Chapter 4: Our Bearings in the Sky

Anasazi Recording of SN 1054 in Chaco Canyon , NM

Introduction

For centuries people have observed and recorded the changing patterns in the sky to keep track of the celestial events important to their survival or religious ceremonies. Prehistoric artifacts and remnants of astronomical observatories have been discovered around the globe, providing us with intriguing clues into how knowledge of sky motions developed into timekeeping and calendar systems, and how the sky and its motions became a source of rich and enduring mythologies. A fossilized mammoth tusk from a cave in France records the lunar cycle, inscribed 17,000 years ago during the last Ice Age. At Stonehenge, in England, the Sun rises over the heel stone during the summer solstice (the first day of summer). In Central America, the Mayans aligned their observatories according to their predictions of the first appearance of Venus in the predawn sky; their calculations were accurate for more than 100 years in advance. On White Mesa in northern Arizona, the Navajo appear to have recorded the Crab Nebula supernova explosion of 1054 AD with rock art drawings. At Fajada Butte, New Mexico, the Anasazi Indians arranged slabs of rock so that on the day of the summer solstice, a sliver of dagger-shaped sunlight shining through an opening in the rocks touched the center of a spiral chiseled into the rock. Keeping their eyes on the heavens to keep track of time and events on Earth, ancient skywatchers became the expert astronomers of their day.

Many ancient observers imagined the sky as a vast bowl or canopy, spinning once around the Earth each day. We know this picture is not correct, but it does help us to get our bearings. Think of the night sky as a great transparent spherical shell with all the stars glued to the inside of the sphere and the Earth sitting in the center. As the sphere appears to turn, the stars appear to move; however, they always maintain their positions on the transparent sphere relative to one another. For centuries, skywatchers have been familiar with the orbital motions involved with the Earth, Moon, and planets, and the apparent motions of the Sun and stars. Independently, they have devised and constructed complex calendars and time-keeping devices from their knowledge of the changing sky. Consistency between time and calendar systems of different cultures was not important, because astronomical knowledge was specific to the mythology and customs of each individual culture. Today most cultures are not isolated, they are organized into states and countries that share and exchange knowledge on a daily basis, and engage in scientific endeavors and studies together. A consistent world-wide system to accurately locate objects in the sky became a necessity, and the resulting celestial coordinate system, a roadmap of the sky, is used by professional and amateur astronomers to locate celestial objects.

Investigation 4.1a: Understanding the Motions of the Earth-Moon System

Your instructor will provide a light source. Standing near the light source, turn around so that you alternately face towards, then away from, the light. If you could draw a line from the bottom of your feet through the middle of your body to the top of your head, this would be your axis of rotation, the center around which you are turning. The Earth also rotates about its axis, taking 24 hours for each complete rotation. Stand still and have another student walk around you. The student is revolving around you. The Earth revolves around the Sun, taking 365.25 days, one year, for each complete revolution or orbit.

When you are facing the light source, the front of your body is illuminated—this is daylight on Earth. When you are facing away from the light, the front of your body is in shadow—this is like nighttime on Earth. Watch a friend rotate in front of the light. What do you notice about the pattern of shadow and light on your friend's body? What does this pattern suggest about the pattern of day and night on the surface of the Earth?

Use the objects at your disposal to answer the following questions. Does the Earth always cast a shadow? Does the Moon always cast a shadow? Do you notice phases on the Moon? Do other planets have phases? If so, which ones? Why or why not? As the Moon revolves around the Earth it also rotates, even though the same side is always facing the Earth. Can you demonstrate and explain this fact? The far side of the Moon is often referred to as the dark side of the Moon. Is it dark?

Using the members of your group and any other objects provided, recreate the sky motions of day and night, the Earth and Moon, stars and constellations. Be prepared to present your demonstration(s) to the other groups.

Investigation 4.1b: Understanding the Motions of the Stars and Constellations Across the Sky

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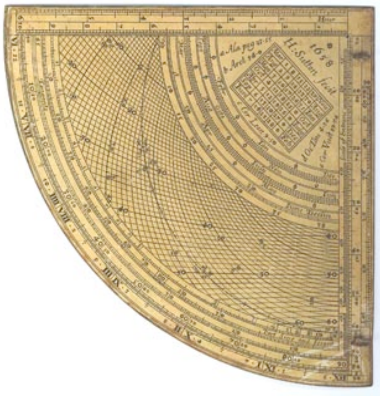
You know that stars and constellations seem to move across the sky. How fast do they move? Locate a bright star that you can easily watch appear over the horizon, a building, or any easily identifiable reference point. Record the time that it just comes into view at your reference point. Do you think the star will appear at the same time every night? Repeat your observation and again record the time three days later. Does the star come into view at the same time? If not, what is the difference? Make five observations approximately three days apart, and take the average. What does this number represent? Remember that a point on the Earth's surface (except at the poles) travels 360° in one rotation, and the amount of time one rotation takes is commonly accepted as 24 hours.

Core Activity 4.2: Using a Quadrant to Measure Motion of the Moon, Stars, and Sun Across the Sky



The Sutton Quadrant, 17th

Over the centuries people have used sightings of the Sun, Moon, planets, and stars for a variety of purposes. One of the oldest devices for this purpose, the *quadrant*, dates back to about 240 BC. The quadrant is used to determine the altitude of a celestial object, in other words, its angular height (how many degrees it appears above the horizon). The quadrant enables the observer to locate celestial objects and determine information about celestial events, such as rising and setting times, motions, and position. Essentially, these simple tools were astronomical “clocks” used to devise calendars of celestial events. In the Islamic world simple quadrants served practical purposes in everyday life. They were used to determine times for prayer, ascending zodiacal constellations, positions of the Moon and Sun, and the alignments of these objects. Over time, improvements to the quadrant produced greater accuracy in observations. Celestial aids were developed in the 16th and 18th centuries to determine the time of night, schedule of tides, observer’s latitude, and the time of the lunar meridian crossing.

Begin building your own quadrant by gluing the template on the next page to a piece of manila file folder. Cut out the quadrant. Cut a straw to the same length as the quadrant and attach with cellophane tape along the folded edge. Using a pencil, poke a small hole on the circle indicated on the quadrant. Pass some string through the hole and knot it. Then attach a washer or other small weight to the end of the string. Your quadrant is now ready to use.

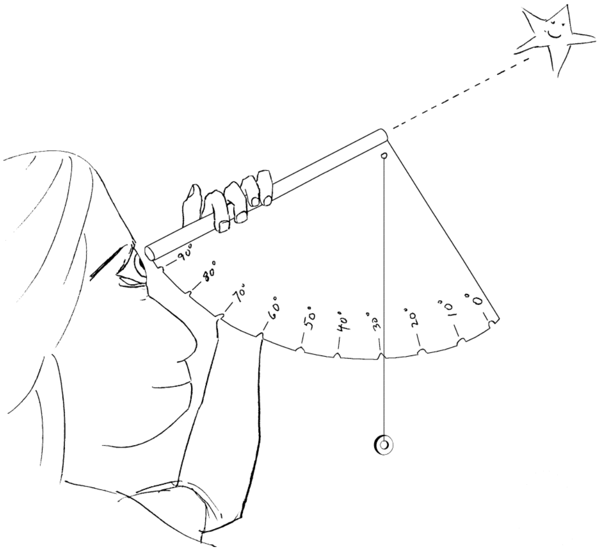
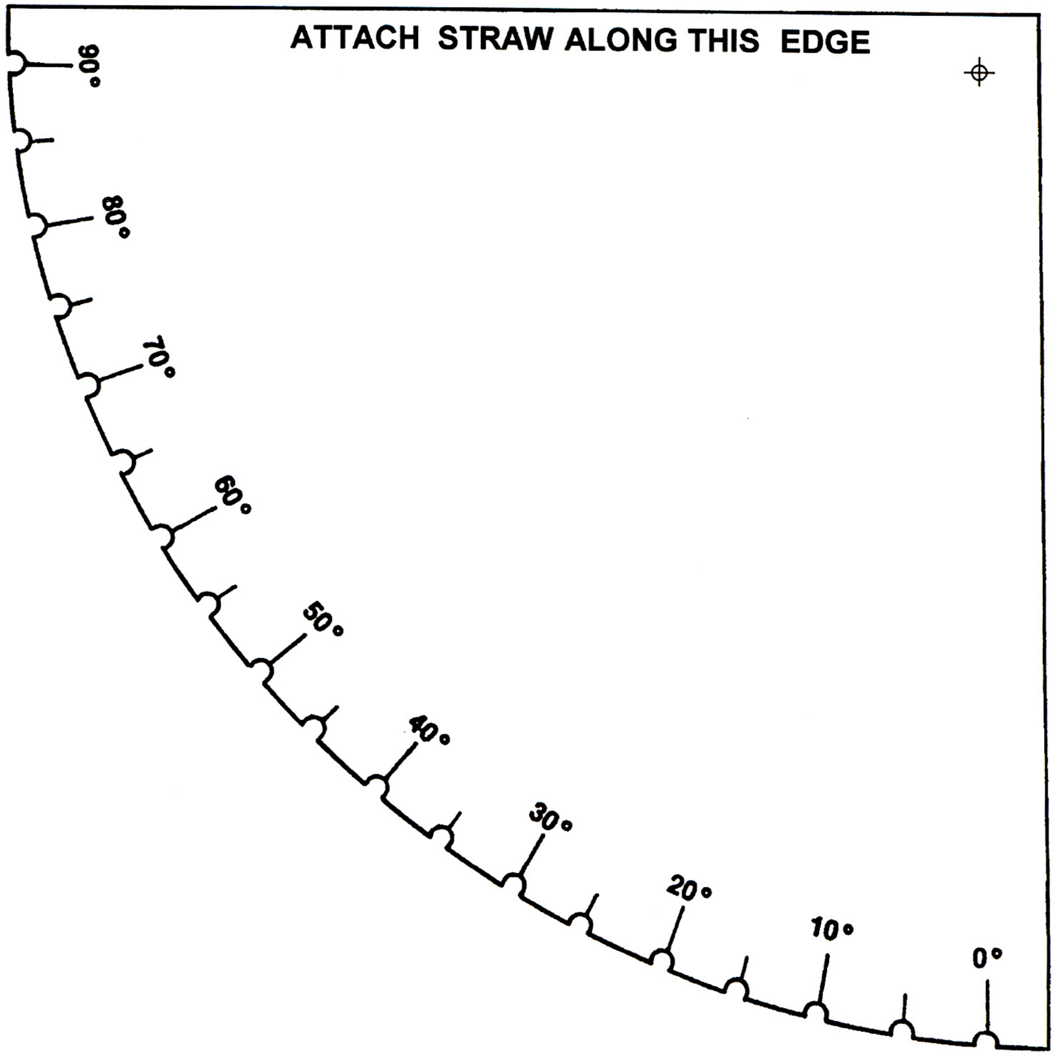


