Chapter 12

Saros and Cycles

In This Chapter

- The Moon's shadow determines the type of eclipse
- Total eclipses occur about every 18 months
- Annular eclipses occur about as often as total eclipses
- Months and years mesh in an eclipse cycle
- Eclipses move around the world

Though the eclipse in Australia in 2002 lasted only 32 seconds, some people enjoyed almost 7 minutes of totality in Baja California on July 11, 1991. How can they know when the next very long eclipse will occur? They just add 18 years 11⅓ days, giving July 22, 2009. The third of a day allows the world to spin from Mexico to China. The clockwork of cycles of the Sun and the Moon give such unusual regularities.

Almost Too Perfect a Fit

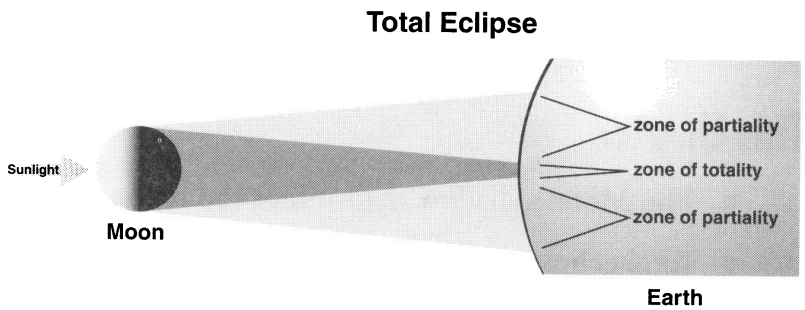
The Moon orbits the Earth every 27⅓ days, if you could look down on it from high above the solar system. But while it does so, the Earth moves ahead in its orbit. So it takes the Moon 29½ days to catch up to the same

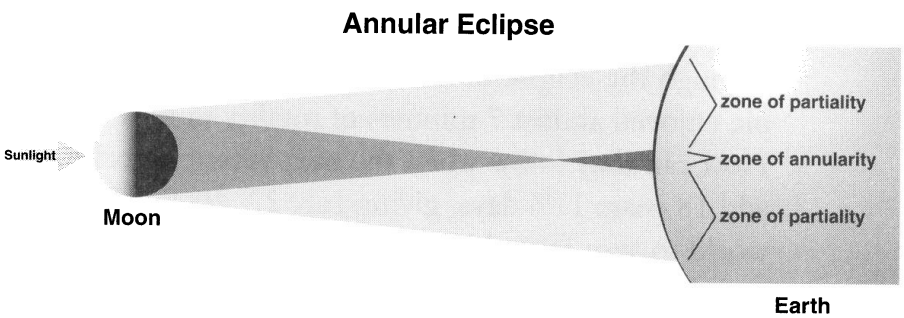
Fun Sun Facts

The Moon's distance from Earth varies from 356,000 km to 407,000 km, about 10 percent around the mean of 384,000. The Earth's distance from the Sun varies much less—from 147 million km to 152 million km, a deviation of less than 2 percent around the mean of 150 million.

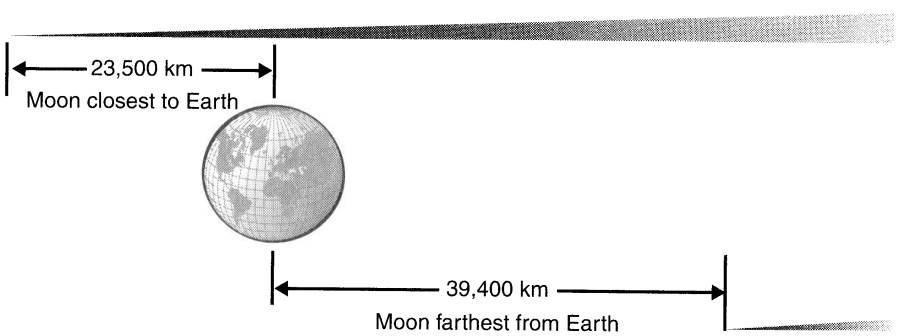
position on Earth with respect to the Sun. Since the phases of the Moon depend on the angle that sunlight hits it, lunar phases repeat with this 29½-day period.

