University of Michigan Astronomy Department

Name:
Partner(s):
Day/Time:
Version: intro

Precession

This ancient people whom we so contemn as our inferiors,...
Knew the precise position of the sun in utter space ere Britain's name begun:
Marked by precession of the equinoxes,
Three thousand years ere those first Christmas boxes
Were brought to Bethlehem by their kindred Magi;...

--The Friend in *The Age* by Philip James Bailey

Overview

- Understand the Earth's precessional motion
- Compare and contrast the tropical year vs the sidereal year, and the visibility of the constellations
- Compare and contrast the ecliptic coordinate system and equatorial coordinate system

Introduction

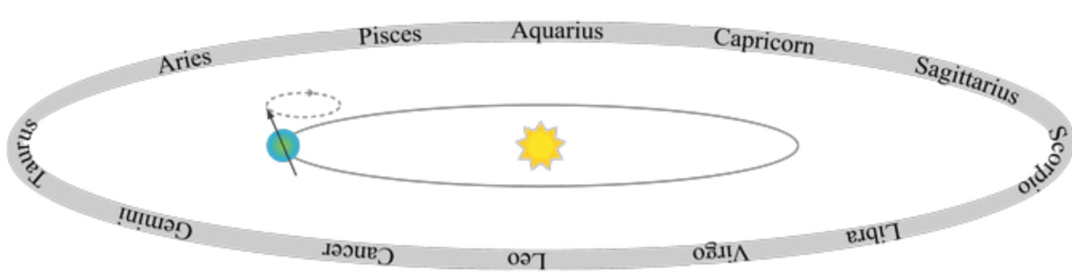
What is the relationship between the Earth's rotational spin and its orbital motion around the Sun? And is the Earth's spin axis fixed?

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.

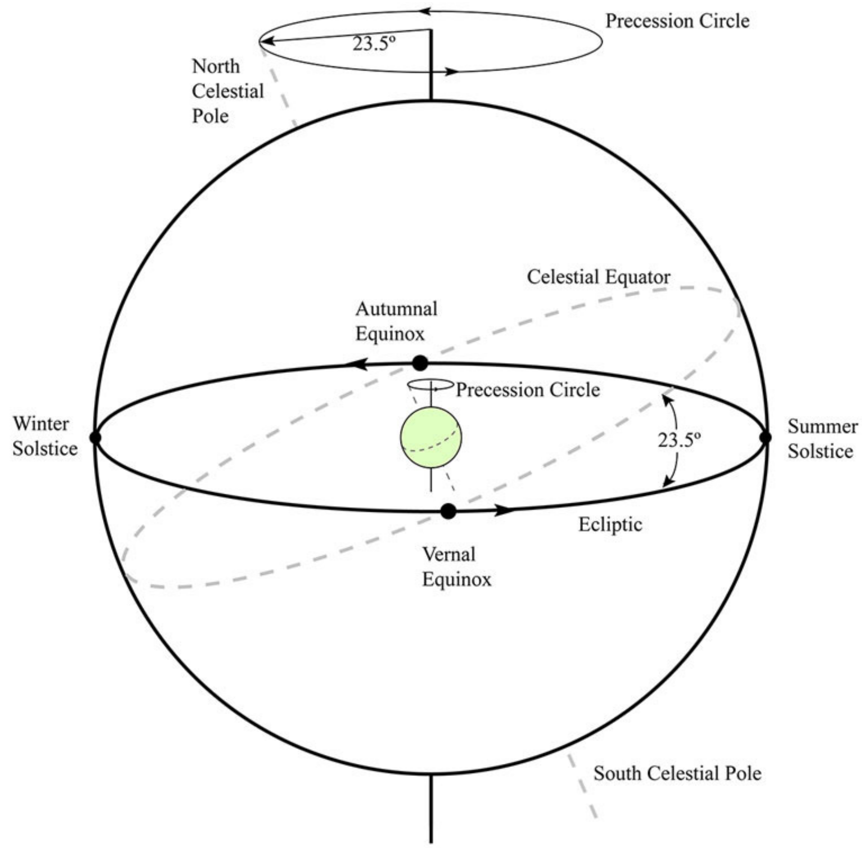
The plane of the Earth's yearly orbit around the Sun is called the **ecliptic** (Figure 1). On Earth, we see the ecliptic defined by the Sun's path in the sky. The **zodiac** constellations are the belt of constellations that lie on the ecliptic, so the Sun and most of the planets are seen against the 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 23.5º (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.

Precession and Equatorial Coordinates

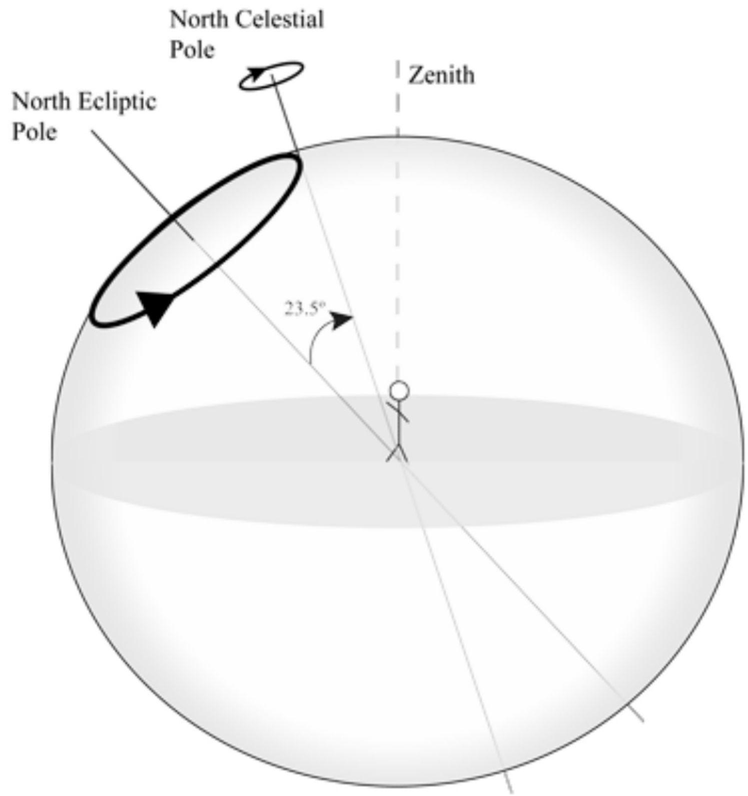
Figure 3: The path of the North Celestial Pole on the sky, around the North Ecliptic Pole.

As the axis gyrates, the projection of the pole traces a circular path on the sky, counterclockwise (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.

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.

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.



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 are much easier to measure with extreme accuracy.

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