COORDINATE SYSTEMS

What will you learn in this Lab?

This lab is designed to introduce you to some of the coordinate systems used by astronomers. The coordinate systems to be introduced are Longitude and Latitude, Horizon Coordinate System, Equatorial Coordinate System and the Ecliptic Coordinate System.

What do I need to bring to the Class with me to do this Lab?

For this lab you will need:

- A copy of this lab script
- A pencil
- SC star chart
- Audubon Guide
- Star Wheel
- Red Flashlight

Introduction

Astronomers use coordinate systems to find the location of objects. The specific coordinate system used depends upon what is being observed and often the way the objects being observed move or appear to move. A subset of these coordinate systems are:

Longitude and Latitude
Horizon Coordinate System (Altitude and Azimuth)
Equatorial Coordinate System (Right Ascension and Declination)
Ecliptic Coordinate System (Ecliptic Longitude and Latitude)
Galactic Coordinate System (Galactic Longitude and Latitude)

Maps of the Earth: Longitude and Latitude

As a starting point for finding your way in the night sky, we first review maps of the Earth and how they were established. A coordinate reference frame is essential so that the location of remote places can be identified, such as islands at sea, cities, towns, mountain tops, etc. On the Earth the coordinate system employs **latitude** and **longitude**.

Latitude: is measured in *degrees*, *arcminutes* and *arcseconds*, *north* or *south* of the Earth's Equator. The zero point in latitude is naturally established by how the Earth rotates on its axis. The Earth's Equator is at a latitude of 0º, while the north pole is at a latitude of 90º N = +90º. Similarly, the south pole is at a latitude of 90º S = -90º. Tempe, Arizona is at a latitude of +33º.

Longitude: is measured in *degrees*, *arcminutes* and *arcseconds*, but unlike latitude there is no natural or physical characteristic of the Earth from which to set the zero point in longitude. As a result of global navigation, and what is now history, the British established a zero point in longitude, used primarily by the British Royal Navy (the Office of the Admiralty). The location of the zero point of longitude is in Greenwich, England. The Royal Observatory at Greenwich was established in 1676 for purposes of worldwide navigation.

Longitude and time, measured with clocks on board ships, was established as ships set out to sea on the Thames from London. A ship's navigator checked the time from clocks at the Royal Observatory that could be seen from the Thames. Then at sea the navigator would measure the position of the sun at noon (according to the shipboard clock). The angular amount that the sun was east of the local meridian[1] at noon for a westward moving ship would give a measure of the ship's longitude west of Greenwich. Before accurate and reliable clocks were invented there was no way to precisely establish the ship's longitude. For purposes of navigation in the east-west directions, it is essential that accurate time be established. Prior to 1676 ships had no way of determining their east-west location (i.e.. their longitude), other than by landmarks, which did not exist once a ship was out at sea.

Historically various countries established their own zero point of longitude, which is given the name: zero meridian. National observatories were established in Paris, London, Berlin, Leningrad, Madrid, and other major capitols with the purpose of determining longitude. Each established their own zero point of longitude, which meant that the longitude of a given place on the Earth differed depending upon which country's longitude system was used. By 1889, through international agreement, most countries adopted the **Greenwich Meridian** as a standard of longitude.

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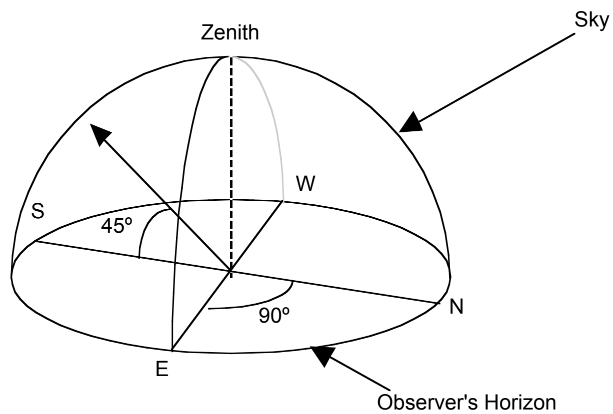
[1] A meridian is a circle on the Earth's surface that has its center at the center of the Earth and passes through the north and south poles.

