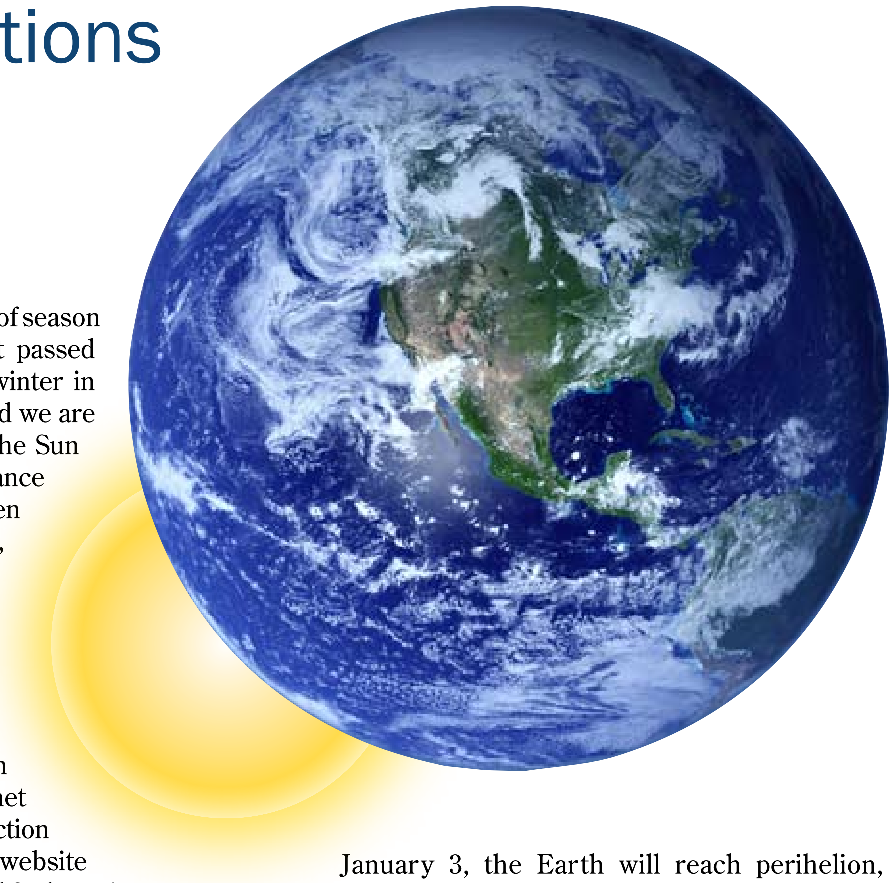
Solar explorations

by Bob Riddle



Even though there is no change of season during January, we have just passed the December solstice, it is winter in the Northern Hemisphere, and we are 147,100,00 km (91,403,702 mi.) from the Sun at Earth's perihelion, its minimum distance from the Sun. This is in contrast to when Earth reaches aphelion during July, when it is 152,100,000 km (94,510,558 mi.) from the Sun. This creates an opportunity for students to explore the idea that distance from the Sun is a factor in causing seasons on Earth.

