degrees one would rotate clockwise to face the target object. Altitude is the number of degrees between the local horizon and the target object. As this coordinate system uses the local horizon as a reference, it is attached to the observer’s location and rotates with the earth. Horizontal coordinates are only good for a particular location, at a particular time. The advantage is that it is easier to use than equatorial coordinates. Horizontal coordinates are useful for event viewing, such as a planetary conjunction or to communicate where the Moon is on a particular night. Angular distances can be approximated by using the hand shapes below held at an arm’s length (Figure 2).

In order to fully grasp the coordinate systems astronomers use to describe the location of celestial objects, we must first become familiar with our local sky. Figure 3 provides an example of a local sky with the observer located at the center of a dome over their head. The point directly over an observer’s head is called **zenith,** which by definition has an altitude of 90°. The line that divides the Earth from the sky at the very limits of
Figure 1. A diagram of the horizontal coordinate system. Azimuth describes how far around from North in degrees, and altitude is how many degrees up. The horizon is at altitude 0° and zenith is at 90°. Image by TWCarlson [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0) or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons.

Figure 2. Hand positions that roughly approximate angular distances at arm’s length. Image by B. Ventrudo. One Minute Astronomer. https://oneminuteastronomer.com/860/measuring-sky

Figure 3. A view of an observer’s local sky.
how far you can see is called the **horizon**, which is the namesake for the **horizontal** coordinate system. By definition, the horizon has an altitude of 0°. Astronomers cleave the sky into an Eastern and Western half by drawing an imaginary line that stretches from due North, through the local zenith, to due South. This line is called the **celestial meridian**, but is often just referred to as the **meridian**.

### 2.2 - Equatorial Coordinates

The equatorial coordinate system maps the celestial sphere into lines of right ascension and declination. Comparing the celestial sphere to a globe of the earth results in a helpful and frequently used analogy: right ascension is like longitude, and declination is like latitude. **Declination** (Dec.), our “celestial latitude”, is the number of degrees above or below the celestial equator, which is formed by extending the earth’s equator in a plane out into space. It extends from -90° at the South Celestial Pole through 0° at the Celestial Equator, up to +90° at the North Celestial Pole. Instead of using fractional degrees, declination uses the astronomy angular measurements of arcminutes (′) and arcseconds (″). Our “celestial longitude” is divided into 24 hours of **right ascension** (RA), measured from the Sun’s location during the vernal equinox. Instead of fractional hours, right ascension continues the time theme and uses minutes (″) and seconds (″), where 1 hour (equivalent to 15°) is 60 minutes minute is 1/60th of an hour (15°/60 = 0.25°). The result of all this is a coordinate system that appears to move with the stars,
allowing for a set of coordinates that an astronomer at any location on Earth can agree upon. You can think of this as the coordinates for the stars, which helps create a map of the celestial sphere.

These coordinate systems can be difficult to grasp on paper (Figure 4), and challenging for instructors to diagram on a blackboard. As part of this lab, you will use Stellarium to observe the sky with these two coordinate systems overlain on the sky. Seeing these coordinates with respect to the location of the stars and how objects move on diurnal and annual timescales is essential to fully grasping both of the horizontal and equatorial coordinate systems.

2.3 [Activity Section] Exploring the Concepts with Stellarium

Let’s explore the local sky vocabulary, horizontal coordinates, and equatorial coordinates by looking at them projected onto a Stellarium simulated view of the sky. Open Stellarium and familiarize yourself with the program. Figure 5 shows you some of the controls.

Figure 5. Stellarium with primary controls indicated. The “Date & Time” Window is currently toggled ON. You can see the display of the current Date and Time in the upper left of the image. You can move this box around so it is not in the way of what you are observing.
Stellarium Controls

- ● starts and stops time
- ● speeds up the flow of time. Each time you click it the rate time passes will speed up
- ● slows time down
- ● displays the Horizontal Coordinates on the sky called “Azimuthal Grid” in Stellarium
- ● displays the Equatorial Coordinates on the sky
- ● displays the Date & Time Window
- ● displays the Location Window
- ● displays the Search Window
- ● displays the Sky Viewing Options Window
- ● ? displays the Help Window

Now that you feel comfortable with Stellarium, let’s explore the horizontal coordinate system.

