Name Class Section

Planetarium Based Laboratory Activity
Celestial Sphere, Seasons and Precession

Introduction

In this lab we will learn about seasons markers and precession. The discussion below will get you acquainted with relevant terminology and concept.

The Ecliptic

In previous activities you saw that the Earth's rotational axis points very close to Polaris. This means that basically, Polaris is always due north, and can be used to find that direction. However, that wasn't always the case. The plane of the Earth's yearly orbit around the Sun is called the ecliptic (Figure 1). On Earth, we see the ecliptic defined by the Sun's path in the sky. The zodiac constellations are the belt of constellations that lie on the ecliptic, so the Sun and most of the planets are seen against the backdrop of the zodiac constellations.

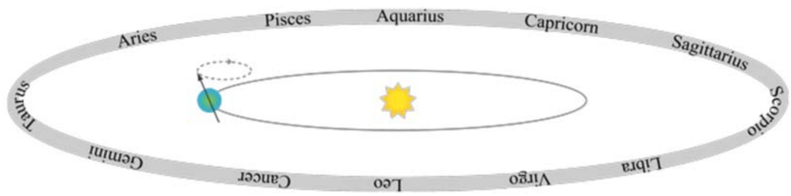

Figure 1: The ecliptic and zodiac constellations.
The Earth is shown at the December solstice, when the Sun is in the constellation Scorpio.
You know that the Earth's rotational axis determines the celestial equator of the equatorial coordinate system (see the Coordinate Systems Activity.) The Earth's rotational axis is tilted relative to its orbital plane around the Sun. Thus, the celestial equator and the ecliptic are planes that intersect, at an angle of 23.5° .

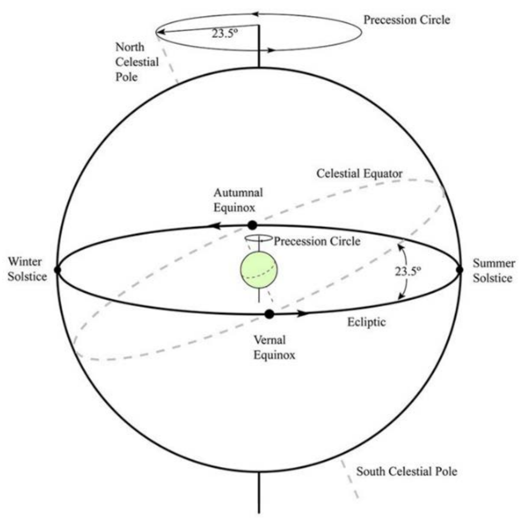

Figure 2

The points at which they intersect are the equinoxes, the days of the year on which the length of day and night are equal. The two equinoxes define the start of spring and fall. Halfway between the equinoxes are the solstices, the points at which the poles are pointing exactly toward and away from the Sun. These mark the start of summer and winter. These seasonal phenomena are described in detail in the Seasons Activity Figure 2: Relation between the celestial equator and ecliptic, and the precession circle. The angle between the celestial and ecliptic poles is also 23.5 degrees, because the equator is perpendicular to the poles. The ecliptic pole is vertical in this figure, so the north and south celestial poles are tilted. The equinoxes rotate around the ecliptic as the Earth, and celestial equator, precess.

Precession

Like a top, Earth's rotational axis gyrates, with a period of 26,000 years. This motion is called precession, or "precession of the equinoxes". The Earth's spin causes it to be slightly flattened at the poles relative to the equator. Precession occurs because the Sun's gravity induces torque, or angular force, which pulls the Earth's equatorial bulge toward the ecliptic. Therefore, the axis of precession is perpendicular to the ecliptic, and is aligned with the ecliptic axis. This axis projects to two points, the north and south ecliptic poles, which are inclined 23.5º to the celestial poles (Figure 2 and 3). Note that precession affects the direction of the Earth's axis, but it does not affect the angle of its tilt relative to the ecliptic. Thus, precession affects the time of year in which various constellations are visible. The 23.5º axis tilt is constant, and so the seasons themselves continue just like they are now (see the Seasons activity).

Our standard Gregorian calendar is based on the solar, or tropical year, the time it takes the Sun to return to the same equinox, which is defined by the direction of the Earth's axis relative to the Sun (Figure 2). Since the seasons are intrinsic to the tropical year, our Gregorian calendar is calibrated so that the March equinox always falls on either March 20 or 21. This forces the seasons to occur during the same months, regardless of precession. However, the stars visible in the evening will slowly change. Figure 1 shows the winter solstice in the north, with the constellation Taurus prominent at midnight. If the Earth's axis were pointing in the opposite direction, Taurus would still be prominent at midnight, but it would be the summer solstice. So, for the solar calendar, the seasons occur in the same months, but we view different constellations during those months.