Figure 4.1, Mike Saladyga, artist

To use the quadrant to make vertical angular measurements (altitude): Hold the quadrant so that the straw is in your hand, with the end marked “90°” at your eye, and with the string hanging freely down. Sight the object you want to measure through the straw, then press the string against the quadrant card and note the angle at which the string lies on the card (Figure 4.1).

Practice using the quadrant. Determine the angular height (altitude) of a tall object such as a nearby building. Take three separate measurements and determine the average.

Quadrant Template



Besides measuring the altitude of celestial objects, the quadrant can also be used for measuring the angle separating any two celestial objects, such as stars. To make a horizontal angular measurement (azimuth), hold the quadrant horizontally and bring the end of the straw that is at the right angle of the quadrant to your eye. Through the straw, sight the first object you want to measure, and slide the string along the curved part of the quadrant so that it lines up with the second object. If the string is not in one of the notches, hold it carefully so as not to lose the measurement. (It is easier to have one person line up the quadrant and another hold the string.) Read what the angle is where the string lies: take this number and subtract it from 90°. The result is the angle separating the two objects in the sky. Determine the angular separation of any two objects in your vicinity for practice.

MEASURING THE MOTION OF THE MOON

Relative to the horizon, how much does the Moon change its altitude over a period of time? Choose a time to make a nightly or daily measurement of the Moon's altitude. Make three separate measurements at the same time each night or day and enter these data into a table, along with the direction of movement and the lunar phase (or shape). Calculate the average. The longer the observations are made, the more useful the data will be for answering questions and making predictions. What do you notice about the Moon's position from day to day? Does maximum height correspond with a particular phase? How much does the Moon move relative to a planet such as Venus or Jupiter? How much does it move relative to one of the pointer stars in the Big Dipper (in Ursa Major)?

MEASURING THE MOTION OF A CONSTELLATION, SUCH AS URSA MAJOR (THE ASTERISM IS THE BIG DIPPER)

Measure the altitude of two of the stars in the Big Dipper at 8:00 PM, 9:00 PM and 10:00 PM, taking three measurements and determining the average. Select the star at the end of the handle, and the pointer star at the other end. Do the same for Polaris and enter the data into a table. Take the measurements over an extended period of time (one week minimum). How much does the Big Dipper change from hour to hour? From day to day? From week to week? What is the motion of Polaris? Would you get the same amount of movement if you took your measurements from a different latitude?

MEASURING THE MOTION OF THE SUN

Figure 4.2, Mike Saladyga, artist

(**NOTE: NEVER** look at the Sun through the straw on the quadrant.The ultraviolet rays will damage the receptors in your eyes, causing blindness.) Hold the quadrant by the straw so that the angle markings face you, and the right angle end of the straw points in the direction of the Sun (see Figure 4.2 at right). Slowly move the straw: you will know you are close to getting a good reading as you see the shadow of the straw become shorter on your hand or on the paper. Continue moving the straw until a small circle of light forms on your hand or the paper; now the straw is pointing directly at the Sun. Now take a reading for the Sun's altitude. Take three measurements, record the data, and find the average. Take the measurements as close to noon as possible when the Sun is on the meridian and at its highest point in the sky for that day. Continue to take the data over a period of several weeks, or even for the entire school year. Does the noontime altitude change? Does the Sun ever get directly overhead? Where does the Sun get directly overhead? Does the altitude increase or decrease? Is this pattern of change related to the seasons? What pattern would develop in the Southern Hemisphere?

Core Activity 4.3: Why Constellations Appear in Different Places in the Sky at Different Times of the Year

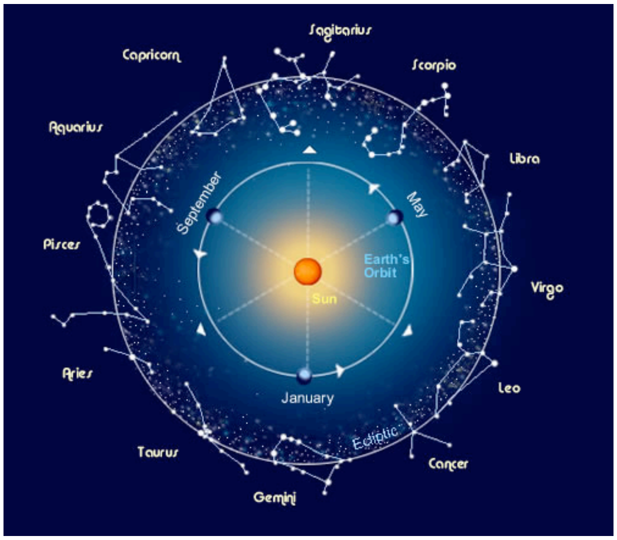
Introduction

Throughout the year we watch the orderly procession of constellations across the sky. We look for Orion to appear in the early winter, and know that Scorpio will inhabit the summer sky, spreading across it to dominate the southern horizon. March comes in like a lion—a lion named Leo, that is—that regally traverses the spring skies. In autumn there is Taurus the Bull, forever galloping into the sky to lead Orion into the winter skies once more. Why do these constellations seem to move across the sky in such a pattern? In this activity you will develop a model to demonstrate and explain this pattern.

Constructing the Model

Your class will first construct models of the zodiacal constellations, using drawings or any other art form of your choice if not given specific instructions. Each year as the Sun seems to travel on its imaginary path across the sky called the ecliptic, it completes one circuit through these zodiacal constellations.

After constructing your models, place them in a circle around the edges of the room with a large light source in the middle. Each quarter of the circle will then represent one of the seasons. Stand inside the circle between the constellations and the Sun. Since your horizon is a semicircle or 180 degrees, you cannot see the 180 degrees of constellations on the other side of the Sun, so have classmates stand in a straight line on either side of the Sun holding the sheets of paper or cloth provided to block your view of those. Turn counterclockwise, and during the nighttime when you are turned away from the Sun those are the constellations visible to you. The Earth also revolves counterclockwise around the Sun, so move in that direction to the next constellation. The barricade of students blocking your view of the constellations behind the Sun must rotate around one constellation in the same direction. As you turn to your night side you will see that one constellation has gone down in the west and another has risen in the east. As you revolve around the Sun during your "year," you will see the same procession of constellations that you see in the actual night sky during the year.



