Solar Eclipses

Introduction

There are two basic types of eclipses, solar and lunar. A solar eclipse that can only occur when the moon is new, and a lunar eclipse can only happen when the moon is full.

One of the objectives of this unit is to have students understand a little bit about the repetition of the eclipses as well as eclipse terminology. The Babylonians were able to understand this approximately 200 years BC. We are in 2021, so I am assuming that I should be able to explain it to college students and you should be able to understand it. The repetition of eclipses is very mechanical, like drum beats. There are three distinct beats in understanding the repetition sequence. The major (most important) beat is the synodic period or the phase period of the moon, 29.5 days in length. There is also the nodical beat and the anomalistic beat; both will be explained in due course.

Three students volunteer and start beating their hands on the tables at different rhythms, all starting off with a sharp slap on the wood. Students listen for the three beats to hit at the same time. Eventually the three students slap the table at the same instance.

Okay, did you hear that? Several beats ago, we all hit the tables at the same time, and then we started getting out of rhythm once again. When the second simultaneous slap of the table occurred, another solar (or lunar) eclipse would have occurred.

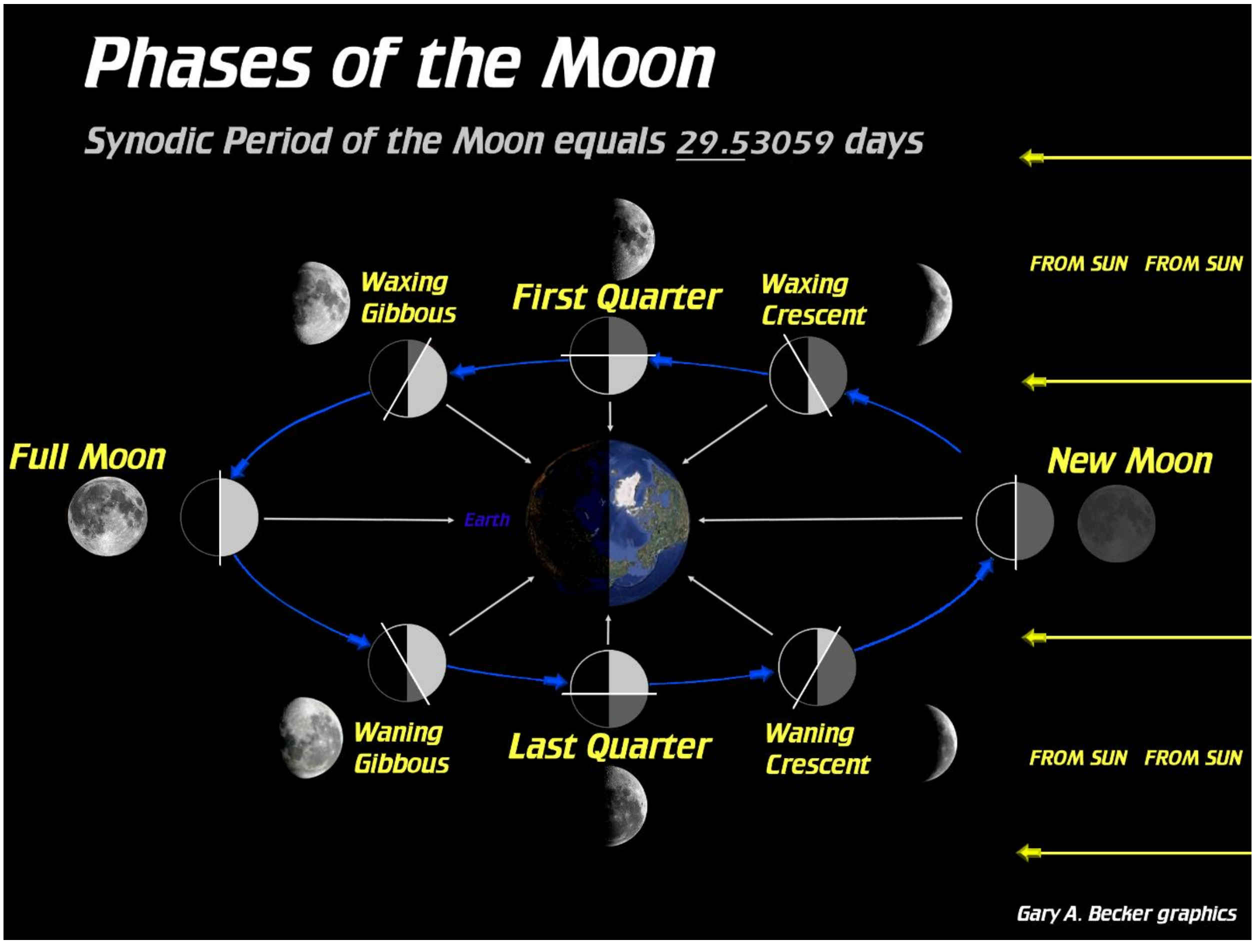
These three beats are called the synodic beat, which you definitely know some about, because that's the phase beat of the of the moon, which equals 29,5 days. The other beat is called the nodical beat while the third beat is the anomalistic period. All three of these beats must hit simultaneously, if there is going to be a solar or lunar eclipse. Two of these beats get out of synchronization. Eventually after 3.8 years two of these three beats come into synchronization. There must be another eclipse but it may not be similar to the last eclipse, it may be a different type of solar or lunar eclipse.

What people thousands of years ago were really interested in predicting were total solar eclipses, where the sun was completely hidden by the moon. In this case all three beats had to occur simultaneously, and the last eclipse in the series had to also have been a total solar eclipse.

That specific rhythm was discovered by the Babylonians 200 to 300 years before Christ was born. Some smart (Einstein) Babylonian must have looked into thousands of years of records and came up with a repetition cycle that the Greeks named the saros. One other thought is that if you don't put a total solar eclipse on your bucket list, I guarantee you, when you die, I will be there waiting to harass you to make your life totally miserable. But I am getting a little ahead of myself. Let us talk about the language (the nomenclature) of eclipses.