The Moon's orbit around the Earth isn't perfectly round. Sometimes the Moon is about 10 percent closer to Earth and sometimes 10 percent farther away from its average distance. So sometimes the cone of the Moon's shadow hits the Earth, while at other times it doesn't quite reach.





The total eclipse, top, is viewed with the naked, unfiltered eye or camera. The annular eclipse, bottom, must be viewed only through a special filter that blocks all but about $^{1}/_{100,000}$th of the sunlight.



The cone of the Moon's shadow reaches the Earth in a total eclipse but doesn't reach it in an annular eclipse.

Total and Annular Solar Eclipses

When the cone of the Moon's shadow hits the Earth, we have a total solar eclipse. People standing within that cone and looking back toward the Moon see it blocking the everyday Sun entirely. The sky turns black, and we see the solar corona.

When the cone of the Moon's shadow doesn't quite reach Earth, we have an annular solar eclipse. People standing within the extension of that cone and looking back toward the Moon see a ring of bright sunlight around it. *Annulus* is a word (from the Latin) for "ring," so the event is called an *annular eclipse.* Even when only a tiny rim of sunlight remains visible, even down to a fraction of a percent, enough sunlight remains to keep us from seeing the corona.

Sometimes the point of the cone of the Moon's shadow just barely reaches the Earth at the part of the Earth's surface that is directly facing the Sun. On these rare occasions, we have an *annular-total eclipse.* In 2005, an annular eclipse will cross the Pacific Ocean. For only a few miles in the middle of the path, the Moon's shadow will reach Earth and the eclipse will be total. We hope that cruise ships will take hundreds of passengers out to that point, though certainly many fewer people will see totality than the tens of millions of people in Mexico City and elsewhere who saw totality at the 1991 eclipse.

Since both total eclipses and annular eclipses occur only when the Moon is centered on the Sun as seen from Earth, they are called *central eclipses.*

Solar Scribblings

In a typical century, there are 70 total eclipses, 72 annular eclipses, and 6 annular-total eclipses. The longest solar eclipse was over 7 minutes, and the longest annular eclipse was over 12 minutes.

Sun Safety

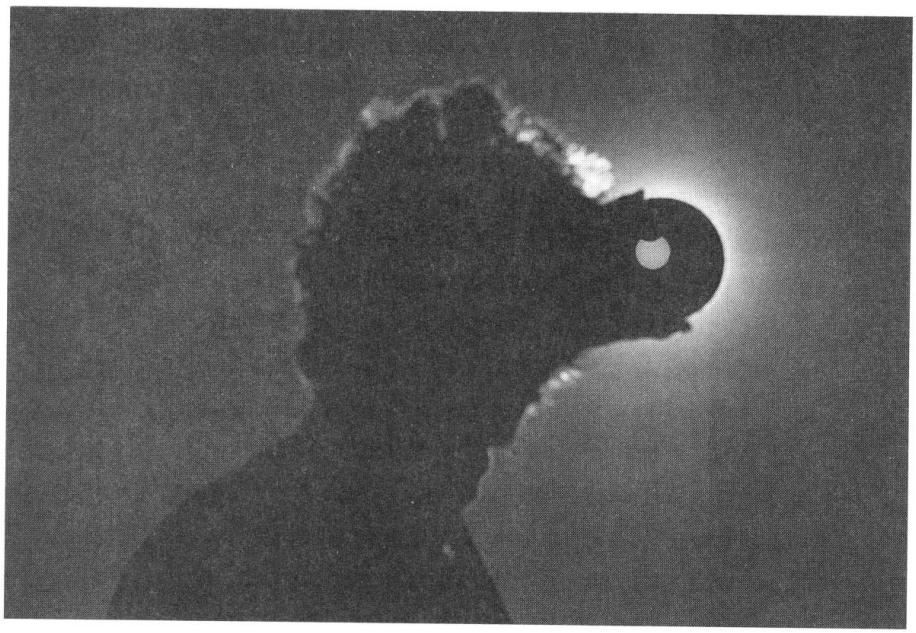
Except during totality of a total solar eclipse, you need a special solar filter if you want to look at the Sun. Never look unprotected at a partial or an annular eclipse.