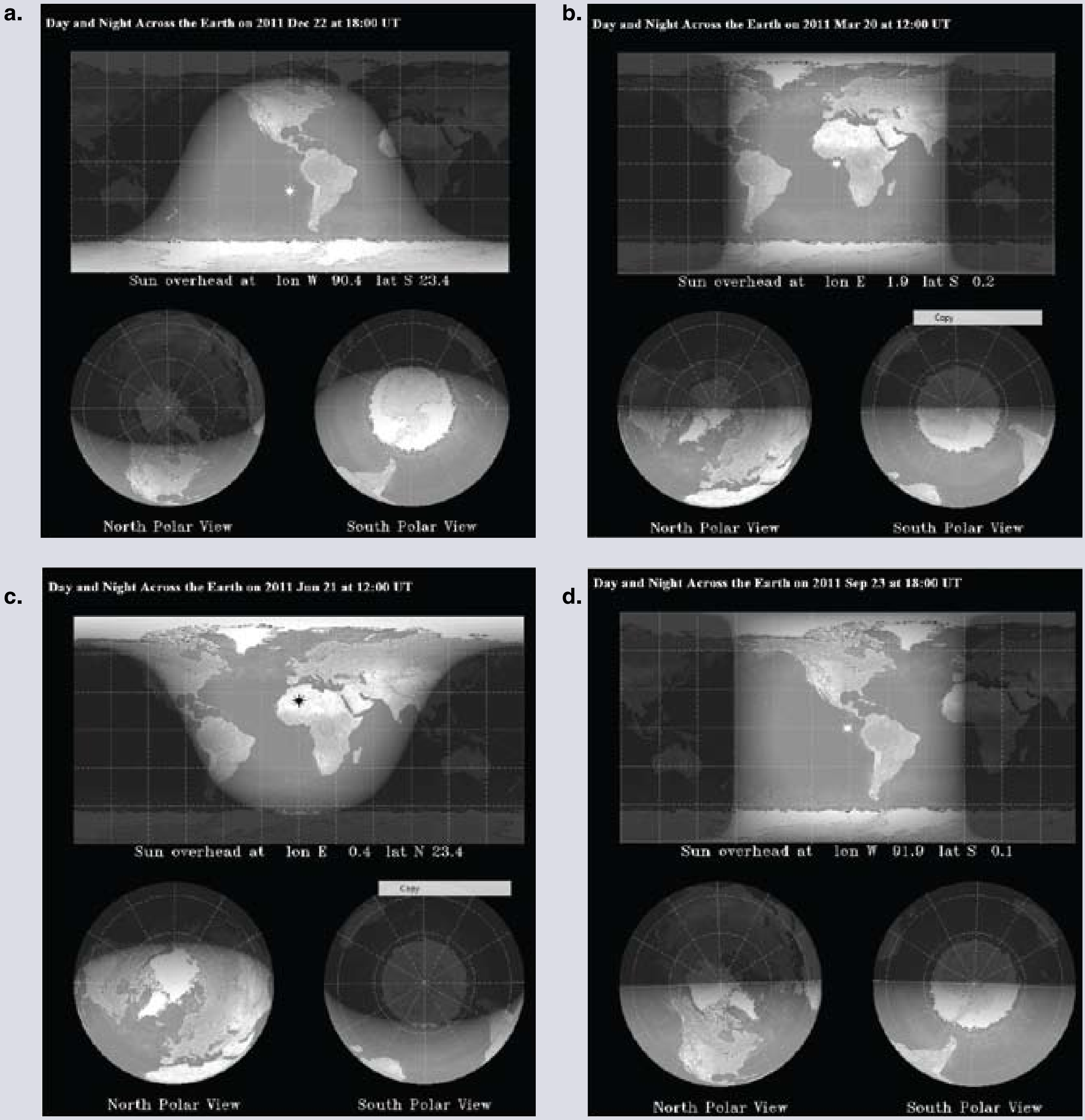
Begin the new year with some Sun-based investigations that students can conduct by taking advantage of internet resources provided in the astronomy section on the U.S Naval Observatory (USNO) website (*www.usno.navy.mil/astronomy*). You will find a variety of options for choosing data or background information about the solar system and other familiar celestial objects. Click on the "Data Services" link to see all of the options available. Students will be using the options related to an investigation of Earth–Sun relationships with regard to distance between the two, how the length of daylight and nighttime hours varies, and the Sun's apparent east-to-west path (and how it varies at different latitudes). Listed below are some of the topics that students could use for this investigation (see Resources).