Eclipse Talk

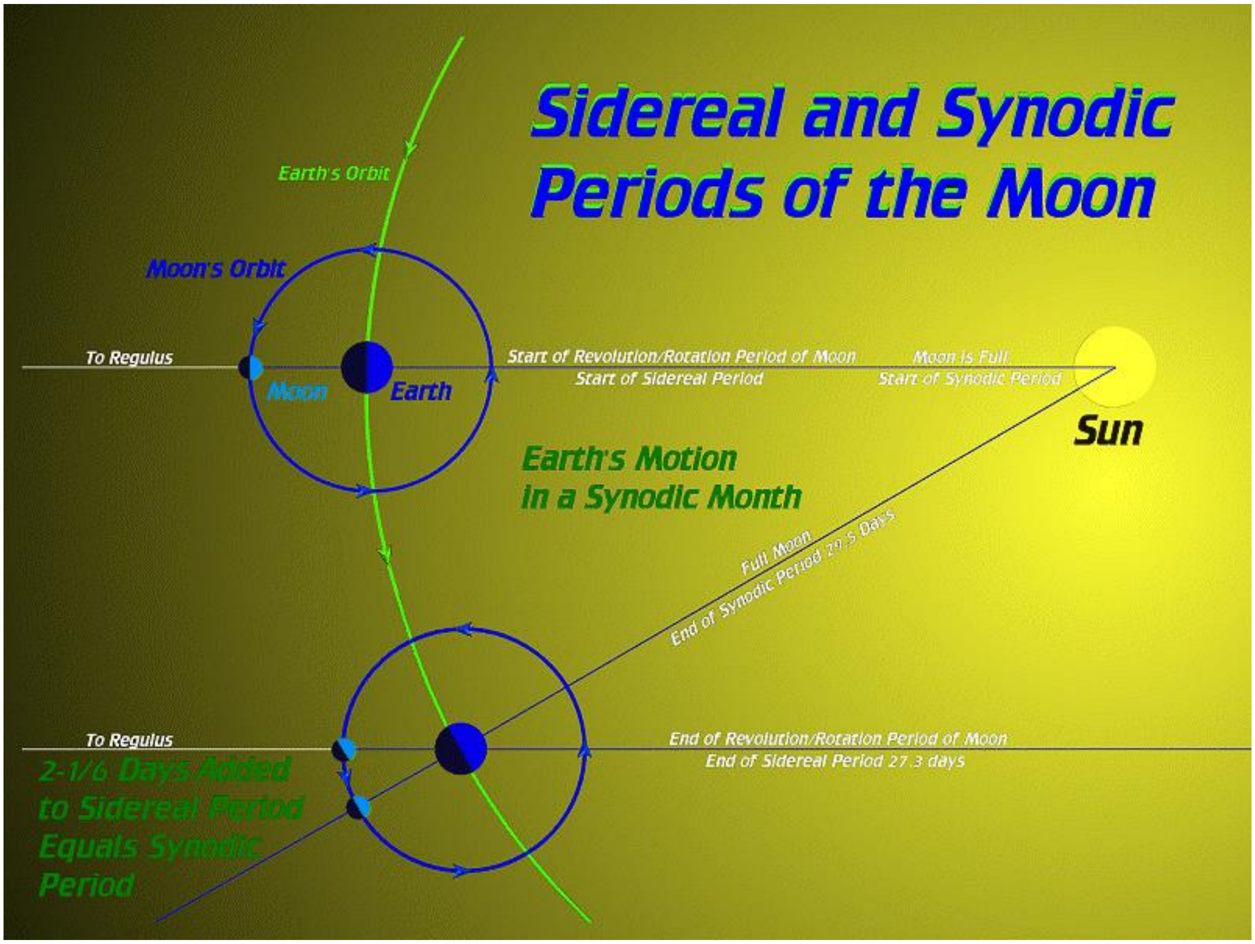
Let us talk a little bit about eclipse terms. The 29.5-day synodic period is the governing beat for eclipses. You simply cannot have any eclipse unless the moon is full or new.



Let's discuss again the difference between the synodic and the sidereal periods of the moon. We did this before, but I think it is an important concept worth repeating. The **sidereal** period is the time it takes the moon to complete one **revolution** around the Earth. The sidereal period of the moon is **27.3 days**. The **synodic** period is the time it takes for the **phases** of the moon to go from one complete cycle which transpires in **29.5 days**.

The more important of the two is the synodic period or phase period, because that is the one that is easy to observe and was responsible for the first calendars. The moon is bright, easy to see and its rapidly changing phases are easy to watch and track. In the picture sun-Earth-moon-Regulus are all in a straight line.

Regulus and the moon lie very close to the ecliptic and the Earth and sun define the ecliptic as the Earth sweeps around the sun. The ancient Egyptians believed that Regulus was the star that in combination with the sun produced the heat of the summer.

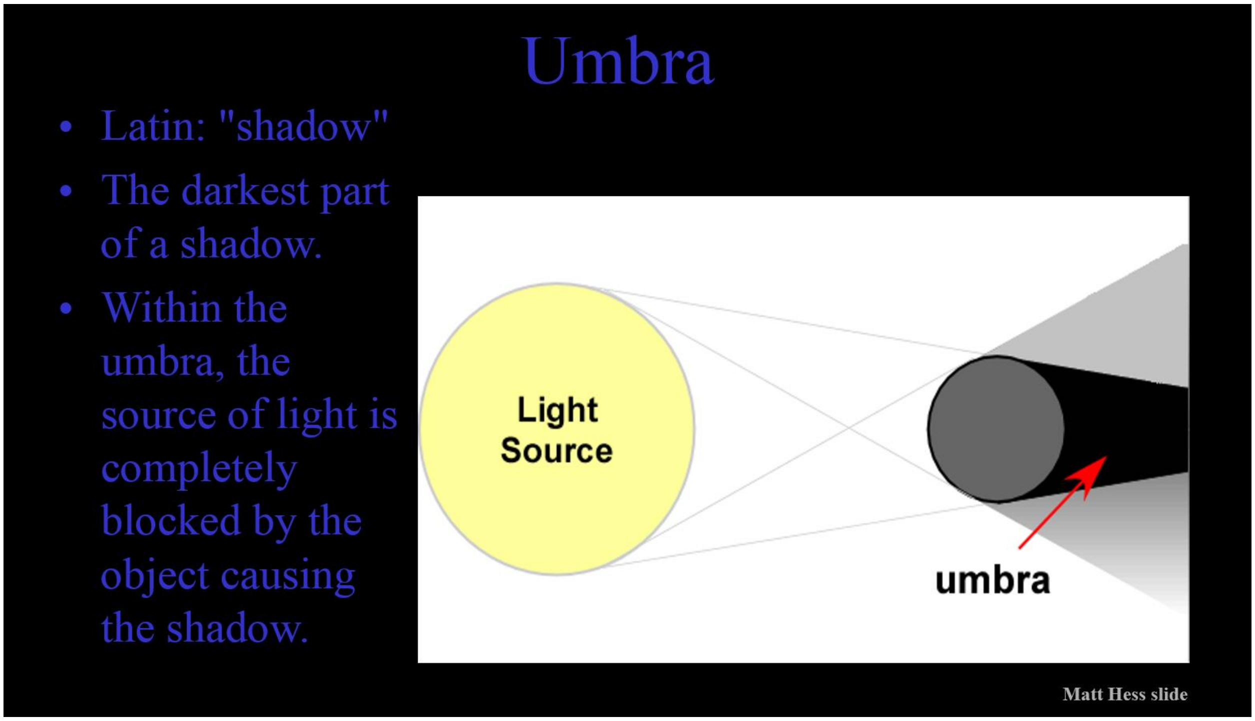


We start out with all four of these objects in a straight line. When the moon passes, Regulus for the second time, the sidereal period will have ended. **Sidereal** comes from the Latin meaning **star**. Once the moon passes the star for the second time, its orbital period, its revolutionary period has ended.