Maps of the Sky:

Horizon Coordinate System: Before introducing the principal celestial coordinate system, it is useful to discuss a more local coordinate system. This coordinate system, established with reference to the observer's local horizon, has two coordinates: **Altitude** and **Azimuth**, both measured in *degrees*, *arcminutes* and *arcseconds*.

Azimuth: Angular distance measured along the horizon from 0º to 360º, measured north through east. For example, an azimuth of 90º corresponds to the east point on the horizon, while 270º points towards the west point on the horizon.

Altitude: This coordinate is measured as an angular distance from the horizon toward the point directly overhead, which is called the **Zenith**. Thus the zenith is at an altitude of 90º, whereas the horizon is at an altitude of 0º. Since we cannot use linear



dimensions on the sky, all positions must be measured as angles. An object's position in the sky can be expressed in terms of its altitude and azimuth.

Unfortunately we cannot use altitude and azimuth coordinates to find the same object in the sky every night. The Earth rotates on its axis and revolves around the Sun and consequently we cannot map positions on the sky as simply as we would map positions on the Earth. Since the Earth gradually orbits around the Sun, the direction that we look out from the Earth into the night sky gradually shifts day by day, changing by about 1º per day, which corresponds to 4 minutes of time. In the course of a year, the Earth moves through 360º. Most of the newly built large telescopes use this system for pointing and fast computers to make sure the telescope moves in the correct direction at the correct rate of motion.

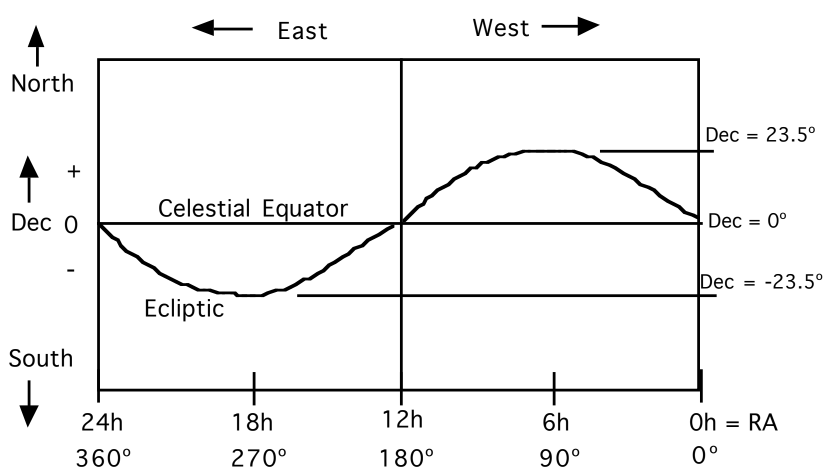
There are a variety of methods to measure the altitude and azimuth of objects. In this lab, you will use a protractor and a plumb bob to measure altitudes and knowledgeable estimation to measure the azimuths. Take one of the <u>protractors</u> and attach the <u>string</u> with the <u>bob</u> on it. Sight along the long flat edge of the protractor. Note the location of the string and read off the angle. This will be the altitude of the object. Note you cannot use it to measure altitudes of greater than 90°. If this occurs, turn around and face the other direction and remeasure the altitude. The method to measure azimuth takes advantage of the fact that you already know the specific azimuths of a variety of locations. These are the 4 cardinal directions. First locate the point on the horizon directly below the object. Remember that an object on the horizon has an altitude of 0°. From this point, estimate how far it is to the nearest cardinal direction making sure you measure along the horizon.

Celestial Coordinates:

We will use two separate celestial coordinate systems in this lab. The first one will be the Equatorial Coordinate System. The second will be the Ecliptic Coordinate System.