Seasonal Changes of Constellation Positions,
Lunar & Planetary Institute

Abe Lincoln and the Almanac Trial

A three-week religious camp meeting conducted by a famous Methodist circuit rider named Peter Cartwright took place at Virgin's Cove, five miles northeast of the junction of Salt Creek and the Sangamon River, in Mason County, Illinois, during August of 1857. Around the fringes of the meeting, temporary bars were set up for the occasion, and drinking and gambling were on-going activities. At one of these outdoor saloons, a fight broke out at 11 p.m. on Saturday, August 29th. William Armstrong and James Norris had an altercation with James Preston Metzker, who mounted his horse and rode to the nearby home of a friend after the fight. He died there three days later of head injuries. Norris and Armstrong were arrested and indicted for murder. Norris was tried and convicted. Armstrong's mother traveled to the home of an old family friend in Springfield, Abraham Lincoln, and asked him to defend her son.

The murder trial of Armstrong took place at the Cass County courthouse in Beardstown, Illinois. The main prosecution witness stated that he was about 150 feet away from the fight but saw everything clearly by the light from a bright, nearly full Moon, high in the sky. Lincoln produced an almanac to prove that the Moon at 11 p.m. was going out of sight, within about an hour of setting, and not overhead as the witness claimed. After a short deliberation, the jury acquitted Armstrong. Exactly which almanac Lincoln consulted is not known. The two most often mentioned are *Jayne's Almanac* and *Goudy's Almanac*. Almost immediately serious allegations circulated that a fake almanac had been used, with the lunar phases and times of moonset altered to fit Lincoln's purpose. The story persisted because many townspeople at the time believed that Lincoln had prepared a fake almanac. Their almanacs showed a Moon nearly in mid-heavens at the hour of the fight, and the almanac Lincoln had consulted could not be found.

The Moon's position "nearly in mid-heavens" is a reference to the Moon's crossing of the meridian, called upper transit or upper culmination by astronomers. Almanacs often contained information on the times that the Moon was on the meridian. How could Lincoln prove the Moon was near the horizon and setting, since the people at the meeting had seen it with their own eyes, shining brightly, nearly full, and standing near the meridian?

The lunar phase and time of moonset on the night of August 29–30, 1857, has been calculated by many prominent astronomers. All found moonset times near 12:04 a.m. on August 30, 1857, supporting Lincoln's claim that the Moon at 11 p.m. on the 29th was low and near to setting. Two investigators, Donald Olson and Russell Doescher from the Department of Physics at Southwest Texas State University, repeated the calculations and discovered a coincidence involving a well-known 18.6-year lunar cycle and its effect on the lunar declination of August 29, 1857. In other words, the Moon on that night crossed the sky at its lowest elevation in 36 years. Their investigation explains the mystery of why so many people thought Lincoln had faked the almanac, and resolves the conflict between Lincoln's astronomical evidence and the recollections of the townspeople.

For an observer at a given latitude in the northern US, the length of time the Moon spends above the horizon depends primarily on its declination. The Moon "runs high" when it has an extreme northern declination, passing near the zenith, and staying in the sky a long time before finally setting in the northwest. The Moon "runs low" at the other extreme in declination, skimming low above the horizon, then quickly setting in the southwest. 1857 was a special year with respect to lunar declination. Every 18.6 years the most extreme lunar declinations occur, when the tilt of the Earth's axis and the tilt of the lunar orbit combine to produce lunar declinations exceeding 28° north and 28° south. On the night of the fight, the Moon was exceptionally low. As the Moon crossed the meridian on the evening of August 29th, its geocentric declination was –28.6°, and correcting for parallax for an observer in central Illinois gives an apparent lunar declination of –29.5°, almost the extreme value the Moon can attain. The Moon traveled from "mid-heavens" (the meridian) to the horizon in only a little more than four hours. Both Lincoln and the townspeople were right. Just before 8:00 p.m., the Moon crossed the meridian in the cloudless sky over Virgin's Cove. By the time of the fight, the Moon was dropping from view. "Honest Abe" did not use a false almanac.

Understanding cycles not only enables us to make predictions of events into the future. It also enables us to work backwards and know about events that happened in the past. There are several historical events that have important astronomical associations.

Henry Wadsworth Longfellow's poem, "The Midnight Ride of Paul Revere," mentions the Moon several times:

> he... Silently rowed to the Charlestown shore, just as the moon rose over the bay....
> The *Somerset,* British man-of-war; A phantom ship, with each mast and spar
> Across the moon like a prison bar...
> Where he paused to listen and look down A moment on the roofs of the town,
> And the moonlight flowing over all...
> A hurry of hoofs in a village street, A shape in the moonlight, a bulk in the dark....
> He saw the gilded weathercock Swim in the moonlight as he passed.

Are these statements about the Moon correct? After all, there are several inaccuracies in the poem. For instance, Revere is placed on the wrong side of the harbor, and he was involved in sending the lantern signal, not in receiving it. And Revere did not reach Concord, he stopped in Lexington. Is the poem also wrong about the Moon? Was the Moon rising as Revere crossed the river? Calculations show there was a bright waning gibbous Moon, 87% lit, in Boston on the night of April 18, 1775. The Moon was rising when Paul Revere crossed the harbor between 10 and 11 p.m. Computer simulations also show that the Moon had a southern declination of -18°, which, combined with Boston's latitude of 52° 22' north, caused the Moon to rise considerably south of east. When Revere crossed the harbor, roughly 45 minutes after moonrise, the Moon was low in the southeast. Anyone on the Somerset would have seen the Moon rising over the city of Boston, not over the open water of the bay, and would not have been able to see Revere row across the bay.

The Moon has also played a significant role in this century's wars. The timings of attacks and escapes were planned to coincide with appropriate lunar phases and tides. The German submarine U-47 was able to sneak into the Scapa Flow anchorage off Scotland and sink the battleship Royal Oak by gliding over rocks during an extraordinarily high tide caused by the coincidence of a new Moon with perigee. Amphibious assaults by the US Marines in the Pacific were timed for high tides to minimize the amount of exposed beaches the soldiers had to cross.

Tide conditions were crucial to the allied invasion of Normandy on the morning of June 6th, 1944: troops had to invade at extreme low tide so that the numerous beach obstacles could be avoided and cleared.

The Japanese attack of Pearl Harbor, Hawaii, was timed so a bright Moon would illuminate the carrier decks when the planes were launched; not a full Moon, however, which would have provided illumination all night long. The Japanese chose a Sunday morning with a waning gibbous Moon which rose in the evening, transited the local meridian after midnight, and remained bright and relatively high in the sky until dawn.

Core Activity 4.4: The Rotating Earth and the Sun’s Apparent Motion Across the Sky

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A. Shadow Stick Astronomy

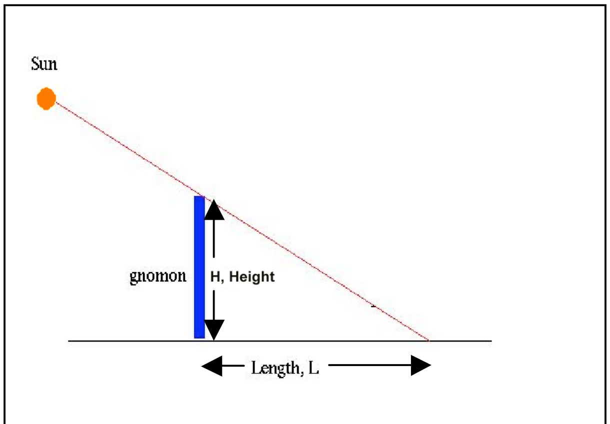


Fig.4.4

If you did not construct the quadrant from Activity 4.2, you may want to do so now. If you do not construct a quadrant, you can use the information in Table 4.1 to calculate the Sun’s altitude instead by measuring the length of the stick and the length of the shadow. Construct a sundial by sticking a straight, sharpened wooden dowel or pencil onto the center of a stiff piece of poster board or manila folder with a small piece of clay. Make sure the stick is vertical. The vertical stick is called a gnomon (pronounced “nō'-mon”; the “g” is silent). Write the E-W and N-S directions on the paper. Take the sundial outside to a flat area that will have an unobstructed view of the Sun throughout the day. Use a magnetic compass to make sure that the compass directions are properly oriented. Clearly mark the place from which you are recording your information so that you can return to the same place for each measurement. Also remember to orient your paper in the same direction for each observation.

Every half hour or hour, beginning in the morning, mark on the paper the following information. The more data points you have, the easier it will be to answer the questions at the end of this activity.