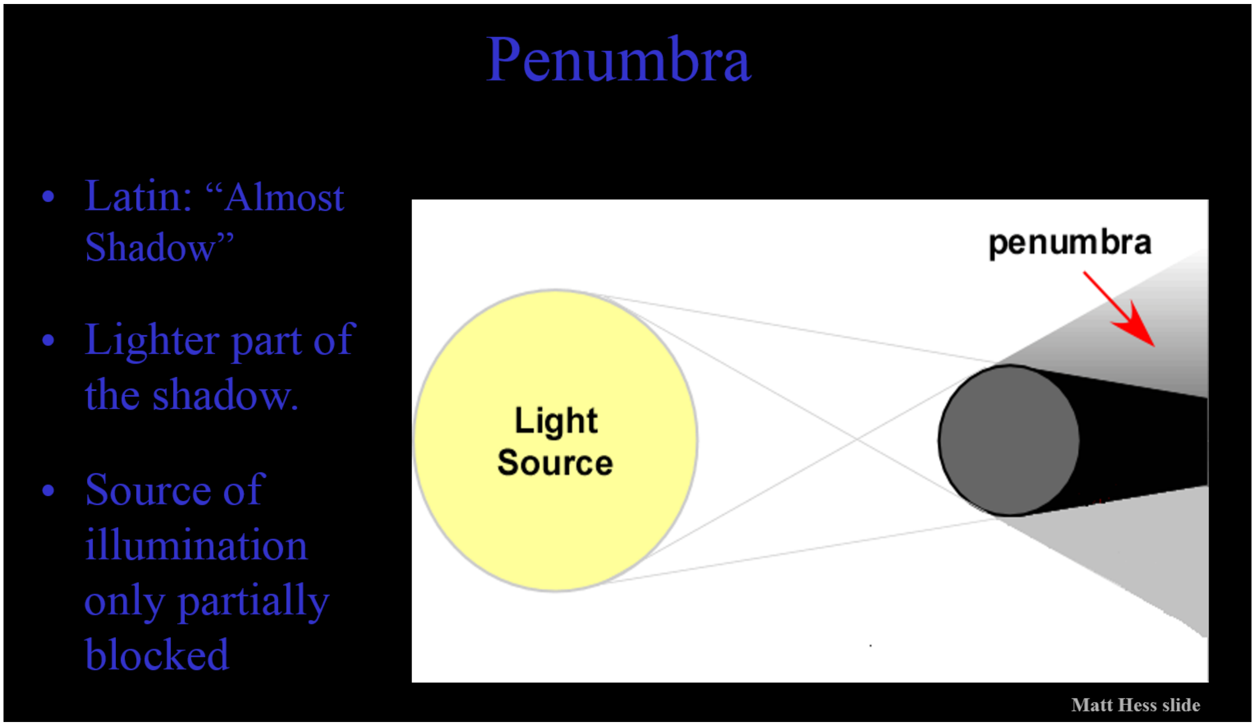
Mentally we say go, and the moon starts revolving around the Earth. The Earth starts revolving around the sun until Earth, moon, and Regulus are again connected by a straight line, i.e., the moon is passing Regulus for the second time. The sidereal period has ended. If you map this out in days, you will discover that it takes 27.3 days for one complete lunar revolution (orbit).

But notice that the moon is not quite full. It is a waxing gibbous moon. It will take a little more time before the moon moves into the correct position to be in the full phase and end the synodic period. How long will it take on average to get the moon into the full moon position after its sidereal period has ended? The answer is about 2-1/6 days for the moon to move through that small angle and bring the moon into a full phase, moon-Earth-sun.

It can be seen in the slide that the terminator is perpendicular to the line from the center of the sun through the center of the Earth through the center of the moon. We have reached the end of the synodic period. Two and one sixth days (2-1/6) plus 27-1/3 days equals 29-1/2 days for the phase (synodic) period of the moon. Keep in mind that the synodic period does vary a little. If the earth is covering more orbital ground like it is in the wintertime, when Earth is closer to the sun, then the time to catch up to complete the synodic period is going to be a little longer. If it is in the summertime, when the Earth is slowest in its orbital motion, the moon with have a smaller distance to travel and the synodic period will be a little bit shorter. The take away from this slide is that the orbital and phase periods of the moon are not the same.

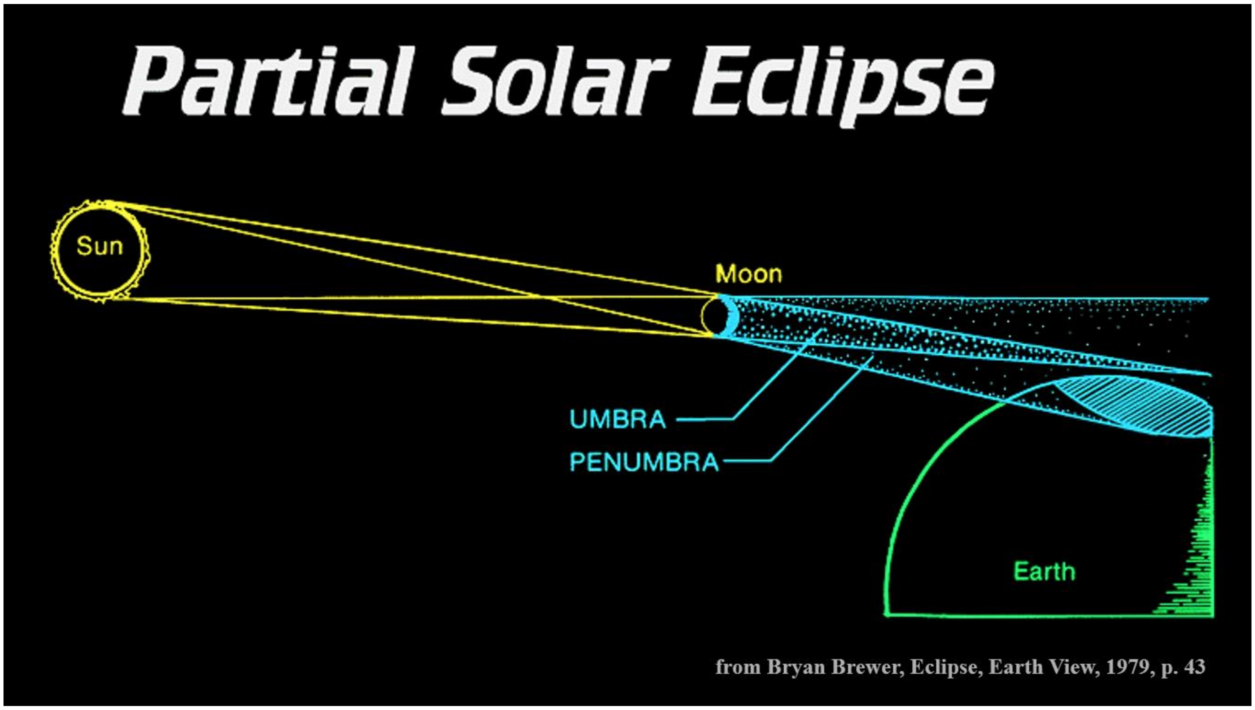


Let's go through some eclipse terminology. An object being illuminated by an extended source like the sun will always produce two shadow, the umbra and the penumbra. Whenever you are in an eclipse situation, the actual shadow being produced by the occulting body is called the umbra. When you are in the umbra, the light source will be invisible because the object producing the shadow is opaque hiding the light source. Umbra comes from the Latin which means shade. If you move away from the umbra, you will encounter the penumbra, which is Latin for light shade.



