Early Greek observers viewed the sky as a transparent sphere which surrounded the Earth. They divided the stars into six categories of brightness and arranged the stars into groupings called constellations (as did many other cultures). Most of the names of the eighty-eight constellations we use today are based on Greek mythology and their Latin translations. Modern astronomy uses the constellation designations to map the sky. On skymaps, the size of the dot is usually related to the brightness of the object (look on your planisphere). Most only show the brightest stars. They are typically named from brightest to faintest using a letter from the Greek alphabet (α, β, γ, etc.) and the constellation name in the genitive form; e.g. alpha (α) Cygni is the brightest star in Cygnus. Many stars also have Arabic names such as Betelgeuse, Algol, and Arcturus; α Cygni is named Deneb and α Ursa Minoris is more commonly known as Polaris. Either designation is correct.

In the exercise "Angles and Parallax," you made a cross-staff and quadrant and learned how to use them to measure objects inside. Now we will use them to measure objects in the night sky, much like Tycho Brahe did in the 1500's.

Remember to record the date, time, and conditions when making any astronomical observations! All numerical data should be recorded to one decimal place.

Objectives:

- Measure angular separations and altitudes of objects in the night sky with instruments
- Estimate angular separations and altitudes of objects in the night sky with your hands
- Determine the direction and rate at which the sky appears to rotate
- Learn how to find the North Star
- Determine your latitude

Equipment:

- Cross-staff with meterstick
- Quadrant with weight
- Planisphere
- Red flashlight
- Timepiece
- Calculator
- Computer with all-sky simulator program such as *Starry Night*, *Stellarium,* or *Celestia*
- Two different colored pens
- Protractor

I. THE CELESTIAL SPHERE

Above, we noted how the ancient Greeks viewed the heavens as a transparent sphere centered on the earth. This sphere has several features that are analogous to features on Earth. For example, the celestial sphere has an equator and poles, just like Earth. Each location on the Earth can be described in terms of a pair of coordinates known as longitude and latitude. Astronomers use a similar system to pinpoint locations on the sky. These coordinates are known as right ascension (RA) and declination (DEC), respectively. Declination is measured in degrees, minutes, and seconds north and south of the equator (0°0'0"), just like latitude. It can be positive or negative or simply "N" or "S". Right ascension is measured in units of time (hours, minutes, and seconds) from the vernal equinox (point at which the Sun crosses the celestial equator moving northward, i.e. intersection of the ecliptic and celestial equator). Thus, the vernal equinox is $0^h0^m0^s$, or 00:00:00.

ANSWER THE FOLLOWING QUESTIONS AS COMPLETELY AS POSSIBLE.

1. **Draw a representation of Earth and label ONLY these features: North Pole, South Pole, equator, lines of latitude, and lines of longitude. Now draw a separate representation of the celestial sphere and label ONLY the celestial analogs of the above terrestrial features.**

II. USING YOUR HAND AS A MEASURING DEVICE

Another way to measure angles on the sky is to use a tool you [almost] always have available – your hand. It is somewhat crude and of course only an approximation, but it works surprisingly well for most people. If you make a fist and extend your arm all the way, its angular size is about 10° from bottom to top. If you like, you can calibrate your hand using what you learned in the "Angles and Parallax" lab.

ANSWER THE FOLLOWING QUESTIONS AS COMPLETELY AS POSSIBLE.

2. **Do you expect this method to work for everyone? Why or why not? If not, can you think of a way to standardize or improve this method?**

III. MEASURING ASTRONOMICAL OBJECTS: ANGULAR HEIGHT AND SEPARATION

On a reasonably clear night, allow your eyes to adjust for a bit then align yourself so that you can match your planisphere to the sky. Locate the constellation Orion and the stars Rigel and Betelgeuse. Measure the angular separation between Rigel and Betelgeuse, five times with your cross-staff and five times with your hands. Though not necessary, you may find it useful to alternate one method with the other to obtain more independent measurements. Record your data in a table similar to that below (Figure 1). Calculate the average separation and standard deviation for each method.