Sun Words

An eclipse of the Sun in which an annulus (a ring) of bright everyday sunlight remains visible around the Moon is an **annular eclipse.**

An eclipse of the Sun that is annular for the ends of its path but total in the middle is an **annular-total eclipse.** A total or annular solar eclipse is a **central eclipse.**

But the Sun and Moon don't have to be perfectly aligned for the Moon to partly block the Sun for people on Earth. If the point of the cone of the Moon's shadow passes above the Earth's North Pole or below the South Pole, it never hits the Earth. Then we on Earth see no more than a partial eclipse. This circumstance happens more often than do total or annular eclipses. We can have as many as five solar eclipses each year, but most of them are only partial, and the beautiful phenomena of a total eclipse don't appear. Some years have as few as two solar eclipses.



Looking up through a special solar filter at the partial phase of an eclipse.

(JMP; Williams College Expedition)

Eclipse Seasons

The Moon's orbit is tilted by 5° compared with the plane of the Earth's orbit around the Sun. So most months, the Moon merely passes above or below the Sun in the sky at the time of new moon. The Moon's orbit passes through the plane of the Earth's orbit around the Sun at two points on opposite sides of the orbit. Those points are called *nodes.* Only when the Moon and Earth are both near one of the two nodes do we have an eclipse. These times repeat every 173 days, once on each side of the orbit. These times are *eclipse seasons.* Twice that time makes 346 days, which we call an *eclipse year.*

Sun Words

A **node** is a place where two curves cross or a wave doesn't change over time.

An **eclipse season** is the time of year when the Earth and the Moon are close enough to the nodes to potentially have an eclipse.

An **eclipse year,** 346.62 days, is the period with which the Earth passes through opposite nodes.

The time the Moon takes to go from one of its nodes through the other and back again is called the *nodical month*. Since eclipses happen according to this schedule, the intervals are also called *draconic months*. *Draconic* refers to the mythical Chinese dragon that ate the Sun to make eclipses.

The central part of the shadow cone is called the *umbra*. A lighter shading in the diagram shows locations where the Sun is only partially shadowed by the Moon. From those locations, part of the Sun is visible; people there have a partial eclipse. These locations are the shadow's *penumbra*. In an annular eclipse, Earth passes beyond the point of the umbra into a region sometimes known as the *antumbra* (for "anti-umbra").

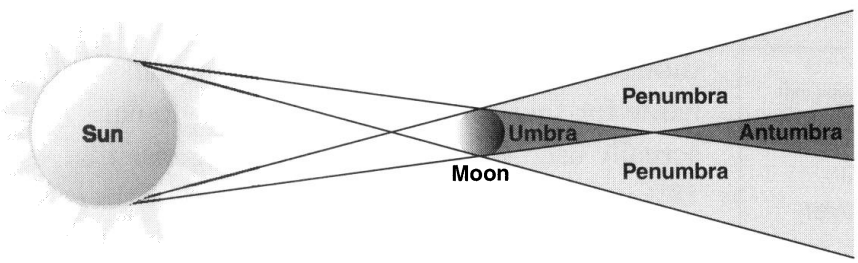
Sun Words

Nodical months, or **draconic months,** 27.21 days, are the intervals between the Moon's return to the same node.

The **umbra** is the completely dark part of a shadow.

The **penumbra** is the set of places that are only partially shadowed.

The **antumbra** is the continuation of the umbral cone beyond its point.



The parts of the Moon's shadow: umbra, penumbra, and antumbra.

Over and Over, but Not Quite the Same

You have learned that the Moon misses blocking the Sun most months because its orbit is tilted. But several times a year, the Earth is close enough to one of the nodes when the Moon passes through it. Then we have a total or annular solar eclipse.

Whenever three astronomical bodies are in a line, we have a *syzygy*. (I love that "yzy," which stumps many people when they are playing the word game Ghost.) Since the Earth goes around the Sun in 365¼ days and the Moon goes around Earth in 27⅓ days, there is no particular reason for the three bodies to come back in a line at regular intervals. But through a fluke, a syzygy of the Sun, the Moon, and the Earth occurs when the

Sun Words

A **syzygy** is a lineup of three astronomical bodies.