Let us pretend that you are at the tip of that red arrow in the penumbra slide. You would see the occulting body in the direction of the light source. The opaque body is covering up a good part of the light source, but not all of the light source. Some of that sunlight is getting into the penumbra, which means that the penumbra cannot be as dark as the umbra. If I move closer to the umbra, more and more of the sun's light is blocked and the penumbra becomes darker until I get to the umbra where all light from the source is blocked. The penumbra should go from a boundary which is nearly invisible to very dark at the umbra, penumbra boundary. I have never seen a slide that has duplicated that situation, so you will just have to deal with a uniform greyness within the penumbra.

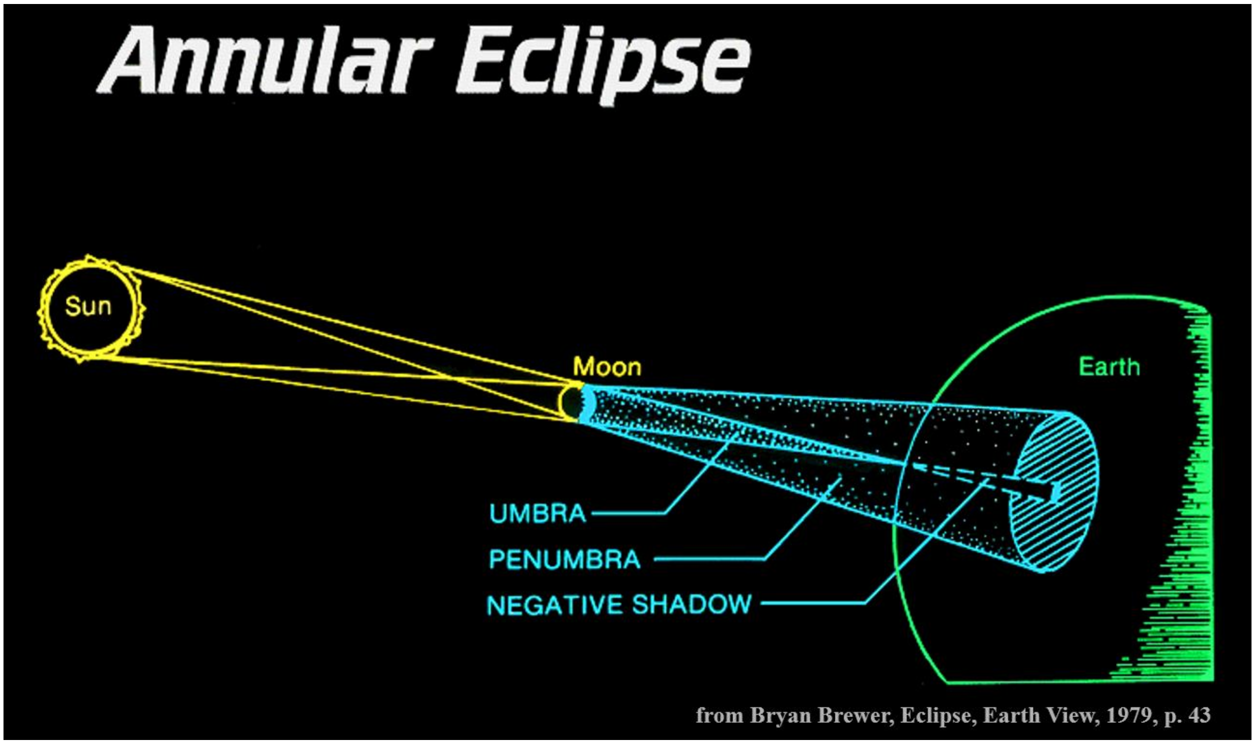
There are four types of solar eclipses: partial, annular (broken annular), hybrid, and total eclipses.



Every solar eclipse has a partial aspect to it where the observer is not quite close enough to the umbra to see the moon completely cross the sun’s disk. In this particular case the umbra misses the Earth completely and all that can be seen is the penumbra. The alignment of sun-moon-Earth is not good enough for the umbra to reach the surface of the Earth. Nobody on the surface of the Earth sees a total solar eclipse. It is a partial solar eclipse everywhere where any shadow reaches our planet. Partial solar eclipses are the standard types of eclipse in a series of eclipses called a saros cycle when that cycle begins and ends. They occur only at or near the poles of the Earth. Again, we'll talk more about saros cycles later in this lesson.

This is an image of a partial solar eclipse that occurred throughout much of North America on December 24, 1973.

The next slide shows the geometry of an annular eclipse.



In an annular eclipse, the moon is too far away from the Earth for the umbra to reach the surface of our planet. You might say correctly that in all area where the eclipse is visible the observer is within the penumbra of the moon's shadow. The moon's umbra is not long enough to reach to the surface of the Earth. This may tell you something about the moon's orbit.

There is an area called the negative shadow zone, which lies under the umbra and is the location where a smaller moon can be seen silhouetted against a larger sun. The sun, if viewed with the proper filtration would appear as a ring of sunlight surrounding the darker, opaque moon. This ring of sunlight is called the annulus, which is Latin for ring. This type of eclipse is named an annular eclipse.

The sun is 864,000 miles in diameter, but it's also 93 million miles away. The moon is only about 2160 miles in diameter, but it's only about 240,000 miles away. The moon is about 1/400 the diameter of the sun, but it is approximately 400 times closer to Earth than the sun. The sun is about 400 times the diameter of the moon but it is 400 times farther away. The net result is that both the sun and the moon look about the same angular size, (about 1/2 degree) in the sky. It just turns out that the moon and the sun have almost a perfect inverse relationship between distance and size. Both the Earth and the moon revolve around the sun and Earth in elliptical (oval-shaped) orbits. With changing distance comes changing size. If I approached you, I would look bigger, and if I moved away from you, I would look smaller. The sun looks biggest in the sky when we are closest (perihelion) in early January and smallest when we are farthest away (aphelion) in early July. This will be discussed shortly.