Now locate the object designated by your instructor as the correct one for height. Measure the angular height of the object above the horizon, five times with your quadrant and five times with your hands. Again, you may find it helpful to alternate methods to avoid biasing your observations. Record the data and calculate the average and standard deviation for both sets of measurements.

Once you have completed these measurements, use an all-sky simulator program to find the actual angular separation and height and record them (Figure 1). Do not forget to set the date and time to match those of your data or you will not be making a legitimate comparison. Use appropriate units and make sure things are clearly labeled.

ANSWER THE FOLLOWING QUESTIONS AS COMPLETELY AS POSSIBLE.

3. **Did you have any systematic errors in your measurements? If so, what were the causes and how did you correct the problem(s)?**
4. **(a) Calculate the percent error between the actual angular separation of the two stars and your average measurement using the cross-staff. (b) Repeat the calculation using your average measurement with your hands.**
5. **Which method of determining the angular separation was more accurate? Were your measurements within one standard deviation of the *actual* value? *Should* they have been? Why or why not? HINT: think about what you are measuring, i.e. what type of value is it and whether you should expect repeated measurements to cluster around a certain value.**

6. **Which method of determining the angular height was more accurate? *Should* these data have been within one standard deviation of the *actual* value? Why or why not? HINT: think about what you are measuring, i.e. what type of value is it and whether you should expect repeated measurements to cluster around a certain value.**
7. **When should you use the cross-staff and quadrant (instruments) vs. your hands?**
8. **If Rigel and Betelgeuse are both the same distance from you and 5000 lightyears away from each other, how far away are you? HINT: you must use the relationship between angular measure, linear measure, and distance that you investigated in the Angles lab.**

	Angular Separation: Rigel-Betelgeuse				Angular Height of ____________			
	Cross-Staff	Time	Hand	Time	Quadrant	Time	Hand	Time
1								
2								
3								
4								
5								
$\bar{x}$								
σ								

from computer: Actual Betelgeuse-Rigel separation: ____________ time: ____________

Actual angular height of ____________: ____________ time: ____________

Figure 1. Sample data table layout.

IV. THE ALTITUDE OF THE POLE STAR

We often refer to Polaris as the "North Star" despite the fact that it is neither due north nor directly overhead (at the zenith). Actually, Polaris is *true* north (not *magnetic* north) and it *is* directly overhead *if you live at the North Pole*. Because Polaris is very nearly at the North Celestial Pole, "North Star" is not really a misnomer. This key information allows anyone in the northern hemisphere to easily determine his/her latitude on the planet.

The diagrams in Figure 2 are intended to convince you that the altitude of the pole star depends upon the observer's latitude on the Earth (something you should already have learned in your lecture class). Each diagram shows the Earth, its equator, and the line of sight to Polaris for an observer standing at a particular latitude. The first diagram is for an observer at the North Pole. In this case, Polaris is at the zenith so its altitude is 90°. The second diagram shows an equatorial observer, for whom Polaris would be right on the northern horizon, at an altitude of zero degrees. Thus, in both cases, the altitude of the pole star equals the latitude of the observer. The third diagram shows the situation for an observer at an intermediate latitude. Notice that in each diagram the observer's horizon is shown; it is represented by a plane tangent to Earth's surface at the point where the observer is standing. Objects below the