Equatorial Coordinate System

As an extension of our Earth-based coordinate system (latitude and longitude), there is a similar set of coordinates on the sky that has some subtle but significant differences.



Corresponding to the Earth's Equator is the **Celestial Equator**, which is simply a projection of the Earth's Equator on the sky. Directly above the Earth's north pole is the **north celestial pole** (NCP), while directly "below" the south pole is the **south celestial pole** (SCP). The celestial coordinates that are analogous to longitude and latitude (on the Earth) are called: **Right Ascension** and **Declination**. **RA** is normally measured in units of time: *hours*, *minutes* and *seconds* of time, whereas **Dec** is measured in *degrees*, *arcminutes* and *arcseconds*. On the celestial equator one hour of RA corresponds to 15º, thus 4 minutes of time corresponds to 1º. RA is measured in an eastward direction, starting at 0 hrs and going through a full circle to 24 hrs or 360º.

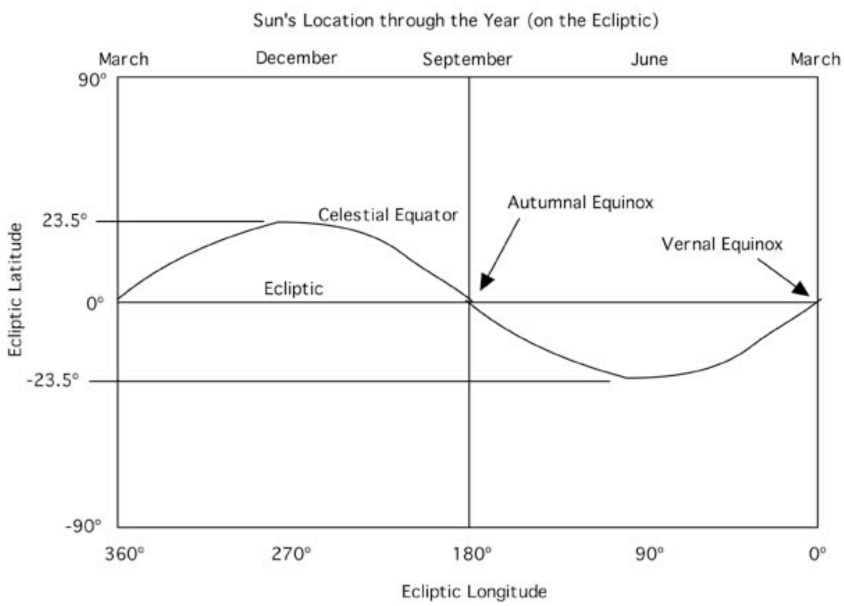
The zero point of RA is established by the point where the Ecliptic[2] crosses the celestial equator. This is the point where the Sun crosses the celestial equator, moving northward. As seen from the Earth, the Sun reaches this position on March 21st. The

[2] The ecliptic is the apparent path of the Sun, Moon, and planets as seen from the Earth. In another sense, the ecliptic is the path of the Earth's orbit projected onto the sky. The orbits of the Earth and most of the other planets move in a relatively flat plane around the Sun.

direction in the sky at RA=0hr, Dec=0º is called the Vernal Equinox. Since the Earth's axis of rotation is tilted by 23.5º relative to the direction perpendicular to the Earth's orbital plane, the Sun, Moon and planets appear to move north and south of the celestial equator by as much as 23.5º.

