Changing of the seasons

by Bob Riddle

Spring in the Northern Hemisphere, as well as fall in the Southern Hemisphere, officially begins on March 20th at 2321 UT (sometimes referred to as UTC or Coordinated Universal Time). Universal Time is what many people know as Greenwich Mean Time, and is based on the time at the Prime Meridian, 0° longitude. Each time zone away from the Prime Meridian represents one hour of time difference and one hour's worth of Earth's rotation. Because North America is west of the Prime Meridian, converting to local time zones across North America is a matter of subtracting the number of hours or time zones that you live west from the Prime Meridian. For example, during Standard Time there is a five-hour difference between the east coast of the United States and the Prime Meridian; the start of spring will be five hours earlier or 6:21 p.m. EST (2321 - 5 = 1821, or 6:21).

From geography or Earth science lessons, students have learned that we mark the change of seasons with the position of the Sun over certain parts of the Earth. Using the Northern Hemisphere as an example, we know that summer is when the Sun is north of the equator, at 23.5° north latitude, over the Tropic of Cancer. This is followed in three months by the start of our fall, when the Sun is over the Earth's equator at 0° latitude, one of two equinox days. Three months later, the seasons change again, from fall to winter, when the Sun is south of the equator, at 23.5° south latitude, over the Tropic of Capricorn. Spring arrives three months later, when the Sun has reached the Earth's equator, 0° latitude.

The specific time and date for the change of seasons is determined by the position of the Sun, not above the horizon necessarily, nor geographically, but rather where the Sun is using astronomical coordinates. Astronomical coordinates are essentially an extension of the Earth's grid system of latitude and longitude projected onto the sky onto what is called *the celestial sphere*. Figures 1 are pieces of an equatorial-based star chart showing the coordinate positions of the Sun at the start of each season. (See Resources to download a free copy of the SFA star charts).

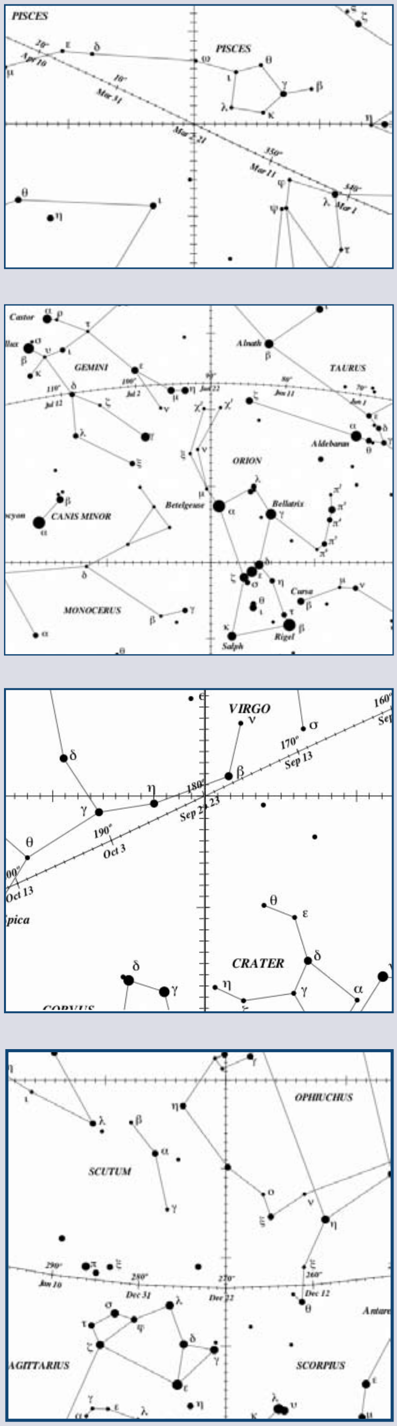
On the equatorial-based star chart, the sky is divided into a grid much as the Earth's surface is a grid with longitude and latitude. This is a flat map of the celestial sphere, showing the entire sky from the celestial equator north and south to only 60° in order to minimize the distortion caused by flattening a sphere. Two additional separate star charts show the polar regions from 60 to 90°. The celestial sphere has a grid system that includes degrees of declination rather than degrees of latitude for measuring north or south from the celestial equator. These, like latitude, are parallel with the equator and are used in the same way with 0° at the celestial equator and 90° at either celestial pole. The other lines on the celestial grid are arranged similar to meridians of longitude, but each line is known as an hour circle. On the celestial sphere, unlike on the Earth's surface, there is only east when using hour circles. Each hour circle, just as each meridian of longitude, is 15° apart at the equator, and each line tapers to meet at the poles. Hour circles are numbered from 0 to 23, with the 0 hour circle simply known as—you guessed it—the 0 hour circle, not the celestial Prime Meridian.