1. The position of the end of the shadow made by the stick;

2. The time of day you are taking the measurement;

3. The altitude of the Sun measured with the quadrant, OR calculated by using a gnomon and Table 4.1 as follows:

    a. Measure the height of the gnomon (shadow stick).
    b. Measure the length of each shadow cast by the gnomon.
    c. Divide the length of each shadow by the height of the gnomon.
    d. Use the ratios you have just calculated to look up the corresponding angles on the table.

Table 4.1

ratio	angle°	ratio	angle°	ratio	angle°
0.00	0	0.58	60	1.73	30
0.02	89	0.60	59	1.80	29
0.03	88	0.62	58	1.88	28
0.05	87	0.65	57	1.96	27
0.07	86	0.67	56	2.05	26
0.09	85	0.70	55	2.14	25
0.11	84	0.73	54	2.24	24
0.12	83	0.75	53	2.36	23
0.14	82	0.78	52	2.48	22
0.16	81	0.81	51	2.61	21
0.18	80	0.84	50	2.75	20
0.19	79	0.87	49	2.90	19
0.21	78	0.90	48	3.08	18
0.23	77	0.93	47	3.27	17
0.25	76	0.97	46	3.49	16
0.27	75	1.00	45	3.73	15
0.29	74	1.04	44	4.01	14
0.31	73	1.07	43	4.33	13
0.32	72	1.11	42	4.70	12
0.34	71	1.15	41	5.14	11
0.36	70	1.19	40	5.67	10
0.38	69	1.23	39	6.31	9
0.40	68	1.28	38	7.12	8
0.42	67	1.33	37	8.14	7
0.45	66	1.38	36	9.51	6
0.47	65	1.43	35	11.43	5
0.49	64	1.48	34	14.30	4
0.51	63	1.54	33	19.08	3
0.53	62	1.60	32	28.64	2
0.55	61	1.66	31	57.29	1

After all the data have been collected, draw a smooth line connecting the points at the end of the shadows and measure each distance from the base of the shadow stick to the end of the shadow. Then answer the questions on the next page and discuss your results with the other groups.

1. Is the line connecting the points straight or curved?
2. Does the line curve away from the stick or around the stick?
3. Graph the altitude of the Sun versus the time the measurements were taken. At about what time was the Sun at its highest altitude?
4. At about what time was the shadow cast by the Sun the shortest?
5. Is there a relationship between the length of the shadow and the altitude of the Sun?
6. How would your results differ if you were recording your observations six months from now?
7. When and where would you have to be to have no shadow cast at some point along your graph?
8. Can you determine compass directions based on your observations?
9. Is your shadow always behind you?
10. How can shadows be used to tell time?
11. What problems would we encounter if we used a sundial to tell time?
12. When and why were sundials developed? Are there different kinds of sundials?

B. Shadows on a Sphere

You will be given a clear plastic hemisphere. Imagine that you are standing inside, at the center; the dome represents the sky. You are now going to track the Sun's path as it actually appears to you in the sky.

Glue a plain piece of paper onto a stiff piece of cardboard and place a small "x" in the center of the paper. Attach your hemisphere over the base with tape and mark the cardinal directions N, S, E and W on the paper and also on the base of the hemisphere. Make sure the hemisphere is centered over the base, with the top of the sphere directly over the "x" and firmly attached.

Place the hemisphere on a flat surface that will be in direct sunlight for as long as you intend to take measurements. With a compass, orient the hemisphere so that the North side of the hemisphere is actually pointing North. You may want to draw an outline around the cardboard with chalk if possible in case the hemisphere is moved. If this is not possible, check frequently to make sure that the hemisphere North is pointing North. Start this activity in the morning and take data as long as possible throughout the day.

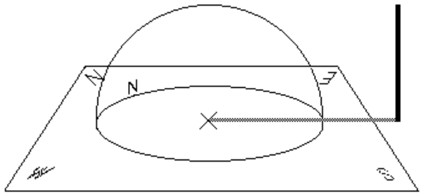


Fig. 4.5

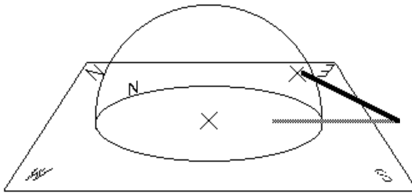


Fig. 4.6

Holding it vertically with the sharp end up, move a sharp pencil around on or near the cardboard until the shadow cast by its tip falls exactly on the center of the base diagram (see Figure 4.5). Without moving the base of the pencil, lean it over until the tip of the pencil touches the hemisphere. Make a dot with a non-permanent marker where the pencil touches the hemisphere at the same time that the shadow of its tip falls exactly on the center of the base diagram (see Figure 4.6). Place a number 1 on the dot on the sphere and in a notebook enter the time that the first data point was plotted. Continue to plot points and record the time every half hour.

When you are finished with the series of plots, trace them on the *inside* of the globe for a permanent record. Then erase the marks on the outside when it is time to take another series of observations next month, or next season. On the inside of the globe connect the plotted points with a solid line and label the line with the date. Answer the following questions:

1. From what direction did the Sun rise and in what direction did it set?
2. Where was the Sun's position at noon (what was the approximate angular height)?
3. Compare and contrast the shape of the path of the Sun across the dome with the shape of the path of the Sun in the shadow stick activity. Are the results the same? Explain what you see.
4. You may want to repeat this activity every month using different colors each time you draw the line on the inside of the globe, or repeat it once each season.

   Predict what the changes would be and see how closely your results agree.
5. Would your results change with longitude? Latitude? How far away would you have to be and in what direction to detect a difference?

Mapping the Sky: The Celestial Sphere Coordinate System

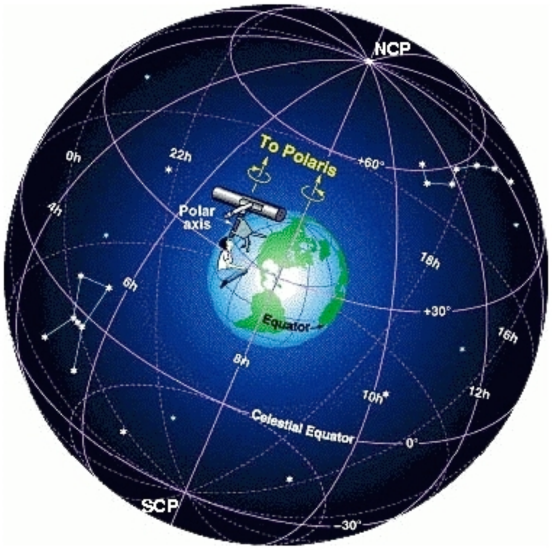


Figure 4.7

The *celestial sphere* is an imaginary, hollow, transparent sphere centered on the Earth (see Figure 4.7). The Earth's terrestrial coordinates are extended out onto the celestial sphere and superimposed upon its surface. The Earth's equator becomes the celestial equator (CE), the north terrestrial pole becomes the north celestial pole (NCP), and the south terrestrial pole becomes the south celestial pole (SCP). The terrestrial coordinates of longitude and latitude are also extended to the celestial sphere and are called *right ascension (RA)* and *declination (Dec)*, respectively (refer to Figure 4.8 below). Now all celestial objects can be located on the celestial sphere, an imaginary map with the specific coordinates of right ascension and declination. We can now use these coordinates to locate all objects in the sky exactly the same way we locate places on Earth—by using longitude and latitude.