Ecliptic Coordinate System

The other celestial coordinate system we will be discussing is the ecliptic coordinate system. Whereas, the equatorial coordinate system was based on the surface of the Earth, the ecliptic coordinate system is based on the orbit of the Earth. The units of the ecliptic coordinate system are degrees and the two coordinates are ecliptic latitude and longitude. Since the Earth revolves around the Sun once a year, it appears that the Sun travels once around the sky with respect to the background stars in the same time. This path of the Sun is called the **ecliptic**, and represents the "equator" described by the plane of the solar system. It runs all around the sky and so traces out a **great circle**. The ecliptic latitude is simply measured in degrees away from that great circle. The ecliptic longitude much like the longitude on Earth and Right Ascension in the equatorial coordinate system does not have a very obvious origin. The origin chosen was the same one as that for the equatorial coordinate system. The **vernal equinox** is the 0° longitude point in this system as well as the equatorial system. The longitude is then measured along the path of the Sun in the same direction that the Sun appears to be moving around the ecliptic. The ecliptic coordinate system is a very useful system to measure the location and motion of solar system objects since their apparent motion in the sky follows it.



Observations

Before either the outdoor or indoor portion of this lab, you will be taken to the department Planetarium for a quick introduction to coordinate systems. In this environment we have the capability of drawing the critical lines and axes on the sky for you to see. Then you can hold these in your mind's eye when you subsequently look at the night sky outside.

Procedure – A table is provided below in which you should record the observations.

1. Measure the altitude and azimuth of 5-10 (number determined by your TA) bright differently placed objects. Record the name of the object next to the object number in the table. Remember to measure from the nearest cardinal direction. Record the time of these observations as well. Remember to estimate how uncertain your measurements are to discuss in your "conclusion".

2. Find and record at least one bright star located near the meridian tonight – record its altitude and azimuth and note it as "meridian object" in your table

3. Make another set of Northern and Southern Sky sketches as you did in the previous naked eye lab. Make sure you mark the location of the ecliptic and the meridian. Make sure you mark the location of the stars that your TA told you to note on your sketches in *Introduction to the Night Sky*.

4. Find the Moon and any bright planets, if visible. Record their altitudes and azimuths in the table.

<u>Go back to the classroom</u>:

5. Using your SC charts, determine the RAs and declinations of the stars and other objects you observed tonight. Put them in the table as well.

6. Using your SC charts, estimate the ecliptic longitude of each of the objects you just measured. What was the zodiacal constellation on the meridian tonight?

7. What is the ecliptic longitude of the Sun today? From your SC charts and/or starwheel, use this information to make an approximate estimate for the time of sunset tonight? Does that seem about right?

At least an hour later than the first set of observations:

7. Measure the altitudes and azimuths of the same 5-10 stars you measured earlier. Later, determine the RAs and Decs of these stars. Include in the table you started previously.

8. Complete parts 3 and 4 from the Indoor procedure below with your star charts.

Indoor alternative:

1. Choose 5-10 bright stars (number determined by the TA) from locations all around your SC charts. Where on Earth could you go to see each of these stars at the zenith? You will need one location for each of these objects.

2. Using your SC charts, record the ecliptic longitude and latitude, Right Ascension and Declination of the Sun for the 20^{th} of every month. What correlations between these values do you see? What phenomena does this correlation create?

3. Find a cluster, nebula, galaxy, variable star, and double star on your SC charts. What are their RAs and Decs? What day of the year would they be on the meridian at about 8pm?

4. Using the Audubon guide, what other information can you give about each of these 5 objects?

Additional Questions

1. How did the altitude and azimuth of your observed objects change?

2. How did the RAs and Decs of your observed objects change?

3. How did position in the sky affect either of these answers?

4. Will the ecliptic coordinates of these objects change?

5. How much does the ecliptic longitude of the Sun change every day?

6. What effect will this have on the sky you see from night to night?

7. How much does the RA of the Sun change every day?

8. Is the rate of change of the RA of the Sun constant? Why or why not?

9. Why are the Moon and planets not located on the SC charts or starwheel?

Conclusion:

Southern sky sketch

Name: ______________________________

Date: ___________________ Time: ______________________________

Instructor verification: __________

South

Northern sky sketch Name: ____________________________

Date: __________________ Time: ____________________________

Instructor verification: __________

North