One additional line that is significant to the understanding of the celestial coordinate system and the occurrence of a change in season is a line known as the ecliptic. This is a line that, in actuality, is the orbit of the Earth, but from our perspective on the Earth, it appears to be the path (the apparent path) the Sun follows throughout the year. Each day, as the Earth orbits the Sun, the Sun appears to move the same amount, in the opposite direction, toward the east along the ecliptic. The ecliptic, as we "see it" from the Earth's surface, or a star chart, is not parallel to the celestial equator, but is a curved path with respect to the celestial equator. It is a curved path that connects the daily position of the Sun using hour circles and degrees of declination. The ecliptic appears curved due to the axial tilt or inclination of the Earth. Inclination of the Earth or any planet in our solar system is determined by measuring the amount of tilt a planet's north to south axis is away from the plane of the ecliptic. The plane of the ecliptic is the Earth's orbit extended outward from the Sun through the entire solar system. It is used as a common reference point for all objects orbiting the Sun. The inclination of the Earth or other planet in turn sets up the Sun's range of motion relative to the equator. The value for inclination is the same as the amount of degrees the Sun will be north and south from the equator. If there were no inclination, then the Sun would remain over the equator throughout the year. If this were the case for Earth, there would virtually be no change in seasons—it would be forever spring!

Seasons around the world

The Earth's orbit around the Sun is very nearly circular, enough such that distance has little effect or no effect on our seasons. We know that on our planet it is the axial tilt and revolution that accounts for having seasons. But do other planets have seasons and weather changes? If they do have seasons, are they caused by the same reasons?

FIGURE 1 Equatorial-based star chart showing the coordinate positions of the Sun at the start of each season.



March equinox

June solstice

September equinox

December solstice

Answering questions like these will have students, among other things, examining data like that shown in Figure 2 and comparing orbital properties to see what relationships may exist. While specific dates are not shown for the change in seasons, each planet will have a change in season under the same circumstances as Earth with regard to the relative position of each planet's equator and the Sun. As long as a planet has an inclination, is tilted on its axis, and revolves around the Sun throughout that planet's year, the Sun will move north and south from the planet's equator. Therefore, each planet with an axial tilt will have the same sequence of seasons as we have—spring, summer, autumn, and winter—albeit of different lengths based on the planet's distance from the Sun. But is a planet's axial tilt, as on Earth, enough to cause the seasons or could there be other factors? For example, not all planets have the same orbital shape, or eccentricity. Could the eccentricity, or shape of the orbit, also be a factor in causing seasons? Eccentricity is a measure of how circular or elliptical a planet's orbit is. Eccentricity values range from 0 to 1 with 0 being circular and 1, while not used, would be a straight line. The closer the eccentricity is to 1, the less circular and more elliptically shaped is the orbit.

Students could use the Earth as their frame of reference when comparing other planets. For example, the Earth has a nearly circular orbit, an axial tilt, is approximately 150 million km from the Sun, and has noticeable changes in seasons. The two inner planets, Mercury and Venus, are much closer to the Sun, and receive more solar energy than the Earth, while the outer planets, Mars and beyond, receive less solar energy. Orbital shapes (eccentricity) and axial tilt vary considerably among the planets, suggesting that if these are factors in seasons, then some of the planets, such as Mars, should have seasonal changes that are more extreme than on Earth.

The use of the term *seasons* for most of the planets in our solar system seems to be more appropriately used to describe where the planet is along its orbital path, in addition to the position of the Sun relative to the planet's equator, rather than the change in temperatures as we experience on Earth. Nonetheless, it would be an interesting project for students to investigate the different planets in our solar system. For example, students can develop weather reports or travel brochures, highlighting the seasons or weather on one of the planets in our solar system.

Mars, with an eccentricity of 0.093, has the greatest eccentricity of the eight planets. Northern hemisphere winters are severe on Mars because they occur at aphelion, when Mars is at its most distant point from the Sun and moving more slowly than at perihelion. At that aphelion distance, even the southern hemisphere summers would be cold; quite different from the Martian summer in the northern hemisphere, when the planet is 40 million km closer.