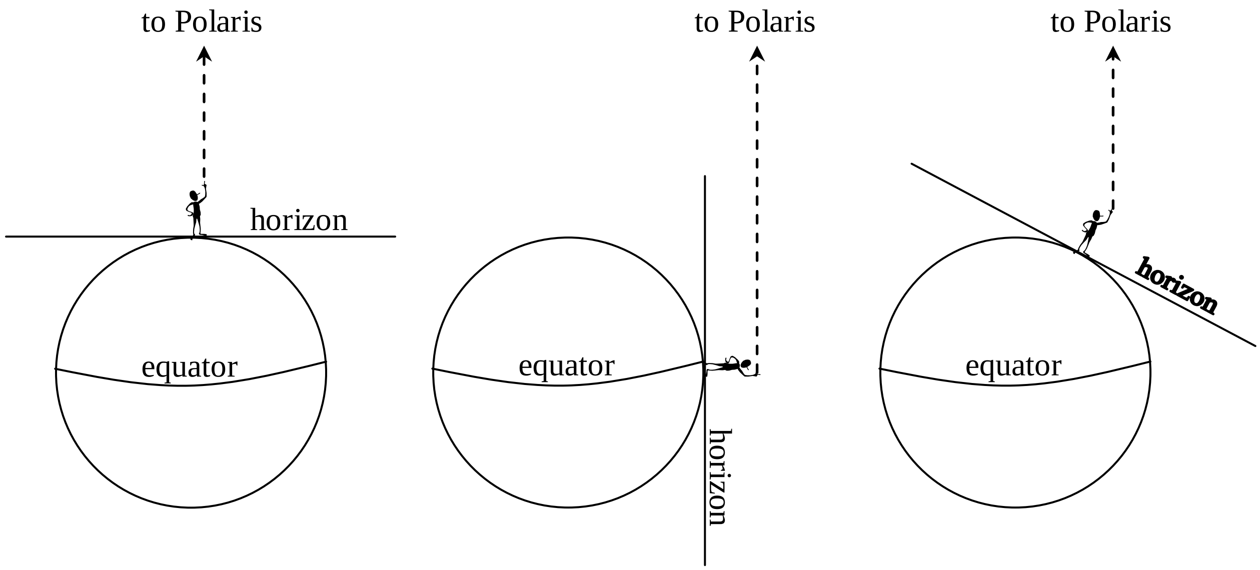

Figure 2. The altitude of Polaris and latitude of the observer.

observer's horizon are not visible. Notice also that the direction to the pole star is indicated as being the same on each diagram, even though the observers are at different locations on Earth. This is because the stars are so incredibly distant compared to the size of the Earth that all observers anywhere on the Earth see a particular star by looking in the same direction *in space*.

Note that if you happen to be going on a trip which involves travel either north or south, the altitude of Polaris will change. If you measure the change, and if you also know how far you have traveled north or south, you can easily compute the circumference of the Earth! The change in altitude of Polaris would be the same fraction of 360° as the distance you traveled is of the Earth's circumference.

V. Measuring Astronomical Objects: Motion of The Night Sky

Go outside and allow your eyes to adjust for a bit then align yourself facing north and locate Polaris. Measure its height at least five times using whatever method(s) you like (hands and/or quadrant; make sure to indicate which). Calculate the average and standard deviation.

Locate two stars to the east and two stars to the west of Polaris. Clearly mark these stars on the starwheel page and make sure to include this with your data. Using your cross-staff, measure the angular separation between Polaris and each of these four stars. Now use your quadrant to measure the angular heights of each of the four stars. You need make these measurements only once. Record the data in an organized fashion in your notebook, making sure to include the necessary observing details. Wait at least two hours (you can even do it on a different night so long as you keep track of how much time has passed – it matters!). Find the same stars and repeat the measurements: angular heights of all five stars and angular separation of each of the four chosen stars from Polaris. You need make these measurements only once.

Analyze the data by plotting what you observed. Mark the horizontal axis off in degrees east and west of north (angular separation) and label cardinal directions. The vertical axis of your graph should be degrees of altitude. It is ***critical*** that both axes have the same scale; for example, if each square on your graph paper represents two degrees horizontally, it must also represent two degrees vertically. Using your data, start by placing Polaris then plot the other four stars' positions relative to Polaris. Use one color for the first set of observations and a different color to distinguish the second set. Note that your graph should look nearly identical to what you saw in the sky and how it "moved".

ANSWER THE FOLLOWING QUESTIONS AS COMPLETELY AS POSSIBLE.