**Horizontal Coordinates Activity**

1. Setting up Stellarium for this activity.
   a. If Knoxville is not set as your location already, set your Location to Knoxville, TN by either entering the city name in the search field
   b. Hit the Play/Pause Button to Stop Time & Set your Date and time to be June 21, 2020 at 22:00 (10 PM)
   c. If needed, change your view to be looking due North by using your mouse to rotate your view.
   d. Push the “Azimuthal Grid”/Horizontal Coordinates button (hotkey should be ‘Z’) to bring up your azimuth and altitude grid.
   e. Did you complete the “Setting Up Stellarium” activity? [1pt]: [Yes/No]

2. The vertical lines represent which horizontal coordinate? [1 pt]
   - Insert Answer Here-

3. The horizontal lines represent which horizontal coordinate? [1 pt]
   - Insert Answer Here-
4. Move your view to look up until you can see the point where all the lines converge. What is the name of that point in the sky? [1 pt]
   -Insert Answer Here-

5. Return your view to looking toward the horizon at due North. In the Northeastern part of the sky there is a bright star labeled Vega. Using the horizontal coordinate gridlines, estimate the horizontal coordinates for Vega. [2 pts]
   You may need to Zoom out a bit to see Vega.
   Vega’s Azimuth is -Insert Answer Here-
   Vega’s Altitude is -Insert Answer Here-

6. Another bright star is located near Vega at approximately azimuth = 49˚ and altitude = 22˚. Locate this star, and left-click it to display the name of the star. The name of this star is: -Insert Star’s Name-
   A left-click will turn off the displayed information about the star.

7. Click the buttons to turn on the constellation figure lines and names, respectively. What constellation is the star from #6 in? [1 pt]
   The star is in -Insert Constellation Name-

8. What is the name of the bright red star located at approximately azimuth = 150˚, altitude = 21˚. What constellation is it in? [2 pts]
   The bright red star is -Insert Star’s Name-
   It is in -Insert Constellation Name-

9. You should now be looking near to due South. Press the Play button to get time moving, and then click the two times to speed up time to be about 1 simulated minute passing every real second.
   Are the altitude and azimuth of the stars staying the same or changing? [1 pt]
   -Insert Answer Here-

10. As time is moving forward, are the azimuth and altitude lines moving or remaining fixed in place? [1 pt]
    -Insert Answer Here-

11. Reset your time to 22:00 and look to the East. Describe how the altitude and azimuth of the stars are changing with time (use terms like increasing and decreasing).
    -Short answer responses here-

12. Reset your time to 22:00 and look to the West. Describe how the altitude and azimuth of the stars are changing with time (use terms like increasing and decreasing).
    -Short answer responses here-
13. What motion of Earth is making the stars move in the above exercises?

-Insert Answer Here-

The horizontal coordinates are great for pointing out where a celestial object is for a specific time and for a specific location (we will explore this soon). Once you get a grasp on altitude and azimuth, it is very easy to communicate where things in the sky are to others. However, you must also give information about when to observe from where, which makes it bad for consistent and professional communication about where celestial objects are in the night.

For a universal coordinate system that is the same for everyone on Earth at any time, we need a coordinate system that is fixed to the stars themselves that moves with the stars as they make their nightly motions through the sky. This coordinate system is the Equatorial Coordinate System introduced in Section 2.2. The two coordinates in the equatorial coordinate system are right ascension and declination. Let’s explore right ascension and declination.

**Equatorial Coordinates Activity**

14. Setting up Stellarium for this activity.
   a. If Knoxville is not set as your location already, set your Location to Knoxville, TN by either entering the city name in the search field.
   b. Hit the Play/Pause Button to Stop Time & Set your Date and time to be June 21, 2020 at 22:00 (10 PM).
   c. If needed, change your view to be looking due North by using your mouse to rotate your view.
   d. Push the “Equatorial Grid” button (Hotkey should be ‘E’) button to bring up your right ascension and declination grid.
   e. Did you complete the “Setting Up Stellarium” activity? [1pt]: [Yes/No]

15. The ring-shaped lines represent which coordinate? [1 pt]
   [Right Ascension / Declination]

16. The lines that all converge to a spot a little above North represent which coordinate? [1 pt]
   [Right Ascension / Declination]

17. The point where all the lines in the previous question converge is what location on the celestial sphere? [1 pt]
   -Insert answer here-

18. What is the declination of this point? [1 pt]
   -Insert answer here-
19. There is a bright star very near to the convergence point, right-click on this star to identify this star. [1 pt]
   This star is -Insert Star’s Name-

20. What is the **altitude** of this star? [1 pt]
   The altitude is -Insert answer here-

21. Open the Location Window in Stellarium and compare the altitude of the star with the latitude of Knoxville.
   -Insert answer here-