- Duration of daylight/darkness for one year
- Rise/set/transit times for major solar system objects and bright stars
- Altitude and azimuth of the Sun or Moon during one day
- Geocentric positions of major solar system objects and bright stars
- Day and night across the Earth

Earth at perihelion

One very regular event occurs along Earth's orbit around the Sun every January, and this month, on January 3, the Earth will reach perihelion, its closest, or minimum, distance from the Sun. On that date, the Earth will be 0.983342267 AU (astronomical units) from the Sun. Conversely, on July 4, the date of aphelion, or most distance, the Earth is 1.016740342 AU. An astronomical unit is the Earth-to-Sun distance where 1 AU is typically expressed as equal to 93,000,000 miles; specifically, 1 AU is equal to 92,955,807 miles, or 149,597,871 km. On the USNO website (*www.usno.navy.mil/astronomy*), there is a link to an online calculator that will display the distance as well as coordinate positions to solar system objects and several stars. To use the calculator, click on the "Data Services" link and then click on the "Geocentric Positions of Major Solar System Objects and Bright Stars" link. For this part of the investigation, it is the distance to the Sun that is needed. Students may wonder about the use of *geocentric*. Explain that the coordinates that are calculated are done as if the Earth were in the center, with everything going around the Earth. We all know that the solar system is heliocentric (the Sun is in the center); however, we see the sky as if we (Earth) are in the center, so coordinates and relative motions are calculated accordingly.

FIGURE 1 Visualizing the changing amount of daylight and night during the year



By middle school, students have learned that the reason for seasons on Earth has to do with the axial tilt of the Earth and its revolution around the Sun, rather than the distance to the Sun. While it seems logical that it is the distance between the two that accounts for seasons, students quickly see that it is not the case by observing the Sun's distance from Earth and the time of year. Using the data, students could graph the Earth-to-Sun distance relationship in a variety of ways, such as a line graph to show the relationship between distance and time of year. Based on what they graph, and what your objectives are, students should be able to interpret that the Earth's orbit is not a circle and that distance probably does not have anything to do with Earth's seasons. To reinforce the idea of distance not being a factor in the cause of seasons, and to make this more visual, have students measure the diameter of the Sun using images taken at different times during the year or by using the excellent online activity at the ClassZone website (see Resources). By correlating these images with dates, students will see that the Sun's apparent size also varies as the Earth-to-Sun distance varies and is further evidence that we are closer to the Sun during our winter months and farther from the Sun during our summer months.

The Sun's daily path

As the Earth rotates, the Sun follows an apparent path, rising in the east and setting in the west. However, the angle at which it does so varies with latitude. In general, the closer to the equator, the more vertical the Sun's rising and setting angle. Farther from the equator, the angle is less steep. What is the angle for your latitude? The answer is simply 90° minus your latitude. How this is determined can be pictured by remembering that on the equinox, the Sun always rises due east and sets due west. At the equator, the Sun rises straight up, and sets straight down at an angle of 90°. We know from experience that at our latitudes north of the equator, the Sun does not rise and set at a 90° angle on the equinox, but at a less steep angle. Because I am north of the equator, the Sun should be lower in my sky than at the equator. On the equinox at 40° north, the Sun would rise and set 40° differently than at the equator, or at a 50° angle (90° minus the latitude, 40°). From my latitude, the Sun would always rise at an angle of 50°, regardless of the season.

How the rising and setting angle remains the same is explained by the relationship between your latitude and the Sun's apparent path across your local sky. To work with this idea, have students look at a globe or a Mercator-type map of the Earth. Point out that due to the axial tilt of 23.5°, the Sun is always somewhere between the Tropic of Cancer, 23.5° north, and the Tropic of Capricorn, 23.5° south, throughout the year. These two imaginary lines are parallels of latitude, and they are the same distance in degrees from the equator, as are the degrees of axial tilt. We know that on either of the equinox days, the Sun rises exactly east and sets exactly west. On either of the solstice days, the Sun rises 23.5° away from due east-northeast in June and southeast in December. It is important to note that the Sun rises parallel to the path that it followed on the equinox. In fact, on any day, the Sun's apparent path is always parallel to the equator.