9. ***Based on your observations*, what is your latitude? Remember that latitudes also have directional indicators.**
10. **Describe how the sky appeared to change over the course of your observations.**
11. **Did you actually observe Polaris (as opposed to some other star that you misidentified as Polaris)? How do you know? (Knowing the latitude of your observing location has no bearing on this question.)**
12. **Use a protractor to measure how much rotation took place during the time interval between your two sets of north polar observations (use all four angles). Calculate the average rate in degrees per hour at which the sky "moved".**
13. **Based on your answer to Question 12, how long will it take to rotate 360°? Briefly comment on your results.**

VI. References

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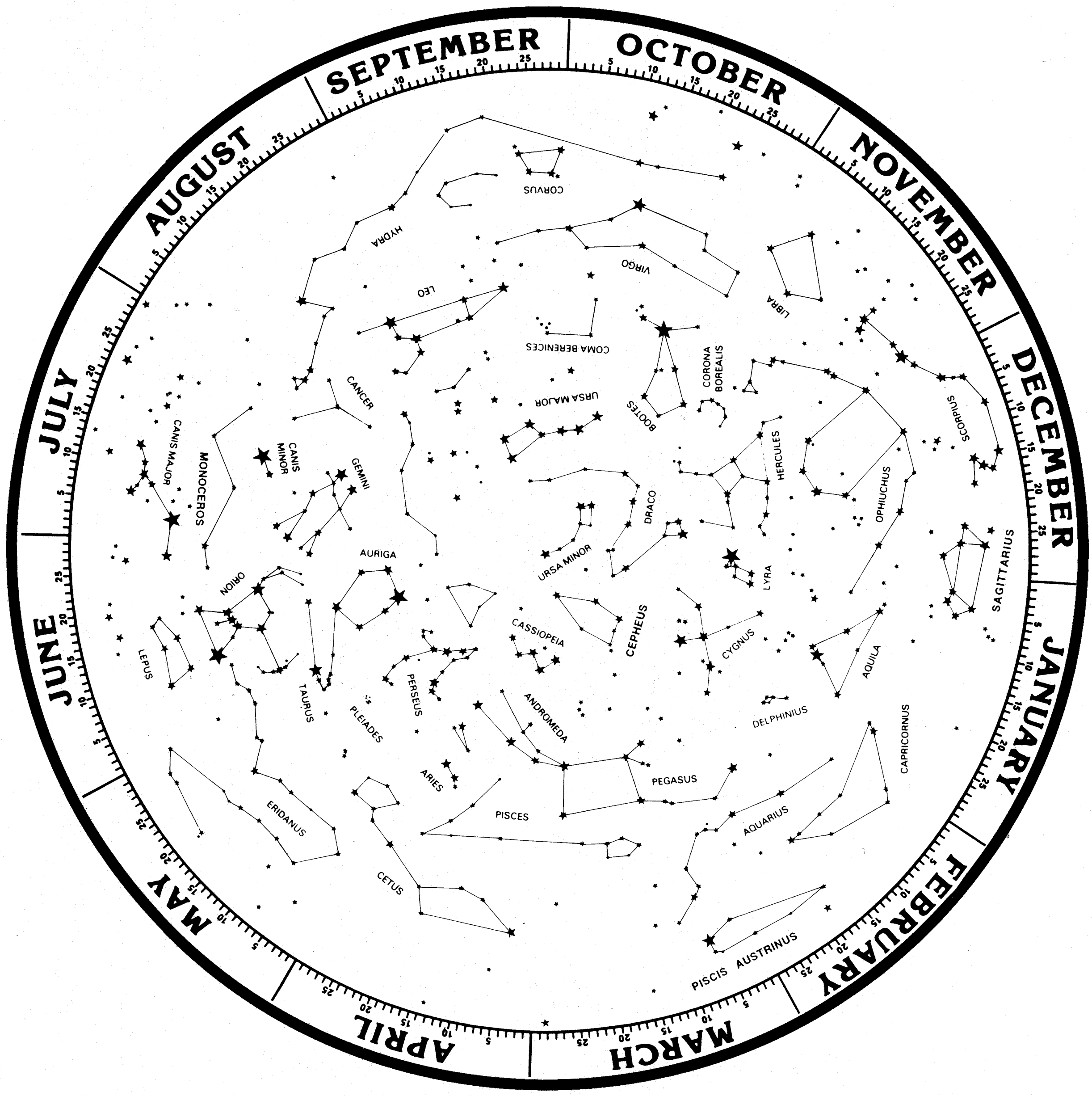
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MARCH
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