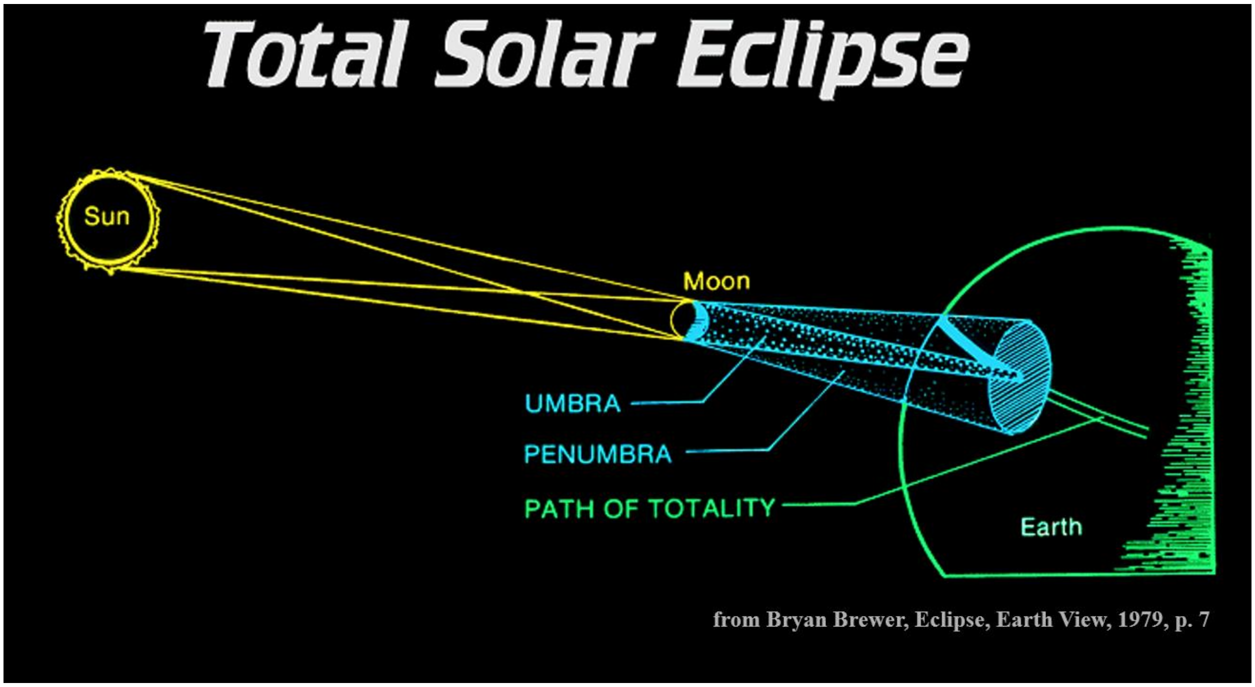
Here (next page) is an annular eclipse that occurred on May 10, 1994 in Canutillo, Texas. I had students along on that trip. The image shows the beginning of the annular portion of the eclipse.

When the moon makes contact with the sun and the eclipse begins, it is called first contact. Second contact happens at the start of the annular portion of the eclipse, when the sun can be seen as a circle of light around the moon. The third contact ends the annular portion of the eclipse. At fourth contact the moon is tangent to the disk of the sun. The eclipse ends at this point.

In the next slide I am in Osceola, North Carolina.

There was a broken annular eclipse here on May 30, 1984. The size of the angular diameter of the moon and the angular diameter of the sun were so close to each other, that when the center of the moon passed in front of the center of the sun, the mountains on the limb of the moon, actually occulted the sun, breaking its limb (edge) up into a beaded structure. Pearls of sunlight streamed from the valleys of the moon. The beaded structure is called Baily's beads, named for the Englishman, Francis Baily, who first explained the phenomenon in 1836. The three images on the right show the mountains jutting beyond the limb of the sun, breaking the sun's light into Baily's beads. The broken annular part of the eclipse lasted only seven seconds. You can learn more about this eclipse in my astronomy text. It is a fun story called *The Great Eclipse Chase* and it introduces my chapter on eclipses.

Finally, the type of eclipse that I really want you see is a total solar eclipse. If you wanted to see an annular eclipse, that would also be fine, but it is a dangerous eclipse to look at. So are the partial phases of any solar eclipse. You need special filtration to be able to see all aspects of the event. There is an annular eclipse on October 14, 2023 that goes across the southwestern part of the United States. I do plan to see that one.



The eclipse that I really want you to put on your bucket list is the total solar eclipse of April 8, 2024. A total solar eclipse is the one that you will never forget, the one that will last in your memory as long as you live. The visual effects are spectacular. After the total eclipse of August 21, 2017, I remember calling my wife because the solar eclipse was partial here in the Lehigh Valley. It also ongoing at the time of my call. When Sue answered my cell, she was so excited. When I heard her voice, I just started to cry. For me the beauty of a total solar eclipse is such an emotional event that I just broke down and cried. It is nature at its most beautiful and mysterious. Keep in mind that anytime the sun is visible, the eclipse is dangerous to view. You must use filters, but when totality occurs the entire moon is hiding the sun, the sun's corona becomes visible and the eclipse is completely safe to view with any type of instrumentation. The landscape can be as dark as if there were three to six full moons in the sky. Planets are visible and sometimes even brighter stars.

The moon’s shadow falling upon the surface of the Earth is a dynamic situation. The moon is orbiting the Earth at about 2000 miles per hour, but the Earth is also rotating in the same direction as the moon. There is only a very small strip of territory over which the shadow will pass, the path of totality. That strip may extend for only seven or eight thousand miles. Chances are that it is not going to go through your town or city.

With respect to all of these different motions, the moon is moving in the same direction as the Earth is rotating. And that's really favorable for eclipses, particularly if the path of totality is nearer to the equator and the shadow is moving in a mostly west to east direction.

The moon's orbital speed is about 2000 miles per hour. If the Earth were not rotating, the shadow would move across the surface of the Earth with a minimum speed of 2000 miles per hour.

Think of the Earth-moon motions. At the North Pole the axis of the Earth goes out into space and heads towards the North Star. In a 23-hour, 56-minute interval I will be going around in a circle as Earth’s rotation carries me along. If there is a total solar eclipse at the North Pole, the moon’s shadow is going to move past that position at Luna’s orbital speed of 2000 miles per hour because all that an observer is doing is spinning. It is a little more complicated than that, but suffice to say, total solar eclipses at the poles do not last very long.