22. Use your mouse to look around the sky with the equatorial grid projected onto the sky. Describe how the grid looks in total. You may need to imagine the ground not being there, or better yet, push the “Ground” button on the bottom toolbar to turn the ground off. [3 pts]
   -Short answer response here-

23. Make sure you turn the ground back on if you turned it off. Find all of the stars from the horizontal coordinate activity and left-click on them to display their information. What are their right ascension (RA) and declination (Dec) coordinates? [3 pts]
   *Use the J2000 RA and Dec information.*

<table>
<thead>
<tr>
<th>Star</th>
<th>Right Ascension</th>
<th>Declination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vega</td>
<td>-Insert RA-</td>
<td>-Insert Dec-</td>
</tr>
<tr>
<td>-Insert Name- Star from #6</td>
<td>-Insert RA-</td>
<td>-Insert Dec-</td>
</tr>
<tr>
<td>-Insert Name- Star from #8</td>
<td>-Insert RA-</td>
<td>-Insert Dec-</td>
</tr>
</tbody>
</table>

Hopefully you are now familiar with right ascension and declination coordinates on the celestial sphere. We will now repeat the turning on time experiment to see the true advantage of the equatorial coordinates.
24. Return to a view of looking North and click ➤ twice to make simulated time move at about 1 min per real second. Let it run for about two hours of simulated time and then hit pause.
Is the right ascension and declination coordinate grid sitting still or is it moving with the stars?
-Insert answer here-

25. The stars all appear to rotate about what point? What is this point? Describe how the stars move (clockwise/counterclockwise) and how the speed they move changes as you move away from the center of rotation [3 pts]
-Insert short answer here-

**Putting it all together - Connecting the two Coordinate Systems Activity**
We are ready to put all of this information together to understand what celestial objects are up in our local skies. Here we will connect the two coordinate systems to investigate what stars are visible from your location on Earth at a particular time of year.

Reset your time to 22:00 on 21 June 2020. For this next observation, it is best to turn off the atmosphere so we can see what stars would be up in the day time. Click on the “Atmosphere” (Hotkey should be ‘A’) on the bottom toolbar to turn off the atmosphere. This will make it so the skies remain dark even when the Sun is up.

26. Continuing with the equatorial coordinates displayed on the sky and looking looking due North. This time increase the speed time passes by pressing ➤ three times. Do all the stars rise and set, or are some constantly above he horizon? [1 pt]
-Insert answer here-

27. The stars that continuously rotate around the pole and never set below the horizon are called **circumpolar stars**. What stars are circumpolar is determined by your latitude on Earth and the declination of the stars. What is the declination that sits just above North, i.e., what is the declination of your Northern Horizon?
-Insert answer here-
28. In Question 18 you determined that the North Star has Dec. = +90˚. In Question 20 you determined the altitude of the North Star when observed from Knoxville. This number was [number of degrees], which means that the Northern Horizon sits [that same number of degrees] below the North Star. Subtract that value from the North Star’s declination of +90˚ to determine the declination of the Northern Horizon. Does this agree with your answer in Question 27? -Insert answer here-

29. Can stars with declinations less than your answer for Question 28 be circumpolar stars for Knoxville, TN? -Insert answer here-

30. Change your view to look straight up. You may want to also turn on the “Azimuthal Grid” to identify the point above your head. What is the declination of that point? [1 pt] -Insert answer here-

31. **You can turn off the Azimuthal Grid if you turned it on.**
   The point overhead, by definition, has an altitude of 90˚. Since lines of declination move you North-South on the celestial sphere, the Southern Horizon must be 90 degrees less than declinatiion of the point overhead. What is the declination of the Southern Horizon? Does your answer match the information shown by the declination grid lines? [1 pt]

32. You have now determined all the declinations that are above the horizon (i.e., up and observable from Knoxville for this night. What is the range of declinations in the sky on 21 June 2020?
   Minimum declination observable: -Insert Answer Here-
   Maximum declination observable: -Insert Answer Here-
33. Move time forward by a month at a time and check the declinations of the Northern and Southern Horizons for the next 3 months. Do the values for the declination of the Northern and Southern Horizon depend on the time of year? [1 pt]. Yes/No

**Latitude & Time of Year Dependence on the Local Sky**

We have thoroughly explored the local Knoxville skies, and successfully observed
- the altitude of Polaris has an altitude equal to your latitude on Earth,
- the declination of your local zenith is equal to your latitude, and
- that (in the Northern Hemisphere), the Northern Horizon is at
  - **Equation for Declination of Northern Horizon (in the Northern Hemisphere): Equation 1**
    \[ \text{Dec. (N. Horizon)} = 90^\circ - \text{[your latitude]} \]

and the Southern Horizon is at
  - **Equation for Declination of Southern Horizon: (in the Northern Hemisphere) Equation 2**
    \[ \text{Dec. (S. Horizon)} = \text{[your latitude]} - 90^\circ \]

Here we investigate how your sky changes with latitude.

