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THE CELESTIAL HORIZON SYSTEM

I. Introduction

When we stand at most locations on the Earth, we have the distinct impression that the Earth is flat. This occurs because the curvature of the small area of the Earth usually visible is very slight. We call this "flat Earth" the **Plane of the Horizon** and divide it up into 4 quadrants, each containing 90°, by using the cardinal points of the compass. The latter are the North, South, East, and west points of the horizon. We describe things as being vertical or "straight up" if they line up with the direction of gravity at that location. It is easy for us to determine "straight up" because we have a built in mechanism for this in the inner ear (the semicircular canals). Because it seems so "natural", we build a coordinate system on these ideas called the Horizon System.

The **Celestial Horizon System** is one of the coordinate systems that astronomers find useful for locating objects in the sky. It is depicted in the Figure below.
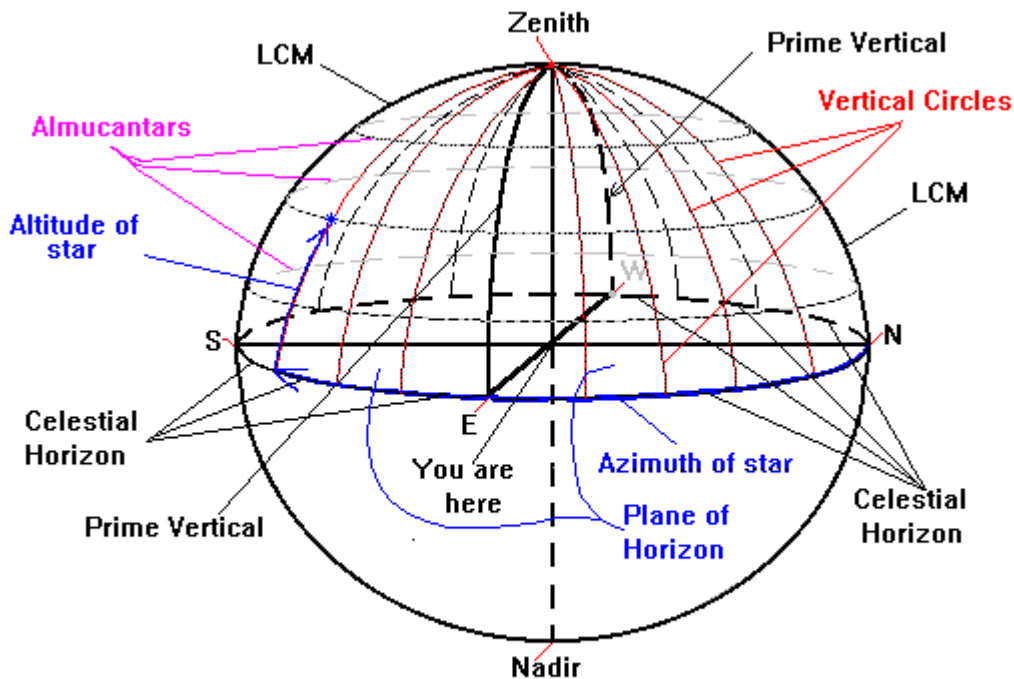

Figure 1. The above diagram is a skewed perspective, schematic diagram of the celestial sphere with circles drawn only for the half above the horizon. Circles on the far side, or western half, of the celestial sphere are drawn as dashed curves.

All the reference circles of this system do not share in the rotation of the celestial sphere and, therefore, this coordinate system is fixed with respect to a given observer. The basis for the system is the direction of gravity. We can describe this as the line from the observer on the surface of the Earth through the center of the Earth. When this line is extended out to the celestial sphere, it intersects the sky in two opposite points called the **ZENITH** and the **NADIR**. For any observer, the zenith is the point in the sky directly overhead. (The point on the celestial sphere that

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is overhead or at the zenith for you is not the same point on the celestial sphere that is overhead for someone at a different location.) The great circle halfway between the zenith and the nadir is called the **Celestial Horizon**, **Astronomical Horizon,** or **True Horizon** and it is the fundamental reference circle for this coordinate system. (Do not confuse the astronomical horizon with the **Visible Horizon**, the place where the earth and sky seem to meet.) See Figure 1, which shows circles drawn for only the half of the celestial sphere that is above the horizon, except for the LCM.

The Earth is extremely small compared to the size of the celestial sphere, therefore, the Earth and any observer on the Earth are to be imagined as a point at the center of the sphere. The celestial horizon is different for different observers. That is, the celestial horizon will divide the sky into different halves, depending on your geographic location on the Earth.

