A candle in space

Measurements of the cosmos

BY BOB RIDDLE

One of the challenging aspects of astronomy is measuring distances to celestial objects. Without being able to physically measure celestial distances within and beyond the solar system, how are these measurements made, and how do scientists know if they are accurate?

Astronomers use a variety of techniques for measuring celestial distances. Picture a ladder where each rung represents a different measuring technique that measures greater and greater distances as you "climb" the ladder.

FIGURE 1: A standard candle represents a celestial object such as this supernova

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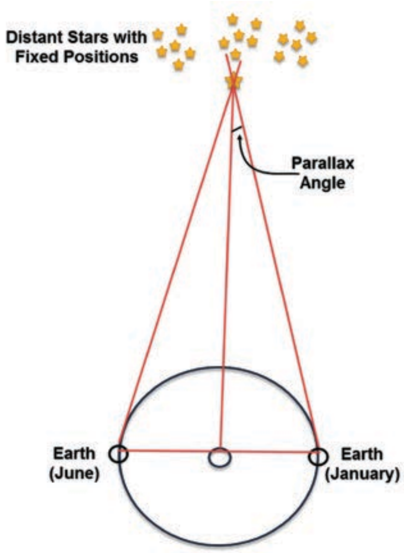
Each rung of the ladder is called a standard candle and represents a specific celestial object such as a supernova (see Figure 1) that has an accepted distance value that could be used to measure the distance of other objects.

Within the solar system and relatively shorter distances between objects, astronomers measure distances using *astronomical units* (AU)—the first rung of the ladder. The AU is the average distance between the Earth and the Sun, or 149,000,000 km (93,000,000 mi.). For example, Earth is 1 AU from the Sun, and Jupiter is around 5 AU from the Sun. Beyond the confines of the solar system, the AU becomes less practical for expressing distances and light-years are typically used. One *light-year* is the distance (approximately 9,656,064,000,000 km [6,000,000,000,000 mi.]) light will travel at the speed of light (299,338 km per second; 186,000 mi. per second) in one year.

The second rung of the ladder represents a few methods using parallax to determine stellar distances. To measure stellar distances beyond the solar system,

FIGURE 2: Parallax angle and distances



astronomers observe the apparent back-and-forth shift in a star's position as the Earth orbits the Sun. This method, known as *stellar parallax*, uses Earth's orbit for the base of a triangle with the two sides intersecting at a distant star.

The *parallax angle* between the two lines measures the angular shift of the distant star as the Earth orbits the Sun (see Figure 2). Specifically, one-half of the angular shift of the star is the parallax angle. The equation, D=1/P (distance equals 1 divided by the parallax angle) measures the distance in light-years between Earth and a star. When the distance between the Earth and the distant star causes the parallax angle to equal 1 arcsecond, the distance between the two objects is 206,265 AU (3.26 light years) and is known as a *parsec* (*par*allax plus *sec*ond). The parsec measures distant objects, but is limited to about 100 parsecs when using ground-based telescopes or about 1,000 parsecs for orbiting telescopes. The parallax angle would be too small to accurately measure distances beyond 1,000 parsecs.

Sharing the rung on the ladder for determining stellar distances is the *spectroscopic parallax method*, which measures the distance between the Earth and a star based on the relationship between a star's absolute and apparent magnitude. For some background, *absolute magnitude* (M) is the brightness of the star at 10 parsecs, and *apparent magnitude* (m) is dependent upon distance, meaning that the more distant a star, the dimmer it will appear. Magnitude values are positive numbers for dimmer stars, whereas negative numbers indicate brighter stars. Each change in magnitude equals a change in brightness or dimness by 2.512 (see Figure 3 and Resources).

The spectroscopic parallax method relies on the *distance modulus*, or difference between a star's apparent magnitude (*m*) and absolute magnitude (*M*). Basically, scientists know how bright a particular type of star should appear when it is 10 parsecs from Earth. If that star appears brighter, then that means

FIGURE 3: Absolute and apparent magnitude values

Absolute or apparent magnitude values	Differences in magnitude
5	2.512 x 2.512 x 2.512 x 2.512 x 2.512 = 100 times dimmer
4	2.512 x 2.512 x 2.512 x 2.512 = 39.8
3	2.512 x 2.512 x 2.512 = 15.8
2	2.512 x 2.512 = 6.3
1	2.512
0	------
-1	2.512
-2	2.512 x 2.512 = 6.3
-3	2.512 x 2.512 x 2.512 = 15.8
-4	2.512 x 2.512 x 2.512 x 2.512 = 39.8
-5	2.512 x 2.512 x 2.512 x 2.512 x 2.512 = 100 times brighter

FIGURE 4: Distance modulus

Distance modulus m − M =	Distance d (parsecs)
-4	1.6
-3	2.5
-2	4.0
-1	6.3
0	10
1	16
2	25
3	40
4	63
5	100

that the star is less than 10 parsecs away. If it is dimmer, then it means that the star is more than 10 parsecs away. By determining the value of $m - M$, we can use a distance modulus chart (Figure 4) to determine the distance of a star in parsecs. This distance can also be calculated using the formula $d = 10^{(m-M+5)/5}$, where d = distance in parsecs, m = apparent magnitude, and M = absolute magnitude.