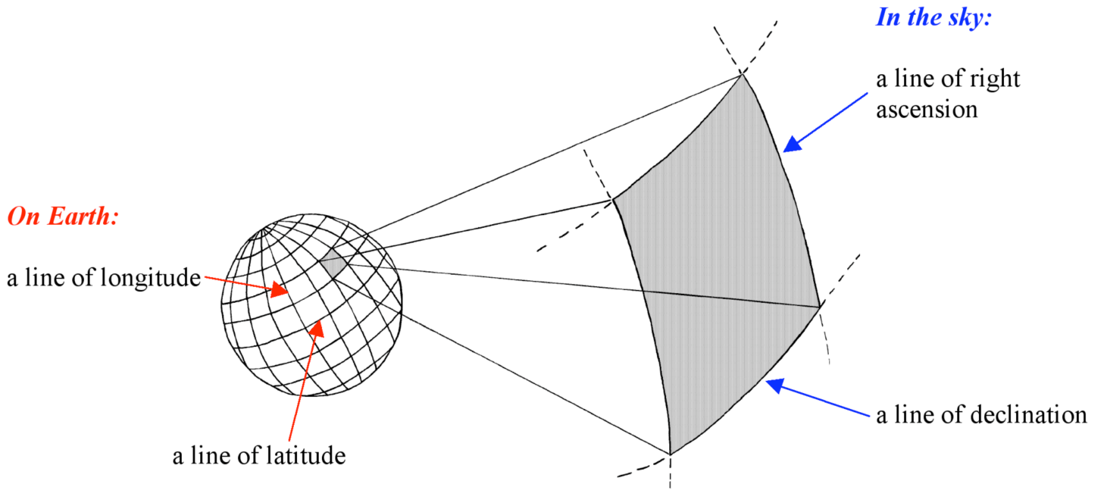


Figure 4.8

The celestial sphere is a geocentric model—it represents sky motions as they appear from Earth, and not as they actually are. Remember that even though models are useful, they also include distortions: the Earth is rotating, not the sky. The apparent path of the Sun, the ecliptic, is also superimposed onto the surface of the sphere, and so both the Sun and the sky appear to move around the Earth; the celestial sphere is a reflection of the Earth's rotation and tilt. The ecliptic is inclined from the celestial equator by 23½°, and has four important points along its path. The point 23½° below the celestial equator (Northern Hemisphere) is the winter solstice, and the point 23½° above the celestial equator (Southern Hemisphere) is the summer solstice. The two points where the ecliptic intersects the celestial equator are the vernal (spring) equinox and the autumnal (fall) equinox (see Figure 4.9 below). At the vernal equinox, the Sun starts its ascent into the Northern Hemisphere, climbing to 23½° above the celestial equator by the summer solstice, when the duration of daylight is the longest. The Sun then descends past the autumnal equinox into the Southern Hemisphere as far as 23½° below the celestial equator to the winter solstice, when the duration of daylight is the shortest in the Northern Hemisphere, before starting the climb back to the vernal equinox. The equinoxes have equal hours of day and night.

Declination is measured, like its terrestrial equivalent of latitude, as the angle north or south of the celestial equator in degrees, minutes, and seconds of arc. Declination goes from 0° at the celestial equator up to +90° at the North Celestial Pole and down to –90° at the South Celestial Pole. Right ascension, corresponding to longitude on Earth, is not measured in degrees as it is on Earth, nor is it measured east or west. It is measured in units of time: hours, minutes, and seconds eastward. Right ascension goes from 0 hours, located at the vernal equinox, in one-hour increments to 23 hours; 24 hours is the same as 0 hours, which brings us back to the starting point at the vernal equinox. The vernal equinox, 0^h RA, corresponds to the prime meridian on Earth, the line of longitude that runs through Greenwich, England (refer to Figure 4.10 on the next page). The 0^h right ascension line on the celestial sphere is also called the celestial meridian and runs through the constellation of Pisces, the fish, in the Northern Hemisphere.

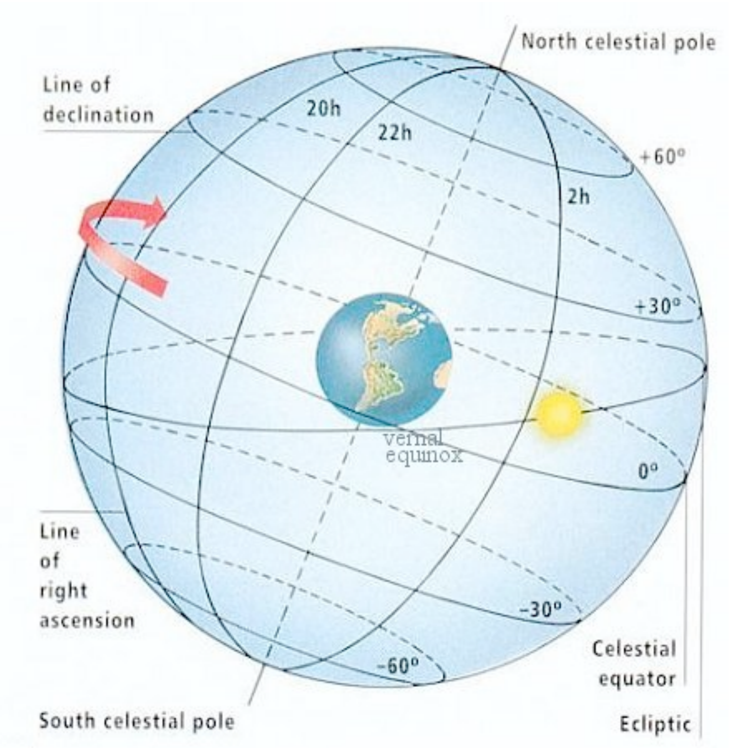


Figure 4.9

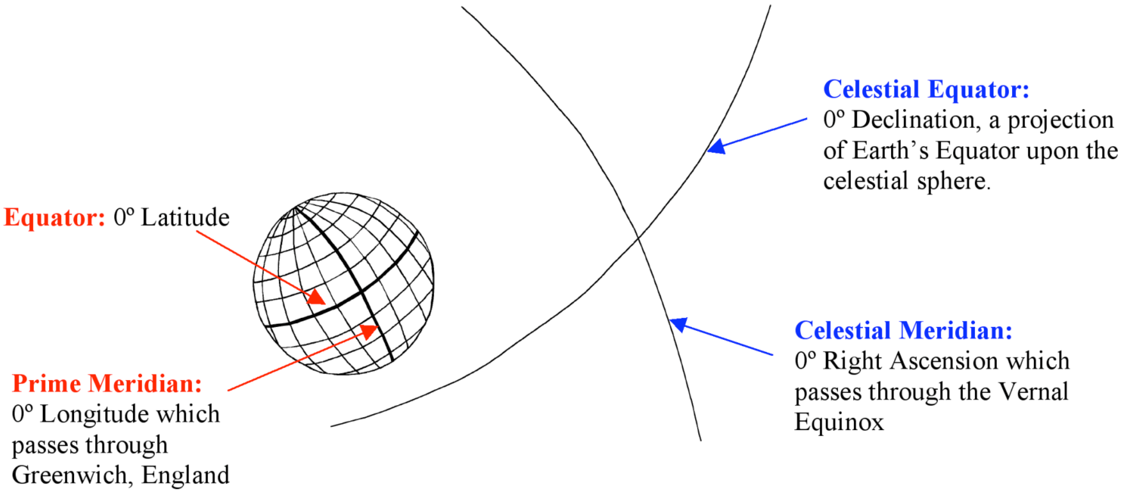


Figure 4.10

Since there are 360° in a circle and 24 hours of right ascension, 15° corresponds to one hour of time. The Earth rotates 15° every hour, and after a 24-hour period has rotated through all 360°, i.e. 24 hours of right ascension. This is the timekeeping device referred to as *sidereal [“sī-dir′-ē-al”] time*, or telling time by the stars. The *sidereal day* officially starts at midnight, when the vernal equinox (0^h RA), passes over your meridian, and ends the following midnight upon returning to your meridian. Therefore, one sidereal day is equal to one rotational period of Earth. Twenty three hundred (2300) hours (11:00 PM) means that 23 hours right ascension is at your meridian, and at fifteen hundred (1500) hours (3:00 PM), 15 hours right ascension is at your meridian. (A sidereal day begins at midnight, so 24^h RA = 12:00 AM, 1^h RA = 1:00 AM, 12^h RA = noon, 15^h RA = 3:00 PM, 18^h RA = 6:00 pm and 21^h RA = 9:00 PM.)