Now imagine a family of great circles drawn on the celestial sphere in such a way that each circle of the family passes through the zenith and nadir and crosses the horizon at a right angle. These circles are called **Vertical Circles**. You should be able to identify these circles in the above diagram.

The vertical circle that passes through the east point of the horizon, the zenith, and the west point of the horizon is called the **Prime Vertical**.

The vertical circle that connects the north point of the horizon, the zenith, and the south point of the horizon is very special and is known as the Local Celestial Meridian (LCM).

 In the diagram, the LCM is the only vertical circle that lies in the plane of the paper. The Local Celestial Meridian is a reference circle that is used for measuring local time and will be referred to frequently in future exercises.

The half of the local celestial meridian (LCM) from the north celestial pole (NCP), through the zenith, to the south celestial pole (SCP) is called the upper meridian and the other half is the lower meridian. Notice that a part of the upper meridian can be below the horizon and part of the lower meridian can be above the horizon, depending on one's latitude.

Almucantars and vertical circles form a grid of intersecting circles on the celestial sphere for the celestial horizon system. This grid is analogous to that formed by the parallels of latitude and meridians of longitude on the surface of the Earth.   **Remember, this system of circles is fixed with respect to an observer and does not rotate with the stars**

II. Coordinates

The first coordinate of the horizon system (analogous to latitude on the Earth) is called **ALTITUDE.** It is the **angular distance of a point from the horizon.** The altitude is 0° 00' for an object that is located on the horizon and increases upwards towards the zenith. The altitude at the zenith is exactly 90°. Negative values for altitude mean an object is below the horizon. All objects with the same altitude lie along a circle parallel to the horizon. Such a circle is often called a **parallel of altitude** or an almucantar and are labeled such in the above diagram.

The other angle of the celestial horizon system is called **AZIMUTH.** This is an angle that is measured around the celestial sphere, starting at the vertical circle passing through the **north point**. The value of the angle increases from 0° anywhere along this vertical circle, eastward. At the east point the azimuth is 90°. The azimuth at the south point is 180° and it is 270° at the west point. Refer to the above diagram. The point where any vertical circle crosses the horizon has a definite azimuth, that is, it is located at a definite angular distance from the North Point of the horizon.

III. Diurnal Motion

Recall that the horizon system is fixed with respect to a given observer. Therefore, all the reference circles of this system do not share in the rotation of the celestial sphere. This means the altitude and azimuth of an object on the celestial sphere both change with time and location. Hence, this system is only useful for locating objects on the celestial sphere at a given location on the Earth and at a given instant of time

As the celestial sphere appears to turn around its axis, objects in the sky move relative to the horizon and the local celestial meridian (LCM). **The axis of rotation lies in the plane of the local celestial meridian and it is tilted relative to celestial horizon by an amount equal to the observer's geographic latitude.**

A casual inspection of the sky reveals that all celestial objects rise on the eastern horizon, cross the local celestial meridian, where an object's altitude is a maximum, and set on the western horizon. This path that an object follows across the sky from east to west is called its **Diurnal Circle**.

Diurnal circles are the apparent paths that objects appear to follow as a result of the rotation of the Earth around its axis.

Hence, the apparent rotation of the celestial sphere causes each celestial object to follow its diurnal circle. As an object moves along its diurnal circle, its altitude and azimuth in the horizon system continuously change. Since the declination of a star does not change as the Earth rotates, **an object's parallel of declination is the same as its diurnal circle**. Being able to visualize that this is so, is a necessary step in your understanding of diurnal motion. Later, we shall use the SKYLAB2 software to demonstrate the concepts that have been introduced here.

When an object crosses the upper local celestial meridian, it is said to be at **upper transit (UT).** At upper transit the object is at its greatest distance above the horizon, that is, its altitude is a maximum. When the object crosses the lower local celestial meridian, it is said to be at **lower transit (LT).** At **LT**, an object is at its minimum angular distance (in the algebraic sense) from the horizon. When an object is below the horizon, it's angular distance from the horizon, or altitude, is assigned a negative value.

Objects make one upper transit and one lower transit each day. For an observer in the Northern Hemisphere, both upper and lower transit will occur above the horizon for stars located near the north celestial pole. Such objects will have their diurnal circles entirely above the celestial horizon and, therefore, can be seen every night. Such objects are called **circumpolar stars of perpetual apparition** (stars that are always visible) since they circle around the pole star.

By symmetry, for this same observer, there will be a range of declinations for stars near the south celestial pole that never rise above the horizon. That is, their diurnal circles are completely below the horizon and such an object can never be seen at that latitude. These stars that never rise are called **circumpolar stars of perpetual occultation**.

Which objects are circumpolar and which are not depends on the observer's latitude and the declination of the object.