Mercury and Venus revolve around the Sun more quickly than Earth. Venus, nearly upside down with an axial tilt of 177°, is in reality only tilted 13° from the perpendicular. Mercury, on the other hand, has virtually no axial tilt or inclination. Both inner planets are so close to the Sun that it would be safe to say that they are hot planets, regardless of their eccentricity or inclination. Venus, due to its thick atmosphere of mostly carbon dioxide, will always be hot, regardless of the Sun's location. Mercury, with its close proximity to the Sun, is also hot, especially on the Sun-facing side

FIGURE 2 **Planet orbital properties**

Planet	Axial tilt	Orbital eccentricity	Aphelion distance (km)	Perihelion distance (km)	Revolution period (Earth years)
Mercury	0°	0.020	70,000,000	46,000,000	.24
Venus	177.4°	0.007	108,900,000	107,500,000	.63
Earth	23.44°	0.017	152,100,000	147,100,00	1
Mars	25.19°	0.093	249,2000,000	206,600,00	1.9
Jupiter	3.13°	0.048	815,700,000	749,900,000	11.87
Saturn	26.73°	0.056	1,503,000,000	1,348,000,000	29.46
Uranus	97.77°	0.046	3,003,000,000	2,739,000,000	84.07
Neptune	28.32°	0.010	4,546,000,000	4,456,000,000	164.8

At the opposite extreme, in the outer regions of the solar system are the more distant outer planets where cloud top temperatures rather than surface temperatures are measured in the minus hundreds of degrees. The planet Uranus is virtually on its side as it revolves around the Sun with an inclination of nearly 98°. Seasons on Uranus would have the Sun over the planet's equator two times a year and over each pole two other times.

The Earth, on the other hand, at its distance from the Sun, has temperatures that are neither too hot nor too cold, but are just right.

MESSENGER at Mercury

The **ME**rcury **S**urface, **S**pace **En**vironment, **Ge**ochemistry, and **R**anging mission will become the first spacecraft to orbit the planet Mercury as it enters into orbital insertion on the 18th of this month. The trip to Mercury from Earth will have lasted approximately seven years and involved three flybys of the planet Mercury as the spacecraft gradually adjusted its path for orbital insertion on March 18th. Following orbital insertion and a period of orbital adjustment, the spacecraft will spend an Earth year studying the Mercurian environment. The mission is supported by a well designed and interactive website that provides much in the way of resources and activities for students (see Resources).

March

1	Thin waning crescent Moon rises with Venus
4	New Moon
6	Thin waxing crescent Moon near Jupiter
9	Mercury near Uranus
12	First quarter
13	Discovery of Uranus (1781)
15	Mercury near Jupiter
18	*MESSENGER* Mercury orbital insertion
	New Horizons crosses Uranus's orbit
19	Full Moon
20	March equinox (6:21 p.m. EST)
	Waning gibbous Moon near Saturn
23	Mercury at east elongation
26	Last quarter
	Venus near Neptune
30	*Soyuz* launch to International Space Station
31	Thin waning crescent rises with Venus

Visible planets

Mercury will be visible at sunset over the western horizon—use Jupiter to help locate Mercury.

Venus will be visible before sunrise over the eastern horizon this month.

Mars will be close to the Sun and will not be visible this month.

Jupiter will be visible over the western horizon at sunset.

Saturn will rise after sunset and will be visible all night.

Questions for students

1. How is the length of a season determined, or when do seasons change? *(Seasons change as the position of the Sun changes relative to a planet's equator. The length of a season would be approximately one-fourth of its orbital period, or year. However, the length of a season would not be exactly one-fourth, but would vary depending on the eccentricity of the orbit.)*
2. What are the start dates for seasons on Earth this year? *(March equinox: 3/20 at 23:21 UT; June solstice: 6/21 at 17:16 UT; September equinox: 9/23 at 09:05 UT; December solstice: 12/22 at 05:30 UT.)*
3. Are the lengths of Earth's seasons the same length? Explain why or why not. *(No, the lengths of the seasons are not the same length: Winter 2010–Spring 2011 = 88 days; Spring 2011–Summer 2011 = 92 days; Summer 2011–Fall 2011 = 94 days; Fall 2011–Winter 2011 = 92 days. Seasons are close to being equal length, but are not equal because the Earth's orbit is slightly eccentric. If it were perfectly circular, then seasons would be the same length.)*

Resources

Earth's seasons—*www.usno.navy.mil/USNO/astronomical-applications/data-services/earth-seasons*

Mercury—*http://solarsystem.nasa.gov/planets/profile.cfm?Object=Mercury*

MESSENGER mission—*http://messenger.jhuapl.edu*

SFA star charts—*www.midnightkite.com/starcharts.html*

Sun–Earth Day 2011—*http://sunearthday.nasa.gov/2011/index.php*

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