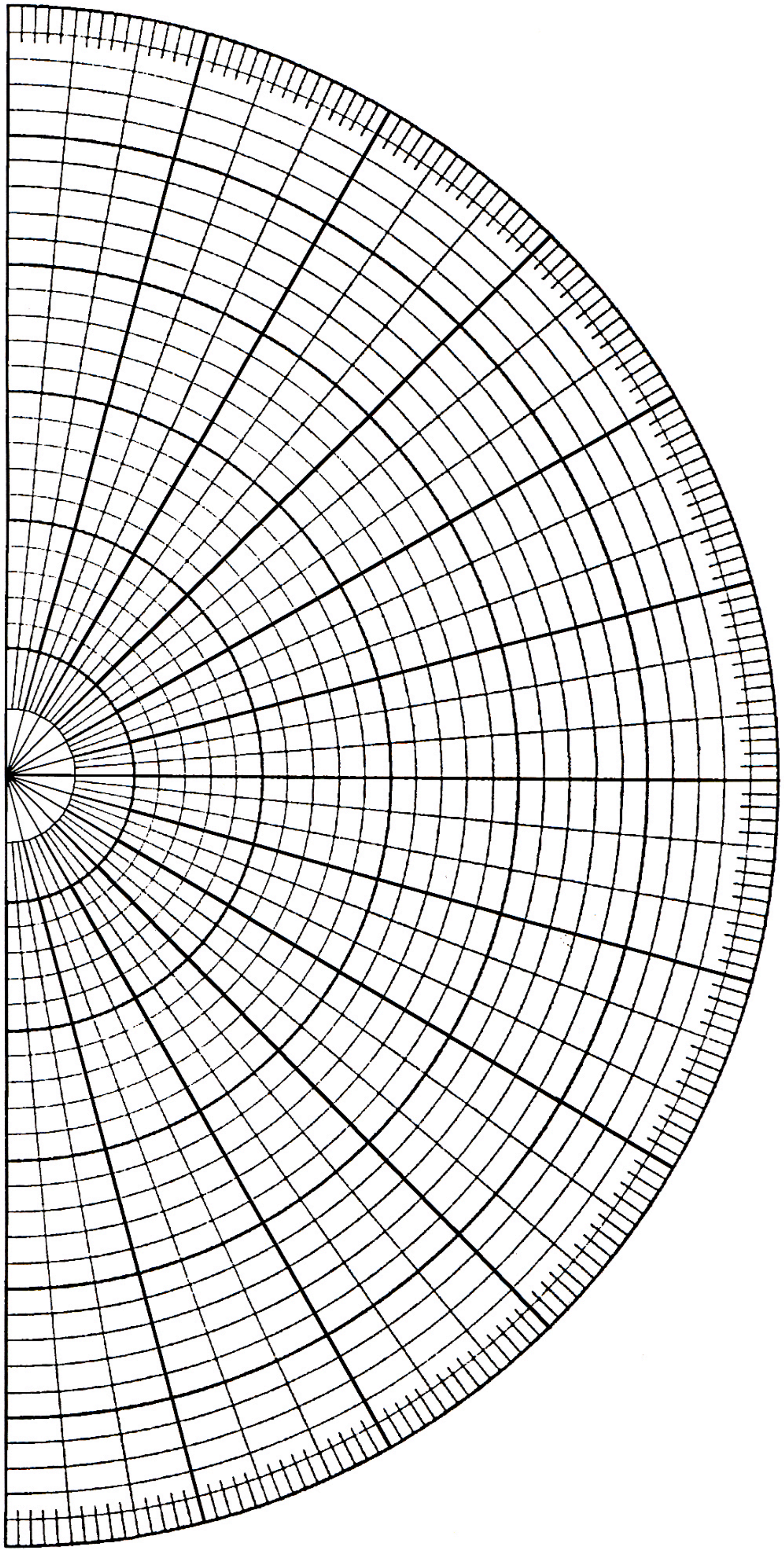
Core Activity 4.5: Constellation Plots

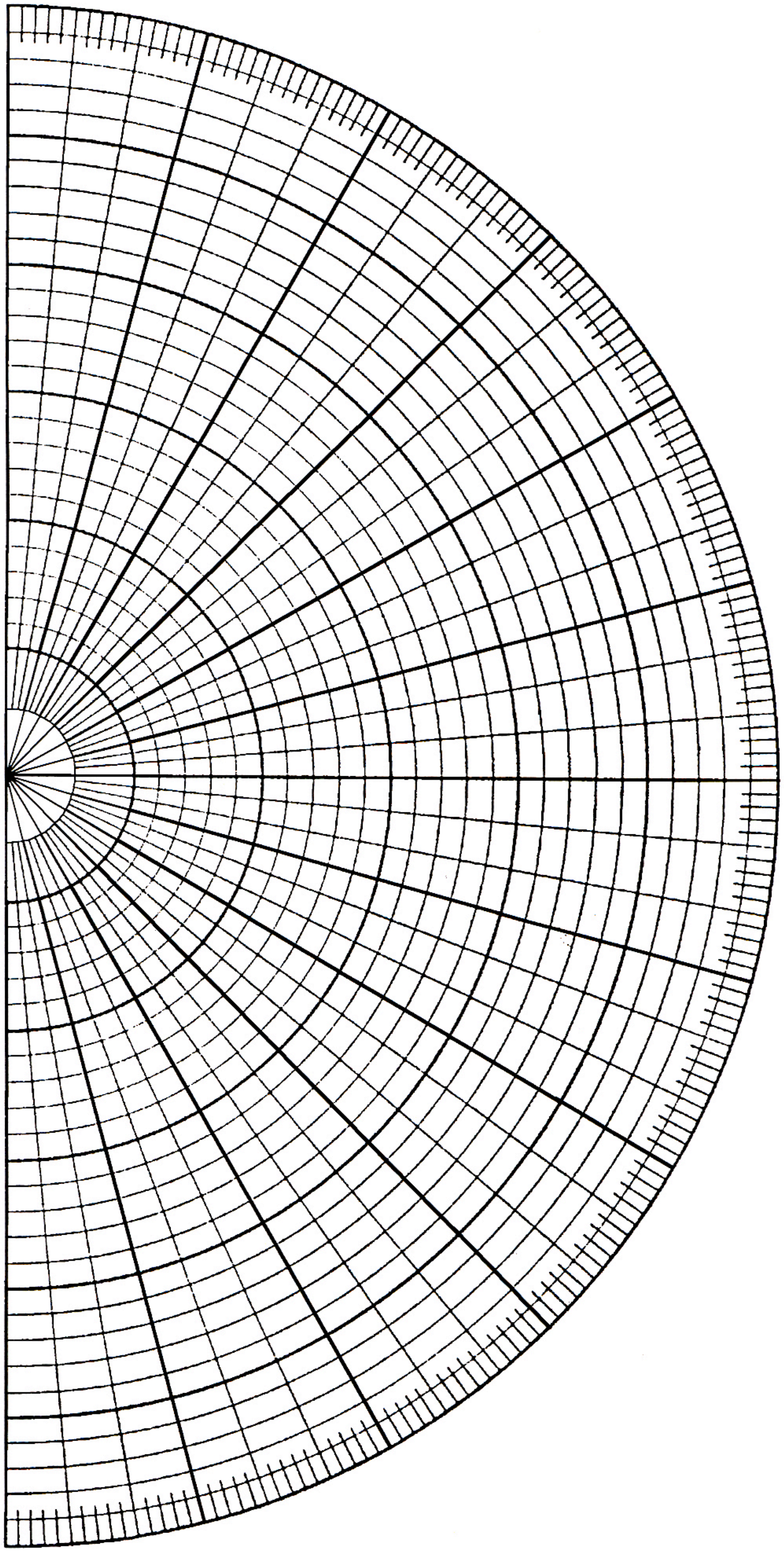
The purpose of this activity is to construct a constellation map with the polar coordinate graph paper provided. The center of the paper is the north celestial pole, the circles are the lines of declination (Dec), and the radial lines are the lines of right ascension (RA). Read the next three paragraphs before you begin.

1. Assemble the polar coordinate graph paper provided by your instructor and label the coordinate system on the polar coordinate graph paper, along with the appropriate units of measurement; then plot the stars listed in the constellation coordinates charts using an appropriate size scale to indicate their apparent magnitudes.

2. Connect the lines for the stars within each constellation to form the familiar asterism and/or outline. It is less confusing to plot the stars and connect them one constellation at a time. You may decide not to connect all stars within a constellation. Some variable stars have been included for some of the constellations, and you may not recognize these as part of the familiar patterns you use to find constellations, although sometimes variables are part of the asterism (such as Polaris). Astronomers use an open circle to plot variable stars. You should do the same, and perhaps color the circle with red ink to make it stand out. As this coordinate system may be unfamiliar and confusing at first, you should use pencil to locate the stars and use ink only after you have ascertained that the constellation outlines are correct by referring to a star chart.

3. The first four constellations are circumpolar for the Northern Hemisphere (Ursa Major, Ursa Minor, Cassiopeia, Cepheus); the fifth constellation, Cygnus, is part of the asterism for the Summer Triangle, and the sixth constellation, Auriga, is a winter constellation.