On the other hand, the sidereal calendar is based on the sidereal year. This is defined to be the time it takes the Earth to return to the same point in its orbit, relative to the fixed stars. (Sidereal time is explored in the Timekeeping and Telescopes at the Detroit Observatory activity.) An example of a sidereal calendar is the ancient Aztec calendar. For the sidereal calendar, precession causes the seasons to occur in different months. For example, Taurus is prominent at midnight during the same fixed month in a sidereal calendar. As we saw in the preceding paragraph, this month may correspond to winter, summer, or anything in between, depending on the orientation of the Earth's axis. So, for the sidereal calendar, the constellations are always seen in the same months, but the seasons occur in different months. More information on different calendar systems is in the Additional Resources section below.

Name Class Section

Precession and Equatorial Coordinates

As the axis gyrates, the projection of the pole traces a circular path on the sky, counterclockwise (see Figure 3). Thus, the north celestial pole does not always point at Polaris, the current pole star. At the time when the pyramids were built, the star Thuban in Draco was the pole star. Note that the angle (i.e., angular distance) between the pole and the ecliptic remains fixed, as can be seen in the Figures. However, the intersection of the celestial equator and the ecliptic rotates, and so the positions of the equinoxes and solstices travel around the ecliptic (see Figure 2). They make a complete circuit in 26,000 years. Since the celestial poles and equator are not fixed relative to the stars, this inconveniently means that the entire celestial equatorial coordinate system is precessing! The equatorial coordinate axes for right ascension and declination (see the Coordinate Systems activity) must be continually updated, and celestial coordinates must be accompanied by a date for which they are valid. This is referred to as the epoch. Coordinates are usually given for standard epochs at 50-year intervals, for example, Jan 1, 1950, and Jan 1, 2000. Astronomers use computer programs to convert the coordinates from the standard epoch to the current date.

Figure 3: The path of the North Celestial Pole on the sky, around the North Ecliptic Pole.

Another way to see this is that over 26,000 years, we see the entire sky precessing around the axis of the ecliptic. This means that near the horizon, some constellations dip in and out of view during this cycle. In Figure 4, the person in Ann Arbor always sees the North Celestial Pole at the same fixed spot in the sky; it has constant altitude and azimuth. The pole does not move; recall that its position in the sky depends on the person's location on Earth, for example, a person at the North Pole will always see the North Celestial Pole overhead, at the zenith. On a daily basis, the sky rotates about the celestial poles, but over millennia, it also slowly gyrates around the ecliptic poles.

Celestial cartographers have known about precession since the time of Hipparchus (2nd century BC), who is believed to have discovered it. It's pretty inconvenient that the equatorial coordinate system is not fixed -- could we define a different coordinate system that doesn't precess? Notice that the ecliptic and ecliptic poles define an ecliptic coordinate system. Early cartographers catalogued stellar positions in ecliptic coordinates because these would always remain constant. The link between ecliptic coordinates and seasonal phenomena was another reason to prefer this system. However, modern astronomers use equatorial coordinates because even the north ecliptic pole is not perfectly constant, and equatorial coordinates are much easier to measure with extreme accuracy.

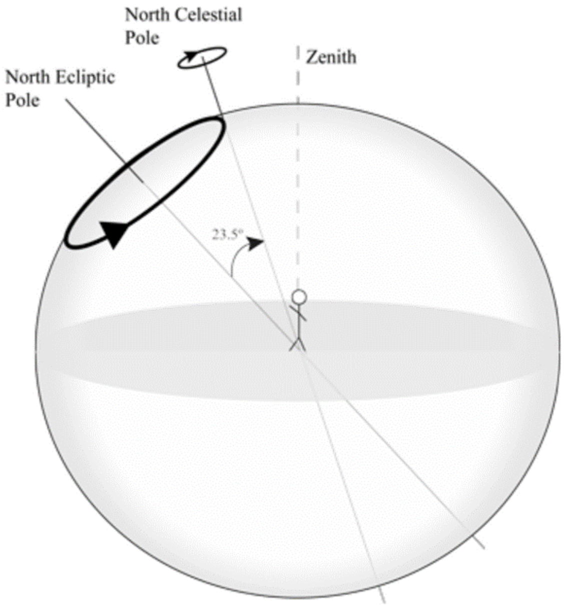

Figure 4: The sky makes one rotation around the North Celestial Pole each night. The North Celestial Pole rotates around the North Ecliptic Pole once in 26,000 years.

Additional Resources:

An introduction to calendars - http://aa.usno.navy.mil/faq/docs/calendars.php

Information about a few calendars in common use around the world - http://astro.nmsu.edu/~lhuber/leaphist.html

The effects of precession, eccentricity and other orbital anomalies on the calendar - http://aa.usno.navy.mil/faq/docs/seasons_orbit.php

Effect of precession on navigation and coordinates
http://www.glyphweb.com/esky/concepts/northerncelestialpole.html

Name Class Section

Instructions: You can work in a group of 2 or 3 students.