Objects located on the celestial equator rise exactly at the east point, while objects north or south of the celestial equator rise to the north or south of the east point. It is very important to realize that objects, which rise exactly at the east point, must set exactly at the west point. Likewise, objects that rise in the northeast set in the northwest and objects that rise in the southeast set in the southwest.

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The time that an object spends above the horizon depends essentially on where it is located with respect to the celestial equator, i.e., its declination. Half of the equator is above the horizon and so any object on it (declination 0°) is above the horizon for 12 hours and below the horizon for 12 hours. Such an object rises at the east point and sets at the west point.

Another important angle related to diurnal motion and time is an object's **hour angle**.

Hour Angle (HA) is the angular distance of an object measured westward from the Local Celestial Meridian.

It is sometimes convenient to use positive and negative numbers to describe the position of an object with respect to the Local Celestial Meridian.

When the object is west of the Meridian, the Hour Angle is denoted as positive and when it is east of the Meridian it is negative.

The Hour Angle changes from negative to positive when the object crosses the Local Celestial Meridian, moving east to west. Note that the object's altitude at this time is a maximum and the object is said to be at **Upper Transit** (UT). The Hour Angle changes sign again when the object crosses the Local Celestial Meridian twelve hours later. At this time, the altitude of the object is a minimum and it said to be at **Lower Transit** (LT).

IV. Procedures and Tutorial

Logon to SKYLAB2 and in the main menu highlight "Celestial Sphere." This will bring up a menu of Celestial Sphere programs. Now highlight "Diurnal Motion" and press Enter. This generates on the monitor screen an exterior, 3D, perspective-view of the celestial sphere, looking from east towards west. Note the following:

The **Celestial Horizon** (CH) is the white horizontal circle connecting the points **N, E, S,** & **W.**

The **Axis of Rotation** is the dark blue line that connects the celestial poles, NCP and SCP. Note that it is tilted at an angle with respect to the horizon. This angle depends on the observer's latitude.

The **Celestial Equator** (CE) is the red circle that is slanted with respect to the Horizon and it lies in a plane that is perpendicular to the axis. The Celestial Equator passes through the East and West points of the Horizon for every observer, regardless of latitude or longitude.

The **Local Celestial Meridian** (LCM) is represented by the light blue circle. It passes through the North Point of the Horizon, the North Celestial Pole (NCP), the Zenith, the South Point of the Horizon, and the Nadir.

The green line connecting the zenith and nadir is perpendicular to the plane of the horizon.

By default, an object with a declination of 0° is shown moving along the Celestial Equator. This object is said to be executing its **Diurnal Motion** or to be moving along its **Diurnal Circle.** This motion is said to be due to the rotation of the celestial sphere and is really a reflection of the

Earth's rotation on its axis. The object is yellow when it is on the front side of the celestial sphere, but it becomes a dashed open circle when it moves to the rear or backside of the celestial sphere. Watch this taking place.

In the upper left of the screen, the observer's latitude and the declination of the moving object are given. In the lower right comer of the screen, the instantaneous value for the object's hour angle is given.

Now press the space bar to stop the diurnal motion. The altitude and azimuth of the object now appear to the lower left of the screen. Take note of where the object is in the horizon system and try to reconcile this position in your mind with the values that have just been displayed. Now hit the space bar again and the diurnal motion will continue. Stop the motion again at some other position and again compare the altitude and azimuth that is displayed with the position of the object. **Note that the altitude is negative when the object is below the celestial horizon.**

Because the moving object has a declination of exactly 0°, it rises exactly at the East Point of the horizon, and therefore, its azimuth is 90°. Because of the skewed perspective of the diagram, the animation does not show an object to be exactly on the horizon when the computer displays its altitude to be 0°. This is a problem with the software and one must learn to allow for this. Note and remember:

When an object just rises or sets, its altitude must be zero degrees.

Now try to stop the object as it just rises, transits the Local Celestial Meridian, or sets. You may have to make several attempts at this to be successful. If you are not successful, it is possible to slow the motion down in two ways:

1. Type "O" for Options and a window menu will drop down from the top of the screen. Highlight the option "Step", and then press the Enter key. The current value for the "step" is then shown and should be 00^d 00^h 14^m (Note there are no seconds.) This is the default value for *Step*, which is the time interval between the positions that the computer calculates and displays on the monitor screen to animate its motion. Tab over to the 14^m and change it to 05^m. **Be careful to pay attention to the different column headings identifying days, hours, and minutes.** Now hit the Enter key. Since the computer must now compute more positions to animate the diurnal motion of the object, it will run slower. You may want to experiment with different Step times.