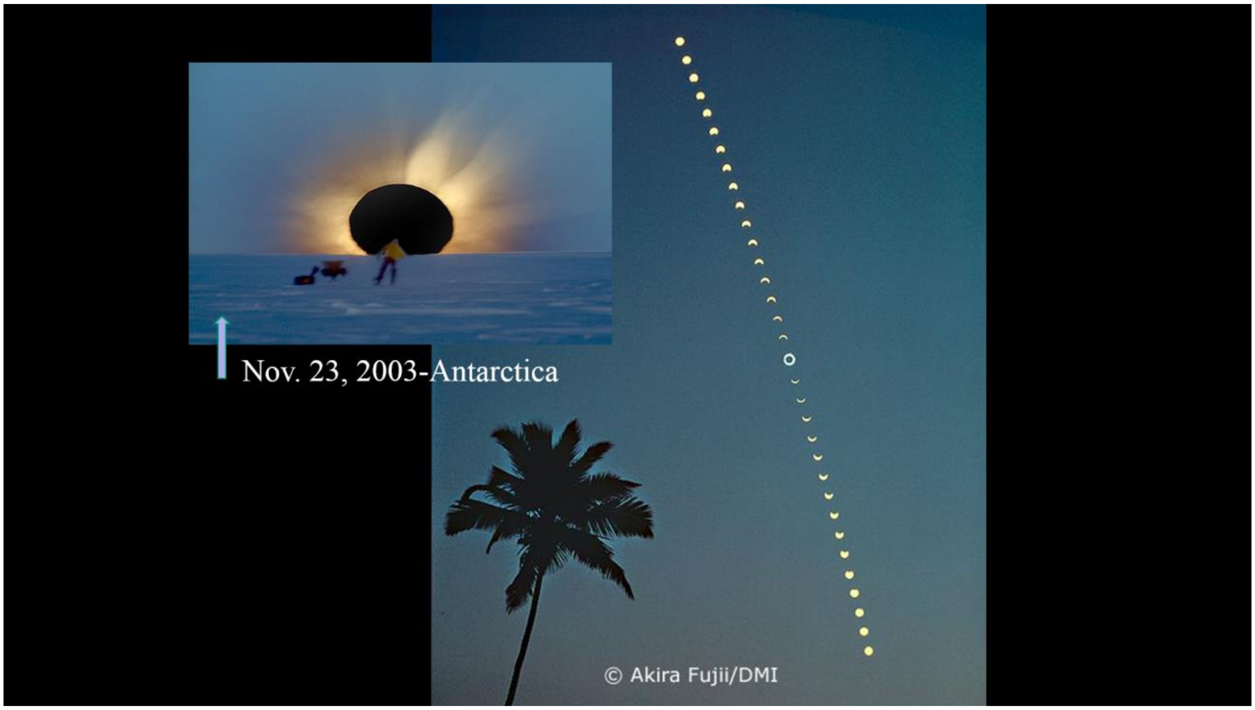
What happens to the speed of the shadow if I am near or at the equator of the Earth? Think about this for a moment. The equator is where the Earth is at its widest. If you consider the Earth's diameter to be 8000 miles and you multiply this number by pi (3.14), let’s say three to make it a mental calculation, you will obtain the circumference which is 3 x 8000 or 24,000 miles. This part of the Earth must rotate one complete time just like the north or south poles in just under 24 hours. This means that the equator is traveling at approximately 1000 miles per hour. The real number is closer to 1050 miles per hour.

Think of it this way. If I am driving a car going 60 miles an hour and I want to pass someone who is traveling at 30 miles per hour, how fast will I pass the slower moving vehicle from the driver’s perspective in the slower moving car? I'm going to move out into the passing lane to get around that person going 30 miles an hour. I'm going 60 miles per hour; the car is going 30 miles per hour. We are both moving in the same direction. Thirty miles per hour is exactly correct. My speedometer still says 60 miles per hour, but I passed the car moving at 30 miles per hour relative to the slower moving vehicle.

If I'm near the equator and there is a total solar eclipse that occurs. The shadow is moving at 2000 miles per hour, but the Earth is rotating at approximately 1000 miles per hour. I can slow down the shadow to about 1000 miles per hour and the eclipse will last longer. If there is an Eclipse that is near the equator, chances are that it is going to be a much longer eclipse than if it would be of the event were occurring at a higher latitude where the rotation of the Earth would not have as much effect in dampening or slowing the motions of the moon's shadow.

Think about this. What are the conditions that would create a very, very long totality in a solar eclipse? The longest duration of totality in a solar eclipse is 7 minutes, 31.5 seconds. Based upon what we just said, where would you want to be? Bethlehem, PA, London, England, Aruba, Jamaica, uh I want to take you…

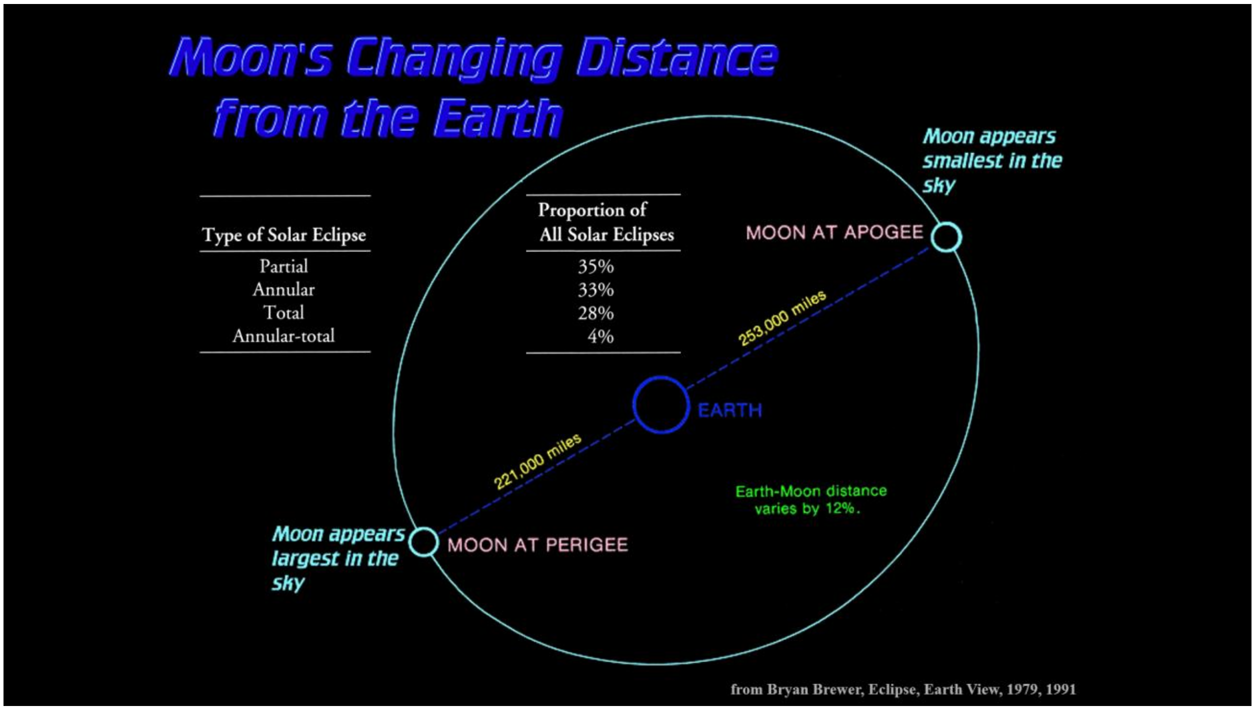
Aruba would be the correct answer because it is the site closest to the equator where the Earth would be moving faster than Allentown or London or even Jamaica. Secondly, what time of the year is the Earth farthest away from the sun. Summer is correct. In the summertime the sun would appear as small as it could in the sky. Every 27.6 days the moon is as close as it can get to the Earth and therefore as big as it can get in the sky. For a long duration of totality, you would want to be near the equator in early July (sun smallest in sky), when the moon was a perigee (largest angular diameter). I saw an eclipse on June 30, 1973 off the coast of Africa where totality lasted 6 minutes, 39 seconds. In central Africa, people were in the moon's shadow for 7 minutes, 3 seconds. There was another very long total solar eclipse on July 11, 1991. I saw this one also, but I was not at the optimal location. I was in Hawaii where totality lasted for just over 4 minutes. At the tip of Baja California, people were immersed in the moon's shadow for 6 minutes, 59 seconds. Baja, California is that part of Mexico which extends downward south of the US state of California. The Gulf of California is in between Baja California and Mexico.