Moon has gone around the Earth a certain integral number of times—that is, an integer like 1, 2, 3, rather than a fraction or decimal—and the Earth has gone around the Sun a different integral number of times. It is just a lucky coincidence. That length of time works out to 18 years 11⅓ days, though it can be 18 years plus 10⅓ days or 12⅓ days, depending on how the leap years fall in the interval.

Fun Sun Facts

Partial eclipses can be fun to see but are usually too bright to view without special glasses. But sometimes at sunrise or sunset, haze on the horizon makes the sun sufficiently dim so that it can be looked at or photographed. When this happens for a partial eclipse, it is nice to see the horns of the Sun as it goes down. In Australia in 2002, some people went so close to the end of the eclipse path that the totally eclipsed Sun was only a Sun's diameter above the horizon. I have never seen a photograph of a fully eclipsed Sun in the process of rising or setting—nor would I ever take the chance of taking such a photograph myself, given a lower percentage of interfering clouds where the Sun is higher in the sky.

Sun Words

The **saros** is the interval of 18 years 11⅓ days (plus or minus a day on the calendar, depending on leap years) over which eclipses repeat.

This interval is known as the *saros*, a name chosen by Edmond Halley (of comet fame), who mistakenly thought that the ancient Babylonians had used the name for such an interval. (The Babylonians had actually used the term for something else that was 18½ years in duration.) So when there is an eclipse, one saros later there is also an eclipse of about the same duration. And that eclipse is one third of the way around the globe from where the earlier eclipse was.

Solar Scribblings

223 lunar (phases) months (@29.5306 days) = 6,585.32 days
242 nodical (draconic) months (@27.2122 days) = 6,585.36 days
So the moon is "new" while it is again going through one of its nodes.
19 eclipse years = 6585.78 days
239 lunar-orbital-shape months (@27.5546 days) = 6585.54 days

In addition to the Sun and the Moon going back to the same place at the same time, even the alignment of the Moon's elliptical orbit goes back to nearly the same place. This alignment follows the *anomalistic month*. So if the Moon is relatively close to Earth, it will be just as close after exactly one saros interval has passed. Thus, if you have a long eclipse, one saros later there will be another long eclipse. And if you have a short eclipse, unfortunately, it will still be short a saros later. (However, the short ones might be even more exciting than the longer ones. After all, you might have only a second or so after the beautiful diamond-ring effect at the beginning before another diamond-ring effect appears.)

Sun Words

An **anomalistic month**, 27.55 days, is the period between perigees—the closest approaches of the Moon to the Earth.

Within a saros interval of 18 years 11⅓ days is a series of total eclipses. For example, between the long eclipse of 1991 and the long eclipse of 2009, eclipses occurred or will occur in the following years:

- **1992**—A short eclipse over the south Atlantic ocean
- **1995**—India South Asia, with a peak of 2 minutes 10 seconds; observed by many for 30 seconds in India
- **1997**—Mongolia and Siberia, with a peak of 2 minutes 50 seconds
- **1999**—Europe, peaking over Romania, with a peak of 2 minutes 23 seconds
- **2001**—Southern Africa, up to 4 minutes 57 seconds over the ocean, 4 minutes 35 seconds at landfall, and 3 minutes 38 seconds in Lusaka, Zambia
- **2002**—Southern Africa and Australia, peaking at 2 minutes 4 seconds over the ocean between them
- **2003**—Antarctica, peaking at 1 minute 57 seconds
- **2005**—A mostly annular eclipse, turning total briefly over the Pacific Ocean
- **2006**—Africa and Turkey, peaking at 4 minutes 7 seconds
- **2008**—Greenland, Siberia, Mongolia, and China, peaking at 4 minutes 27 seconds
- **2009**—India to China, peaking at 6 minutes 39 seconds

The following 18 years will have a series of eclipses of about the same lengths in the same order.

If we follow a pattern of eclipses from saros to saros, you see that eclipse paths move north or south across Earth, starting near one pole, gradually moving through the temperate latitudes and equator, and moving off the other pole some 1,200 to 1,500 years later.