CONSTELLATION COORDINATES

CONSTELLATION	STAR NAME		MAGNITUDE	RA	DEC
Ursa Minor	**α alpha	Polaris	2.02	$01^h\ 22'$	+88° 46′
	β beta	Kocab	2.08	$14^h\ 51'$	+74° 33′
	γ gamma	Pherkad	3.05	$15^h\ 21'$	+72° 11′
	δ delta		4.36	$18^h\ 04'$	+86° 37′
	ε epsilon		4.23	$16^h\ 56'$	+82° 12′
	ζ zeta		4.32	$15^h\ 48'$	+78° 06′
	η eta		4.95	$16^h\ 20'$	+75° 59′
Ursa Major	α alpha	Dubhe	1.79	$10^h\ 58'$	+62° 17′
	β beta	Merak	2.37	$10^h\ 56'$	+56° 55′
	γ gamma	Phad	2.44	$11^h\ 48'$	+54° 15′
	δ delta	Megrez	3.31	$12^h\ 10'$	+57° 35′
	ε epsilon	Alioth	1.77	$12^h\ 50'$	+56° 30′
	ζ zeta	Mizar	2.27	$13^h\ 20'$	+55° 26′
	η eta	Alkaid	1.86	$13^h\ 44'$	+49° 49′
	**R UMa		10.25	$10^h\ 37'$	+69° 17′
	**S UMa		9.75	$12^h\ 38'$	+61° 38′
	**Z UMa		7.80	$11^h\ 50'$	+58° 25′
Cassiopeia	α alpha	Shedir	2.23	$00^h\ 35'$	+55° 59′
	β beta	Caph	2.27	$00^h\ 03'$	+58° 36′
	**γ gamma		2.47	$00^h\ 51'$	+60° 11′
	δ delta	Ruchbah	2.68	$01^h\ 19'$	+59° 43′

** Variable Star (average magnitudes)

CONSTELLATION	STAR NAME			MAGNITUDE	RA	DEC
Cassiopeia	ε	Epsilon		3.38	01h 47′	+63° 41′
(cont.)	**R	Cas		9.80	23h 53′	+50° 49′
	**V	Cas		10.05	23h 06′	+59° 09′
Cepheus	α	alpha	Alderamin	2.44	21h 16′	+62° 10′
	β	beta	Alfirk	3.23	21h 27′	+70° 07′
	γ	gamma	Alrai	3.21	23h 35′	+77° 04′
	**δ	delta		3.75	22h 25′	+57° 54′
	ε	epsilon		4.19	22h 11′	+56° 33′
	ζ	zeta		3.35	22h 07′	+57° 43′
	ι	iota		3.52	22h 46′	+65° 40′
	**T	Cep		8.15	21h 08′	+68° 05′
	**S	Cep		9.75	21h 53′	+78° 09′
Cygnus	α	alpha	Deneb	1.25	20h 38′	+44° 55′
	β	beta	Albireo	3.08	19h 26′	+27° 44′
	γ	gamma	Sadr	2.20	20h 18′	+39° 56′
	δ	delta		2.87	19h 41′	+44° 53′
	ε	epsilon	Gienah	2.46	20h 42′	+33° 35′
	ζ	zeta		3.20	21h 08′	+29° 49′
	η	Eta		3.89	19h 52′	+34° 49′
	θ	theta		4.48	19h 33′	+49° 59′
	ι	iota		3.79	19h 27′	+51° 31′
	κ	kappa		3.77	19h 14′	+53° 11′
	**X	Cyg		6.47	20h 39′	+35° 13′
	**χ	Cyg (chi Cyg)		9.30	19h 46′	+32° 39′
	**W	Cyg		7.85	21h 32′	+44° 55′

CONSTELLATION	STAR NAME		MAGNITUDE	RA	DEC
Auriga	α alpha	Capella	0.08	05h 09′	+45° 53′
	β beta	Menkalinan	1.90	05h 52′	+44° 56′
	γ gamma		1.65	05h 20′	+28° 31′
	θ theta		2.62	05h 52′	+37° 12′
	ι iota	Hassaleh	2.69	04h 50′	+33° 28′
	**R Aur		10.50	05h 09′	+53° 28′

**Variable Star (average magnitudes)

Coordinates and magnitudes (epoch 1900) obtained from the *Bright Star Catalogu*e, 4th revised edition. Dorrit Hoffleit, Yale University Observatory, 1982.

Activity 4.6: Plotting the Actual Positions of the Planets

You can construct a model with a different perspective of the Solar System by using the current celestial coordinates from information provided by your instructor or from a resource such as the latest *Sky & Telescope* magazine, which each month has a table that lists the positions (right ascension and declination) of the Sun and planets. Select a date that is closest to today. Your model will then accurately portray the present positions of the planets relative to Earth. As with all Solar System models, this one also has distortions. Since you will be constructing the positions of the planets from the perspective we have here on Earth, the Earth—not the Sun—will be the center of the model.

If this is a paper model:

On the same polar coordinate paper that you used for the Core Activity 4.5 Constellation Plot, label the coordinates of RA and declination in the same manner as you did in the circumpolar coordinate activity. The Earth will be at the center with the lines of RA radiating outward. Label the RA lines from 0 to 23 hours. Using a scale of 1 cm = 1 AU, indicate on the grid the positions of the Sun and planets with different colored pencils.

If this is an outdoor model:

Lay out your grid with the materials provided, marking the hours of RA as above. The scale is now 1 m = 1 AU. Calculate the appropriate distances for the Sun and planets and place markers at their positions. If you have a way of elevating the markers, you can construct a 3-D model of the Sun and planets by taking the declination coordinates into account. Don't forget that numbers for declination can also be negative. You may also want to add the zodiacal constellations around the outside in the appropriate locations. Stand in the middle (Earth), rotate counterclockwise, and watch the hours of RA seem to rotate clockwise through the sky.

Answer the following questions:

1. What planets should you be able to see tonight? Why?
2. In what constellation is the Sun?
3. What do you think will be the RA of the Sun in 3 months?
4. What constellations will be visible in the night sky in 3 months? In 6 months?

Astrology or Astronomy?

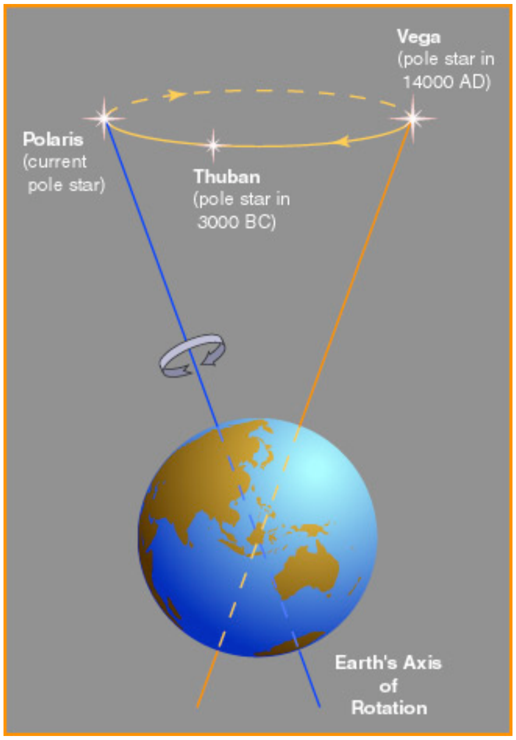
The most obvious and widespread invention of astrology is the horoscope. It is built upon the premise that the constellation behind the Sun at the moment of birth determines the personality, characteristics, and lifelong events of a child. The zodiacal constellations are those that lie along the ecliptic, the apparent path of the Sun, and therefore disappear behind the Sun for approximately one month each year. The Earth moves about 30^o per month in its yearly orbit around the Sun.

Astrologers attach great influence to these zodiacal constellations, called "Sun signs," and use them to produce horoscopes that appear in a large variety of books and magazines which are prominently displayed in drugstores, grocery stores, and bookstores. A large percentage of newspapers in the United States publish either daily or monthly columns on astrology. The code of standard astrology states that "A precise astrological opinion can not honestly be rendered with reference to the life of an individual unless it is based upon a horoscope for the year, month, day and time of day plus correct geographical location of the place of birth of the individual." This statement alone renders all daily forecasts in newspapers null and void. However, even with all information pertinent to the moment of birth, the prophecies of astrology are still fraudulent.

Predictions made by astrologers are so general and vague that most people can usually make associations with their daily activities. But what about the specific predictions made by the most popular astrologers? How correct are they? Astronomers from Colorado State University examined 3,011 specific predictions by famous astrologers and determined that only 10 percent of them actually occurred. Of all such scientific studies to date, every single one has proven that astrological claims have no validity. If the stars lead us to incorrect predictions 90 percent of the time, they hardly seem to be the right guides to help us through life's uncertainties. Stars are not magical, nor are they gods. Stars are other suns similar to our Sun, remote balls of gas undergoing nuclear fusion, as unconcerned with human affairs as nuclear reactors are here on Earth. Unlike our remote ancestors, we understand the fundamental forces of nature and know how they affect galaxies, stars, planets, and people.