On the right is a compilation of many images of a single total solar eclipse. The picture contains 33 images separated by approximately10 minutes each. Totality is the central picture with the corona (solar atmosphere) surrounding the dark moon. After the sequence of eclipse images was obtained, Akira Fuji, a world renowned astrophotographer, snapped one last image of the scene which contained the palm tree. On the right is a picture of a total solar eclipse that occurred in Antarctica? I remember a friend of mine, David Levy, actually saw this eclipse. The plane landed on the ice, people got out and set up their equipment. The tour agency set up tents so people could rest if they decided they were tired. Temperatures were probably above zero. Keep in mind that even in the summertime, Antarctica is still pretty cold.   The highest temperature every recorded was 69.35 degrees Fahrenheit in 2020, more confirmation that the Earth is warming.

Below is my picture of the August 21, 2017 total solar eclipse which I saw in Guernsey State Park, Wyoming. I will have more to say more about that eclipse when we discuss how to plan an eclipse trip.

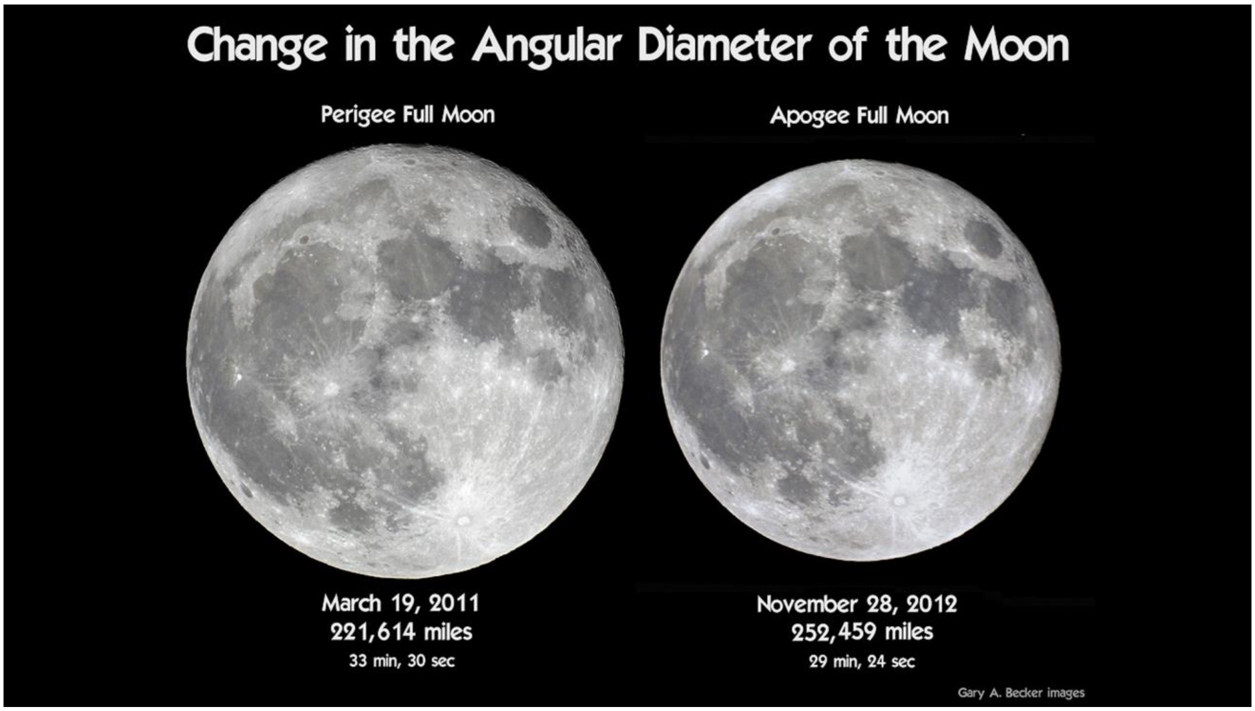
Let's talk about how distance effects eclipses. By now you should have some feelings about this important factor. Note that as the moon orbits the Earth, it is not inscribing a circle, but rather an ellipse (oval). The moon travels faster in its orbit when it is closer to Earth and slower when it is farther away from our planet.



The moon's elliptical orbit has an eccentricity of about 12.5 percent. It gets to a position in its orbit where it is closest to the Earth, a position called, perigee, from the Greek, peri meaning close and gee meaning Earth. As the moon moves to the opposite side of its orbit, it has reached its farthest position in its orbit called apogee. Again, from the Greek, the apo means far or great, while the gee signifies the Earth.

These two positions are opposite to each other along a line segment that is called the major axis, or the line of apsides if you are referring to eclipses. They are two different names describing the same thing. The major axis connects the closest, and the farthest positions of the orbiting moon around the Earth. The reason why I am showing you this picture is that I want you to understand that the moon's distance from the Earth is continuously changing. This mean that the angular size, or how big the moon looks in the sky is continuously changing.