Eclipses and World Travelers

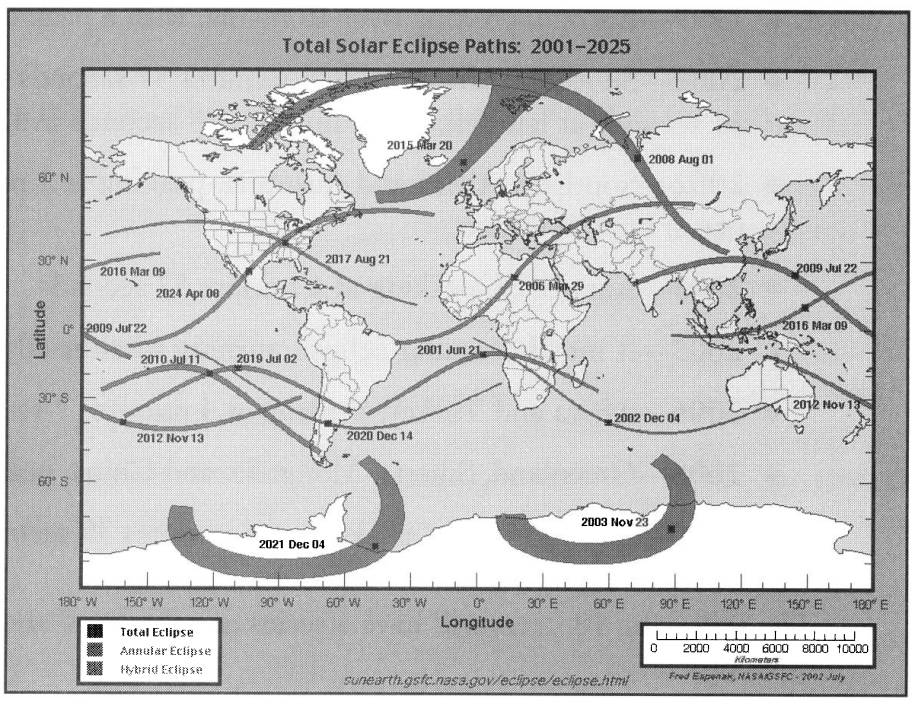
I saw my first solar eclipse within 10 miles of where I was living at the time. So I was enthralled by the eclipse itself, not the tourist aspects. But since that time, the 35 solar eclipses I have seen have taken me all over the world.

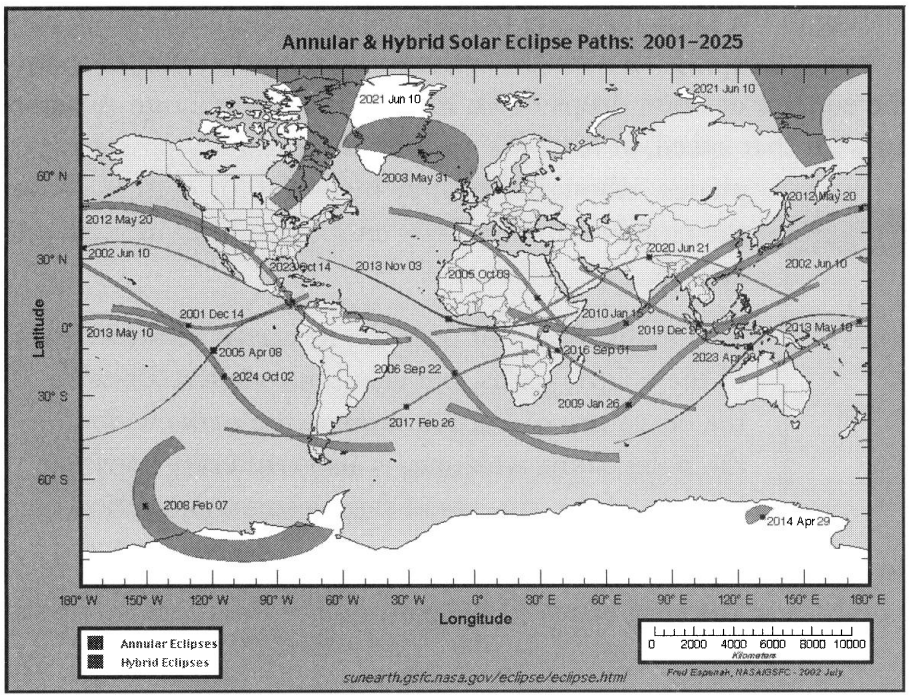
Basically, the Moon's shadow is a tapering cone. If you cut a cone with a plane perpendicular to the axis of the cone, you get a circle. But if the plane is tipped, you get an ellipse. The cone of the Moon's shadow is being intercepted by the curved surface of the Earth, so the actual shape of the shadow on the Earth is complicated but is close to an ellipse.