2. Type "O" for Options and highlight "Delay" in the drop-down window menu, then press the Enter key. Increase the Delay time to 0.70 seconds. Hit the Enter key. The computer now waits this amount of time before displaying the object's next position along its diurnal circle, thereby slowing down the motion.

The first method has the advantage of presenting more closely spaced positions of the object along the diurnal circle. You may decide how to use both methods to your advantage. If you miss stopping the object exactly where it was supposed to be stopped, it is not necessary to wait for it to go all the way around again. *The left cursor key is like a rewind key. As long as you hold it down, the diurnal motion will be reversed at a higher speed. Similarly, the right cursor key is a fast forward key. Try these out.*

V. Assignment

Type "L" to change the latitude and set it to exactly 40° N. Keep the declination of the object to be animated at 0°. Allow the diurnal motion to continue at a rate that you determined above to be convenient for you to stop the object at any point along its diurnal circle. When you have

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successfully stopped the above object at the point where it rises, you are to record the altitude, azimuth, and hour angle on the worksheet on the first line. You have succeeded in stopping the object at the right place only if the computer gives a value of 0°, which may be slightly different than what your eye tells you. Always use the following rule:

For any object to be rising or setting, its altitude must be zero.

Do not use Hour Angle as a criterion for determining when a star rises or sets. What the hour angle is when an object rises or sets depends on its declination and your latitude.

When recording angles, drop the number of arcseconds and record your answers in degrees and arcminutes, like this: 0° 15' or 32° 46'. Do not use the colons. If you are not able to stop an object at exactly 0° 00' altitude when it rises or sets, record the closest value to zero that you can get.

Be sure to set your step size and delay times to values that permit you to work within tolerances < 30' for altitude and < 0.02 hours for hour angle.

Now allow the diurnal motion to continue, and try to stop the object (for Dec.=0°) when it crosses the Local Celestial Meridian (**LCM**) at maximum altitude. Recall that this event is called **Upper Transit (UT).** Note:

The hour angle should read exactly 0.00 when an object is at upper transit.

Again, try to stop the object when its hour angle is as close to 0.00 as you can and record the value of the star's altitude, azimuth, and hour angle on the next line of the worksheet.

Next, stop the object exactly at the point where its sets. This will now be when the top of the ball is just below the West point of the celestial horizon, but the real criterion is when the computer readout for the altitude is exactly zero. Again, record the values you get on the worksheet.

Now continue the diurnal motion until the object is at lower transit on the Celestial Meridian. Recall that **Lower Transit** (LT) is when an object crosses the **LCM** at minimum altitude. Whether lower transit is above or below the horizon depends on both the observer's latitude and the declination of the object. In any event:

The hour angle should be either +12 or -12, for an object to be at lower transit.

Try stopping the object exactly at this hour angle and record the requested coordinates on the worksheet.

Now you will investigate the diurnal motion for objects with other declinations. *The declination can be changed by using the cursor-up or down keys. If you hold down the cursor-up key the declination will increase.* You should watch the value change in the upper left corner of the screen until it is the value you want. *The cursor down key is used to decrease the declination.*

You are to repeat the above measurements for the objects with declinations 25° and 65°, but first review the criteria for rising, setting, and making transit of the meridian before proceeding to another declination.

You will find that some stars do not rise or set but have their diurnal circles either entirely above or below the Celestial Horizon. Recall that such stars are called **Circumpolar Stars** and

should be identified as such on the lines for rising and setting on the answer sheets. You will also find that at any latitude other than the equator or pole, there is a declination at which a star will rise, set, and make lower transit at the same point on the horizon and at the same time. Such stars are the southern-most circumpolar stars for that latitude and they have their diurnal circles entirely above the horizon.

In addition to latitude 40° N, repeat all of the above procedures for another latitude assigned by your instructor.

To change the latitude, type "L" for the latitude window menu to drop down and then press the Enter key. Type in the value of the latitude you want. Be sure to change the fields for arcminutes and arcseconds to zero, such as, **65:00:00.**

Use a different worksheet for each of the two latitudes you investigate. The latitude should be written in the space at the top of the worksheet.

HORIZON SYSTEM ANSWER SHEET

Latitude: _____

Declination	Position	Hour Angle (decimal hours)	Altitude (deg. & arcmin.)	Azimuth (deg. & arcmin.)
0⁰	Rises			
0⁰	UT			
0⁰	Sets			
0⁰	LT			
20⁰	Rises			
20⁰	UT			
20⁰	Sets			
20⁰	LT			
65⁰	Rises			
65⁰	UT			
65⁰	Sets			
65⁰	LT			