Part 1: The Celestial Sphere

Assume that the sketch 1 shown below represents the dome in the planetarium and that the observer is sitting in the center of the planetarium facing the direction of the arrow. The SI will bring up the night sky.

1. Inspect the night sky and based on the constellation of Ursa Minor (little dipper) and Ursa Major (big dipper) answer the following questions.
    a. Label the horizon plane on the sketch.
    b. Label the cardinal points (*N, S, E,* and *W*) on the sketch.
    c. Label the point Zenith and Nadir on the sketch.
    d. Write down the observing date and time below.

    ____

2. The SI will show you the altitude circle with degree scale.
    a. What is the approximate altitude of the star Polaris?

    b. Based on your answer to a) what is the latitude of your observation point.

3. The SI will show you a circle going from east to west in the south.
    a. What is the altitude from south of the highest point of this circle.

    b. What is the name give to this circle on the Celestial Sphere?

c. You can justify the answer to 3b by subtracting the latitude of your observations point from 90. It should be the same as your measurement in 3a). Show this calculation.

d. Draw this circle on sketch 1, Remember in the sketch, from horizon plane to zenith is 90 degrees. So, it is possible to show some level of accuracy in the drawing.

4. The SI will now turn on a circle and show you the passage of the sun from sunrise to sunset. What do we call this circle that the Sun traces on the celestial sphere?

5. The SI will reset the date and time to that in 1d) and turn on a grid called Altitude-Azimuth grid (ALT=AZ). The azimuth on this grid is a circle parallel to horizon (floor of planetarium) that goes from 0 degrees starting at *N* and 90 degrees at E and ending at 360 degrees back at *N*. You will see the azimuth scale above the dome wall. The altitude is a circle that stars at 0 degrees from *S* cardinal point on the horizon and ends at 90 degrees on zenith.
   a. The circle that you named in 3b) and 4) intersect at some point. What is the altitude and azimuth angle of this intersection point? Astronomers call this point first point of Aries or *Vernal equinox*.

   b. Draw this new circle on sketch 1.

6. The SI will now show you sunrise, midday and sunset for the following dates. Collect the data on time, altitude and azimuthal coordinates for the Sun on these dates and record them in the table 1. Then answer the following questions using the data from table 1.

   a. Find the number of daylight hours for each date.

b. On which date is the day longest. Is the Sun highest or lowest in the sky at noon on this day?

c. On which date is the day shortest. Is the Sun highest or lowest in the sky at noon on this day?

d. On what dates is the day and night equal in duration?

e. On what dates does the Sun rise directly East and sets directly West.

Table 1

	A	B	C	D	E	F	G	H	I	J
1	**Date**	**Sunrise**			**Midday**			**Sunset**		
		Time	AZ	ALT	Time	AZ	ALT	Time	AZ	ALT
2	03-21									
3	06-21									
4	09-21									
5	12-21									

Name Class Section

Part 2 Celestial Coordinates

The SI will bring up the Alt-Az coordinates grids and show you the northern night sky for several cities in the world for tonight (11 pm) and 1000 years from tonight. Find the Alt-Az coordinates of the following stars and tabulate them in the table 2 and 3 provided here.

Table 2

City	Polaris (α Umi) Tonight		After 1000 years	
	Altitude	Azimuth	Altitude	Azimuth
Chicago				
Stephenville				

Table 3

City	Shedar (α Cas) Tonight		After 1000 years	
	Altitude	Azimuth	Altitude	Azimuth
Chicago				
Stephenville				

The SI will bring up the Equatorial coordinates grids and show you the northern night sky for several cities in the world for tonight (11 pm) and 1000 years from tonight. Find the RA-DEC coordinates of the following stars and tabulate them in the table 4 and 5 provided here.

Table 4

City	Polaris (α Umi) Tonight		After 1000 years	
	RA	DEC	RA	DEC
Chicago				
Stephenville				

Table 5

City	Shedar (α Cas) Tonight		After 1000 years	
	RA	DEC	RA	DEC
Chicago				
Stephenville				

Name Class Section

Questions

1. Compare the Alt-AZ of each city for tonight with 1000 years from now. Are they very different or very similar? Explain your answer why you think they are different or similar.

2. Compare the RA and DEC of each city for tonight with 1000 years from now. Are they very different or very similar? Explain your answer why you think they are different or similar.

3. Compare the Alt-Az for two cities for tonight, are they the same or different. Explain why they are same or different.

4. Compare the RA and DEC of each city for tonight, are they the same or different. Explain why they are same or different.

Name Class Section

Sketch 1