As the Earth and the Moon move in space around the Sun, and as the Earth rotates, the elliptical intercept of the shadow and the Earth sweeps across Earth from sunrise to sunset. So the path is only up to a couple of hundred miles across, but over 10,000 miles long. The paths of eclipses in the forthcoming period are shown in the following figure.

Total eclipses between 2001 and 2025.

(F. Espenak, NASA's Goddard Space Flight Center)





Annular eclipses between 2001 and 2025.

(F. Espenak, NASA's Goddard Space Flight Center)

Sun Safety

Here's how you can look at the Sun:

Every day: You need a special filter (the same special filter as during the partial phases).

Partial phases: You need a special filter.

Totality: Look directly, without a filter.

Diamond ring effect: Put your filter back on.

Final partial phases: You need a special filter.

The cone of the Moon's shadow actually moves in space at about 2,000 miles per hour. If the Earth weren't *rotating*, the shadow would pass over the Earth at that speed. But the Earth is rotating—that is, spinning on its axis, as opposed to *revolving* around the Sun.

Note that if you are standing on the North Pole, the Earth may be spinning but you aren't moving. So, at or close to the poles, an eclipse moves at the full speed of the shadow in space. But if you are at or near the equator, Earth is turning at a speed of its circumference divided by 1 day, or 25,000 miles divided by 24 hours, which is roughly 1,000 miles per hour. Since

Sun Words

Rotating means spinning on an axis.

Revolving is orbiting another body.

the Earth's surface is rotating in the same direction that the eclipse ellipse is moving, people at the equator are partially keeping up with the eclipse's motion. The speed of an eclipse that occurs at the equator at noon drops down to 1,000 miles per hour. A supersonic plane can keep up with that speed, at least for a while. But ordinary passenger planes—though they may be useful for getting above the clouds—don't go fast enough to keep up with an eclipse.

Fun Sun Facts

The Moon's shadow can be as much as 269 km wide. Because of the Earth's curvature, it can cover a width of over twice that on Earth's surface.

The maps show not only the locations of the centers of the eclipse paths, but also their widths. Because of the curvature of Earth's surface, the paths widen near the poles; some widening is also artificially apparent because of the vagaries of the Mercator projection used.

The durations of totality stay pretty close to the maximum even when you are quite a bit off the center line. Only near the very edges of the path do the durations go down substantially.

Solar Scribblings

If you stand in one spot, a total eclipse appears overhead about every 300 years. But the statistics are more favorable in some spots. One location in Angola saw eclipses in both 2001 and 2002, with an interval of less than 18 months. Even slight traveling lessens the interval. Statistics from a book cataloging all eclipses in England in 3,000 years from 1 C.E. to 3000 C.E. showed that in a 50-mile area around London, the average gap between total eclipses is 330 years, while in a similar area around York, the average gap is only 156 years.

The Least You Need to Know

- When Earth is close enough to the Moon to intercept its shadow, we have a total eclipse.
- Total eclipses and annular eclipses each occur about every 18 months.
- Eclipses of the same duration recur at the saros interval of 18 years 11⅓ days.
- Eclipse paths are no more than a few hundred miles wide, even though they are over 10,000 miles long.
- You must watch partial or annular phases of eclipses through special filters, but no filter is needed for totality.
- Total eclipses cross any bit of Earth every 300 years, on average, but traveling makes totality more frequent.