Questions for students

1. Why are astronomical units used for distances in the solar system? *(Astronomers needed a system that would be more manageable—units such as inches, meters, miles, and kilometers are too small, while the light year is too big for practical use within the solar system. By having the Earth as 1 AU, all of the other planets and solar system objects can have easy-to-manage values for distances based on that constant value of 1 AU.)*
2. Rising and setting tables also include the time for transit. What does it mean when an object transits? *(In astronomy, a transit is when an object crosses in front of something. In this investigation, students will notice that all celestial objects have a transit time. This refers to when an object is midway between rising and setting and at that moment would be transiting the meridian. The meridian is an imaginary line that goes from due south through the zenith [straight up] to due north, effectively dividing the sky into an eastern and western half.)*
3. In the Northern Hemisphere, the Sun follows an apparent path where it rises in the east, is highest above the south horizon at midday, and sets in the west. What would be the difference if the Sun's apparent path were to be viewed in the Southern Hemisphere? *(Students could answer this by setting a location to a southern latitude using the alternate form and generating a table of altitude/azimuth for the Sun. At midday in the Northern Hemisphere, the Sun has an azimuth around 180° [south]; at the same time in the Southern Hemisphere, the Sun's azimuth is around 360° [north]. It rises in the east and sets in the west for both hemispheres.)*

While the rising/setting angle does not change, the direction of the rising and setting Sun changes daily due to axial tilt and revolution. This, however, is measured using either cardinal direction, such as northeast or southwest, or with degrees of azimuth (azimuth is a horizontal, degree-based system where north is 0°, east is 90°, south is 180°, and so on). In the Northern Hemisphere, from spring to summer, the Sun rises farther north until the start of summer, when the Sun reverses direction by rising less to the northeast each day until the first day of autumn and a due-east rising position. It then starts rising to the southeast until the first day of winter, when it reverses directions and rises less to the southeast each day until the first day of spring and a due-east rising position.

Students can investigate this repetitive event and its effect on the length of daylight and night hours through the data generated from the USNO website by designing graphs and other means of displaying the data. Additionally, students can gain a different perspective on how the Sun's seasonal position is relative to the Earth and the length of daylight and night by using the "Day and Night Across the Earth" link on the USNO website. Here, students will see several views of the Earth, as seen from space on the date chosen. One of the more striking displays is how the amount of daylight and Sun coverage vary from season to season. If possible, have four computers set up so that each one displays the Earth views on the first day of each season (see Figure 1).

January

1	Thin waning crescent Moon near Antares
	Asteroid Ceres is discovered (1801)
3	Earth at perihelion
	Quadrantids meteor shower peak
4	New Moon
	Partial solar eclipse
7	Saturn at western quadrature
8	Venus at western elongation
9	Mercury at western elongation
	Waxing crescent Moon west of Jupiter
10	Waxing crescent Moon east of Jupiter
	Cassini flyby of Pandora, Methone
11	*Cassini* flyby of Rhea
	Cassini flyby of Titan
12	First quarter Moon
14	*Cassini* flyby of Titan
19	Full Moon
	New Horizons launched to Pluto (2006)
25	Waning gibbous Moon near Saturn
26	Last quarter Moon
29	Waning crescent Moon near Venus
31	*Cassini* flyby of Epimetheus, Calypso, Prometheus, Enceladus, and Helene

Visible planets

Mercury will be easily seen above the southeastern horizon before sunrise.

Venus will shine brightly above the southeastern horizon before sunrise.

Mars will be too close to the Sun to be seen this month.

Jupiter will be over the south horizon at sunset and will set around midnight.

Saturn will rise after midnight and will be visible over the south horizon before sunrise.

Resources

Cassini Equinox mission—*http://saturn.jpl.nasa.gov/mission/introduction*

Measuring distances: Astronomical unit—*www.iau.org/public/measuring/*

New Horizons—*http://pluto.jhuapl.edu*

Partial solar eclipse—*http://eclipse.gsfc.nasa.gov/SEplot/SEplot2001/SE2011Jan04P.GIF*

Quadrantid meteor shower—*http://meteorshowersonline.com/quadrantids.html*

Size of the Sun—*www.classzone.com/books/earth_science/terc/content/investigations/es2603/es2603page01.cfm*

Solar images—*http://solar.physics.montana.edu/ypop/Classroom/Lessons/Eccentricity/sunpix.html*

U.S. Naval Observatory astronomy resources—*www.usno.navy.mil/astronomy*

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