Put your time back to 21 June 2020 at 22:00. Make sure the Equatorial grid is displayed. Open the Location window, and click on the 35˚ part of the Knoxville latitude. You have to click on the 35! This will make it so you can change your latitude 1˚ at a time.

34. Increase your latitude to 60˚N and observe how the equatorial coordinate grid and the altitude of the stars change. Describe those changes using terms like altitude. It may be easiest to choose a particular star and describe how its position changes. [2 pts]

*To still see the stars, you will need to turn off the atmosphere as you get to the higher latitudes.*

-Insert Short Answer Here-
35. Fill in the following pieces of information for observing from latitude 60˚N. [6 pts]

<table>
<thead>
<tr>
<th>Observing from 60˚N</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Altitude of Polaris</td>
<td>-Insert Answer Here-</td>
</tr>
<tr>
<td>The Declination of Zenith</td>
<td>-Insert Answer Here-</td>
</tr>
<tr>
<td>The Declination of the Northern Horizon</td>
<td>-Insert Answer Here-</td>
</tr>
<tr>
<td>The Declination of the Southern Horizon</td>
<td>-Insert Answer Here-</td>
</tr>
<tr>
<td>Range of Declinations observable from 60˚ N</td>
<td>-Insert Answer Here-</td>
</tr>
<tr>
<td>Range of Declinations for circumpolar stars</td>
<td>-Insert Answer Here-</td>
</tr>
</tbody>
</table>

36. Make sure the Atmosphere is off so you can see the stars. Turn on the Equatorial Grid, constellation lines, and constellation names to help you see the month to month changes. Be sure you are looking due North. At 10 PM on 21 June 2020, the star Algol is just above the Northern Horizon. (Latitude setting is still 60˚ N)

   a. What are the right ascension and declination for Algol?
      Right Ascension is -Insert Answer Here-
      Declination is -Insert Answer Here-

   b. Move time forward 1 month at a time using the up arrow on the month in the “Date and Time Window” until you get to 21 Dec. 2020. How did the position of the stars change in the sky from month to month? [1 pt]
      -Insert Short Answer Here-

   c. The star Chi-Herculis (in the constellation Hercules) is now very near to the same place in the local sky (similar altitude and azimuth) as Algol was 6 months previous. What are the right ascension and declination for Chi-Herculis?
      Right Ascension is -Insert Answer Here-
      Declination is -Insert Answer Here-
d. Rounding the RA values for Algol and Chi-Herculis to their nearest hour, how much do they differ by? How does the right ascension of what stars are up at night change between June and December? [2 pts]
-Insert Short Answer Here-

37. Continue changing the date by 1 month at a time.
   a. The stay Cygnus will be viewable in about the same place in the sky that Algol and Chi-Herculis were on what date? [1 pt]
-Insert Short Answer Here-

   b. What is the RA of Cygnus? [1 pt]
-Insert Answer Here-

   c. How does the sky on 21 June 2021 compare to the one you observed on 20 June 2020? [1 pt]
-Insert Short Answer Here-

38. Set your latitude to the North Pole (lat. = 90° N) and return to the date 21 June 2020. You will notice that it is daytime at the North Pole because during the summer months, the North Pole is in constant daylight (called Polar Day). Turn off the atmosphere using the option on the bottom toolbar so you can see the stars.
   a. What star is located at your local zenith? [1 pt]
-Insert Answer Here-

   b. What declination is at your horizons? [1 pt]
-Insert Answer Here-
c. Click ⏪ twice to have time pass at about 1 simulated minute per real second. Describe the motion of the stars on over the course of a full day (you may want to speed up time one more time to observe at least a full day) [1 pt]
   -Insert Short Answer Here-

   d. Which stars are circumpolar? Does this include the Sun? [1 pt]
     -Insert Answer Here-

39. Pause time, and turn the atmosphere back on. Change the date to 21 December 2020. Like the previous question, speed up time and observe at least 1 full day of the stars
   a. Does the Sun ever rise? [1 pt]
      -Insert Answer Here-

   b. Have the stars that you can see changed, or are they the same as they were on 21 June? [1 pt]
      -Insert Answer Here-