The two parallax methods are only useful when calculating distances to individual stars within our galaxy primarily because of the difficulty in distinguishing individual stars within distant galaxies. The next rung on the distance ladder takes advantage of the properties of other celestial objects, which I will cover in depth in next month's column.

This month's lunar occultations

A *lunar occultation* occurs whenever the Moon passes between a star or a planet. The Moon's orbital path takes it above and below the ecliptic, resulting in several lunar occultations along the Moon's path, and involves stars near the ecliptic. This month, the Moon will have 18 occultations involving a planet, asteroids, moons of other planets, and stars.

Viewing an occultation depends on the latitude and longitude of the observing site and is similar to viewing a total solar eclipse. To see a total solar eclipse, you must be somewhere along the path of the Moon's shadow. Likewise, you must be along the occultation path to see it. Observing and timing an occultation may lead to new discoveries. Previously, the rings of Uranus were discovered when Uranus occulted a star. For more information about occultations, visit the International Occultation Timing Association website (see Resources).

On October 3, the waxing gibbous Moon will occult the outer planet Neptune for the first of two occultations. This occultation will be best viewed from locations around the Pacific Ocean, Antarctica, and the South Pole. On October 30, the Moon again will occult the planet Neptune and will be visible in the same areas. On October 9, the waning gibbous Moon will occult the bright star Aldebaran, but will not be visible from the United States. On October 15, the waning crescent Moon will occult the star Regulus and will be visible from the United States. Watch for the Moon and Regulus to rise around 3:30 a.m. CDT with the occultation beginning around 5:30 a.m. CDT.

On October 17, the waning crescent Moon will occult the 100 km (62 mi.) diameter asteroid Lutetia, but it will not be visible in the United States. Observing an asteroid occultation requires being along a relatively narrow occultation path that's only a few miles wide. Lunar occultations of asteroids provide timing data that can reveal the shape and size of the asteroid (see "Shape of Things" in Resources). ●

RESOURCES

International Occultation Timing Association—*www.occultations.org*
Lunar occultation list—*http://asa.usno.navy.mil/SecA/olist17.html*
Magnitude Calculator—*www.mesacc.edu/~kev2077220/flash/magcalc.html*
Magnitude Scale—*www.icq.eps.harvard.edu/MagScale.html*
Parallax Calculator—*http://astro.unl.edu/classaction/animations/*

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stellarprops/parallaxdiag.html
Parallax Explorer—*http://astro.unl.edu/naap/distance/animations/parallaxExplorer.html*
Riddle, B. 2004. Scope on the Skies: Saturn, ringed jewel of the night sky. *Science Scope* 27 (4): 46–47. *www.nsta.org/store/product_detail.aspx?id=10.2505/4/ss04_027_04_46*.
Riddle, B. 2008. Scope on the Skies: Of moons and rings. *Science Scope* 31 (8): 12–15. *www.nsta.org/store/product_detail.aspx?id=10.2505/4/ss08_031_08_12*.
Riddle, B. 2015. Scope on the Skies: Shape of things. *Science Scope* 39 (3): 88–91. *www.nsta.org/store/product_detail.aspx?id=10.2505/4/ss15_039_03_88*.

For students

1. Use the *distance modulus*, the relationship between a star's absolute and apparent magnitudes, to determine if the following stars are less than, greater than, or equal to 10 parsecs. Star A: M=7, m=9; Star B: M=2, m=2; Star C: M=4, m=1 (see Figure 4)

Star A: more distant; Star B: equal to; Star C: less than

October

1 Moon at descending node
Saturn's rings at maximum tilt

3 Venus at perihelion

5 Full Moon

Mars 0.2° from Venus

7 Mars at aphelion (1.6661 AU; 154,873,670 mi.; 249,245,012 km)

8 Mercury at superior conjunction

9 Moon at perigee: 366,855 km (227,953 mi.)
Waning gibbous Moon near Aldebaran

12 Last quarter Moon

13 Moon near Beehive Open Star Cluster

14 Moon at ascending node

15 Waning crescent Moon occults Regulus

17 Waning crescent Moon near Mars and Venus

19 Uranus at opposition
New Moon

21 Orionid meteor shower

23 Sun enters Scorpius the Scorpion (astrological)

24 Waxing crescent Moon near Saturn
Moon at apogee: 405,151 km (251,749 mi.)

26 Jupiter in conjunction with Sun

27 First quarter Moon

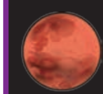
29 Moon at descending node

31 Sun enters Libra the Scales (astronomical)

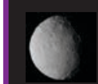
Visible planets

Mercury will move behind the Sun and be at superior conjunction and will not be visible until it reappears as an evening planet toward the end of the month.

Venus will be visible over the southeastern horizon, but each month it will rise closer to the time of sunrise and become harder to see.



Mars will be visible over the southeastern horizon before sunrise.



Ceres will be visible with binoculars over the eastern horizon at sunset.

Jupiter will be visible for the first two weeks of the month over the western horizon at sunset, but each evening it will be lower, setting closer to sunset.

Saturn will be visible over the southwestern horizon at sunset and will set several hours later.