The difference between astrology and astronomy is often not well understood, and astrologers have made skillful use of this confusion. The astrological community utilizes scientific terminology and quotes people from seemingly reputable scientific organizations to reinforce the idea of the legitimacy of their beliefs. It is unfortunate that in the minds of many people astrology is confused with true science. The result of this confusion is to prevent people from developing truly scientific habits of thought that would help them understand the natural, social, and psychological factors that are actually influencing their destinies. Horoscopes are flights from reality, a substitute for honest and sustained thinking. Our destinies are shaped by our own actions in this world; our fate rests not in the stars, but in ourselves.

If you pay attention to your horoscope in the daily newspaper, you are in for a surprise. Since astrologers developed the idea of "signs of the zodiac" more than 2000 years ago, the Earth's position in space with respect to the stars has changed.



The Earth undergoes a complicated motion involved with its rotation called precession. It is similar to a spinning top that starts to wobble when it slows down. As the Earth rotates about its spin axis, it also wobbles, tracing the pattern of a cone in the sky. One wobble takes ~26,000 years to complete.

During this 26,000 year circular sweep of the Earth's North Pole, the pole star keeps changing. In ~13,000 years, the star most directly above the North Pole will be Vega, in the constellation Lyra, the Harp. At that time, the summer triangle will be circumpolar for the northern hemisphere. The Big and Little Dippers will rise and fall with the seasons, and Orion and the other winter constellations will become summer constellations.

Because of precession, the apparent positions of the zodiacal constellations used as Sun signs by astrologers have shifted by more than 25° during the past 2000 years. Each sign or constellation no longer represents the time when the Sun is in the related constellation. So you will discover that, for example, on October 25th the Sun is actually in Libra, not Scorpio as your horoscope tells you. Even the constellations that form the zodiac sometimes change. There are actually 13 zodiacal constellations, not 12! However, since there are 12 months in a year, astrologers want only 12 Sun signs and simply disregard number 13. People born at the end of November or beginning of December are actually associated with Ophiuchus, the serpent holder.

Current approximate dates of the constellations of the zodiac:

January 22 - February 22	Capricornus
February 22 - March 22	Aquarius
March 22 - April 22	Pisces
April 22 - May 22	Aries
May 22 - June 22	Taurus
June 22 - July 22	Gemini
July 22 - August 22	Cancer
August 22 - September 22	Leo
September 22 - October 22	Virgo
October 22 - November 25	Libra
November 25 - December 5	Ophiuchus
December 5 - December 22	Scorpius
December 22 - January 22	Sagittarius

SPACE TALK

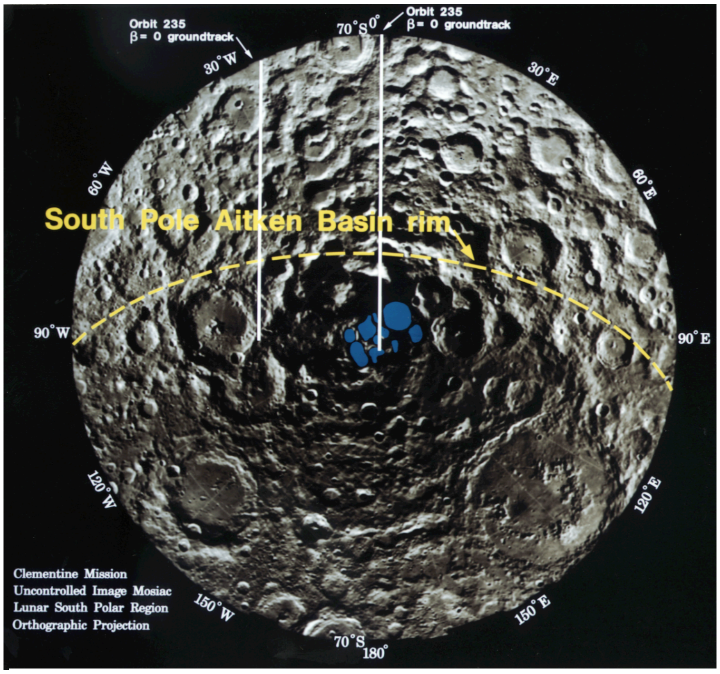
Humankind has always found the Moon fascinating. Ancient peoples thought of the Moon as a goddess, a clock, a calendar. Various enduring mythologies have imbued the Moon with the power to create fertility, love, and insanity. Writers have found the Moon a rich subject for fiction. Kepler took us to the Moon for the first time in his story "The Dream." Later, Jules Verne and dozens of other science fiction writers followed with their own fanciful versions of trips to the Moon.

Today we are no less fascinated with the Moon than were our historical counterparts. On June 20th, 1969, the world watched with wonder and amazement as Neil Armstrong and Buzz Aldrin stepped down from the Apollo 11 lander and left the first footprints on the surface of the Moon in Mare Tranquillitatis (Sea of Tranquility). Would we soon colonize the lunar surface the same way that nations in the past had colonized remote foreign lands? We have landed, walked and driven over the lunar surface, and brought back Moon rocks and soil samples. Equipment left behind by Apollo missions still monitors the Moon for moonquakes and reflects laser beams from Earth back to Earth to measure continental plate movement.

With no atmosphere, bombarded with radiation, and temperatures ranging from 230°F by day to -300°F at night, the Moon is not an inviting environment. And yet we still watch the Moon with interest, observing its lunar phases wax and wane. We see the Moon being eclipsed by the Earth's shadow, and the disc of the Sun covered by the disc of the Moon. These motions were once watched with fear and terror and were considered to be omens of disaster. Now we watch them with pleasure and a reassuring sense of familiarity.

Lunar motions are much more complicated than can be easily detected. It is well-known that the same side of the Moon always faces Earth. Most satellites are locked into the same relationship with the planets they orbit. The tidal forces exerted by the planets alter the **rotation** rates of their satellites until the rotation rate is equal to the rate of **revolution** (orbital period). This phenomena is called **synchronous rotation**. However, we can actually see more than 50% of the Moon's surface due to another set of motions called librations. The combined effects of the librations, or rocking motions, allow us to see 59% of the lunar surface. The Moon displays real physical librations due to the interaction of the tidal forces of Earth and the uneven mass distribution on the Moon. Tidal forces produced by the Sun's gravitational field cause the Earth to wobble (**precession**); tidal forces due to the Earth's gravitational field cause the Moon to rock (librate). The other types of rocking motions the Moon exhibits are not real, only apparent—the result of the Moon being observed from slightly different directions during different times of the year. The Moon's axis of rotation is tilted ~7° from its orbital plane around the Earth. As a result, every month the lunar features seem to shift from north to south as we are able to see from ~7° over the northern polar region to ~7° under the southern polar region. This apparent up-and-down rocking motion is called *libration in latitude*. The Moon also displays a side-to-side rocking motion called *libration in* *longitude*. This occurs because the Moon is in an elliptical orbit around the Earth. The Moon's rotation rate remains constant; however, its orbital rate does not. When the Moon is at its closest approach to the Earth, called **perigee**, its orbital speed is at maximum; when the Moon is at its farthest approach to Earth, called **apogee**, its orbital speed is at minimum. Since the rotational speed of the Moon does not change but its orbital speed does, sometimes its orbital position runs ahead of its rotational position, and sometimes behind. This allows us to see ~8° around the west **limb**, or edge or the Moon, and then ~8° around the east limb.

You can observe and record the apparent changes caused by librations in lunar features such as craters and **maria**, or seas. The dark patches on the Moon, called maria (Latin for seas), were once thought to be oceans. They are actually areas of basaltic materials, outflows from extinct volcanic activity. Both the maria and the lighter areas, called **highlands**, are heavily cratered by meteorites. If you spend some time looking at the Moon you will notice that during full Moon when the face is bright, the surface features seem flat. If you look at these same features when they appear near the **terminator**—the line that divides the lit and unlit parts of the Moon—during any other phase, they will become more distinct, and you can then see that craters have raised rims and deeper centers than the surrounding topography. The line of shadow that marks the terminator brings topographical features into raised relief because the Sun is shining on the Moon at an angle. It is harder to see lunar features near the limb at night if a large amount of surface is reflecting sunlight. You may find it easier during twilight. Select an object near the limb such as Mare Crisium or the crater Aristarchus to study and to draw. Draw the same object at different times throughout the month and you will have an observational record of lunar librations.



Clementine Mission Image with Lunar Ice Indicated in Blue

The southern polar region of the Moon could still be labeled "Luna Incognita"—unfamiliar territory. Lunar missions have either been in near-equatorial orbits or occurred while the region was in darkness. The southern polar region is now being studied as a possible site of lunar ice. The Sun never deviates more than ~2° from the equator of the Moon, and as a result, there are polar regions that have never been touched by sunlight. In 1994 the lunar spacecraft Clementine transmitted data indicating that ice might exist in this area, invoking once again visions of the colonization of the Moon.