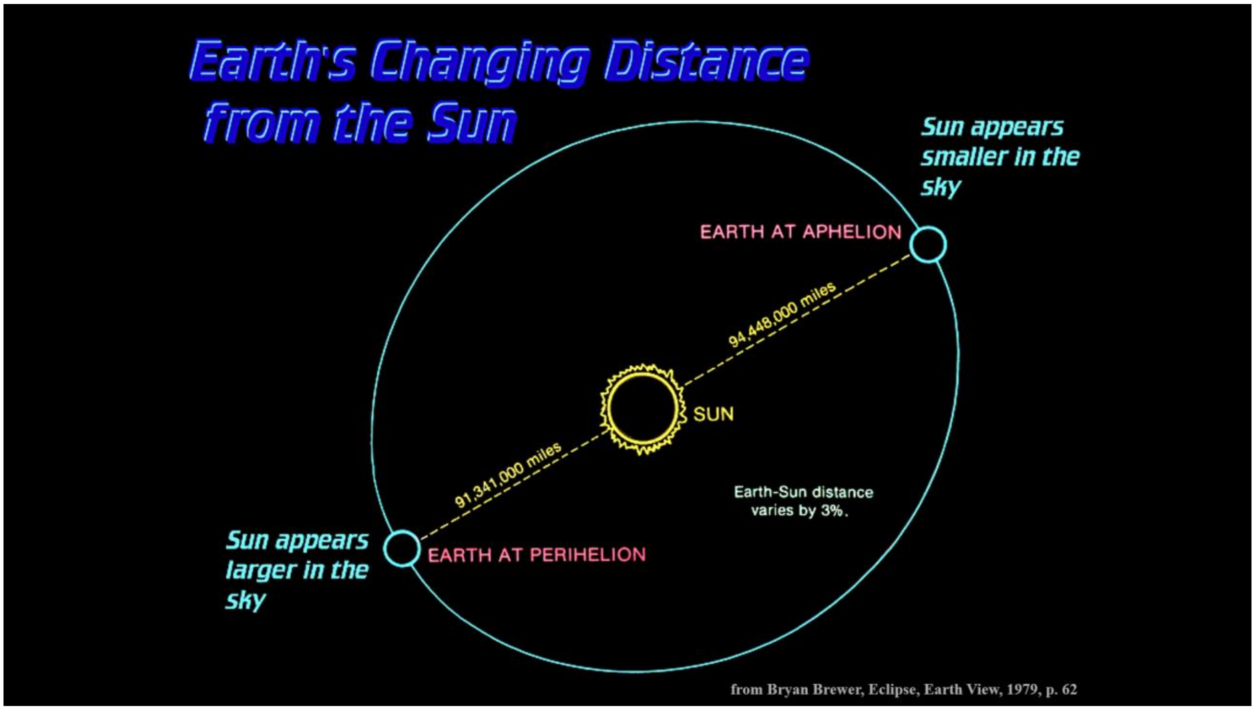
Because the Earth and the moon are so close to the same angular size in the sky, the distance of the Earth from the sun and the distance of the moon from the Earth makes all the difference with respect to the type of central (annular or a total) solar eclipse that will happen.



Here are apogee (far) and perigee (close) images of the moon. On the right is the apogee photograph which I took on November 28, 2012, when the moon was about 252,459 miles from Earth. The image on the left was taken when the moon was at perigee, 221,459 miles from Earth. It should appear larger than the moon on the right.

How is the moon going to react, orbital speed wise, when it is closer and farther from the sun? At perigee, the Earth and moon are pulling hardest on each other and the gravitational attraction between these two bodies is at its greatest. How will that effect the speed of the moon in its orbit? The moon will orbit fastest at perigee and slowest when at apogee.

If the moon is at apogee and a central solar eclipse occurs, the eclipse will always be annular. If the moon is at perigee, a central eclipse will always be a total.

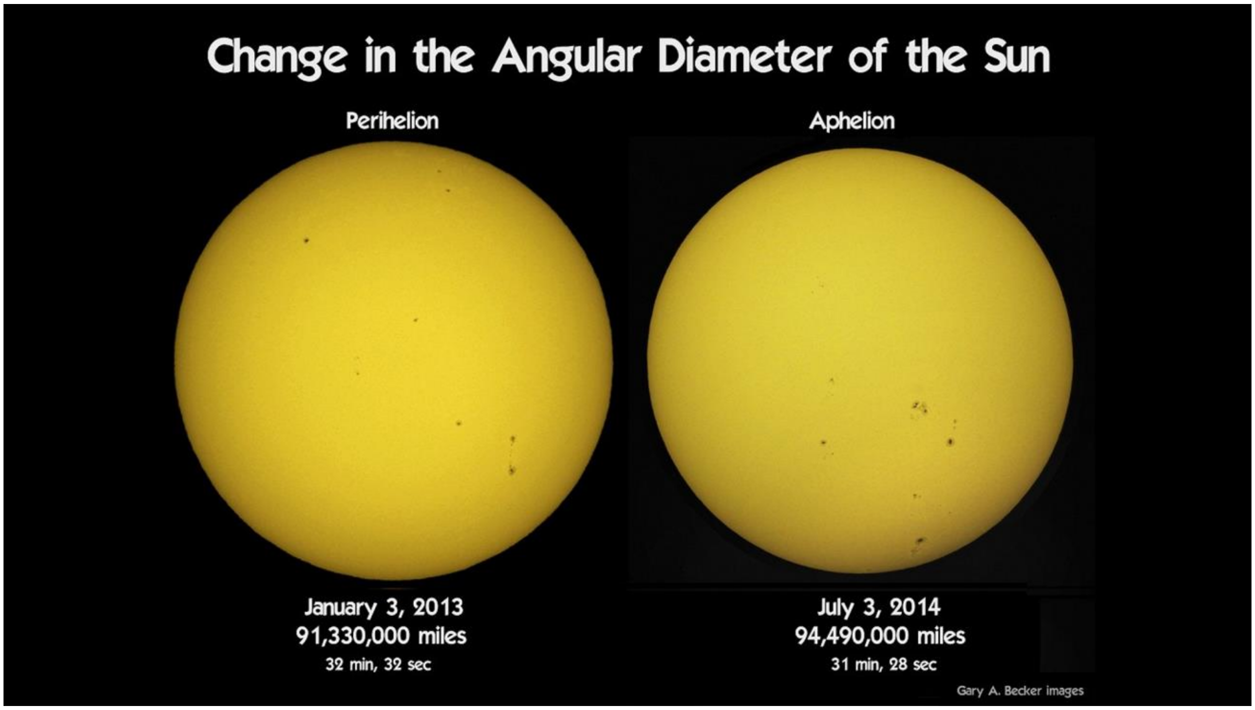


The other consideration that must be taken into account is the Earth's revolution around the sun. Our orbit around Sol is also elliptical by about three percent. What that means is that Earth's distance from the sun is constantly changing too, varying by roughly three million miles between the Earth being closest and farthest from the sun. In early January the distance is about 91.5 million miles. By early July, that distance has increased to approximately 94.5 million miles.

We have words to express the Earth's extreme positions from the sun. If we are closest, that position in Earth's orbit is termed perihelion, peri for close, Helios for the sun. If we are farthest, the Earth is at aphelion, ap for far and Helios for the sun. These words are derived from the Greeks.

If you like to make bets and you are going to bet on central solar eclipses as to whether more would be total or more would be annular, which type, annular or total, would be more common? Let's say there are 100 central solar eclipses, 100 eclipses where the center of the moon passed exactly in front of the center of the sun somewhere on the Earth. Keep in mind that there are two flavors of central eclipses, annular and total, governed by their distance from the objects which they orbit. As a betting person which eclipse type would you always bet on, if you did not know what type of eclipse was going to be occurring? If you lived long enough, you'd make a fortune. Which central eclipse type is more common, annular eclipses or total solar eclipses? The annular type is correct. Out of 100 eclipses, there might be 46 or 47 total and 53 or 54 annular.   Knowing that, you would walk away with some great money.

You would always bet on the annual eclipses, because annular eclipses only occur when the moon is farther away and when the moon is moving slower in its orbit around the Earth.

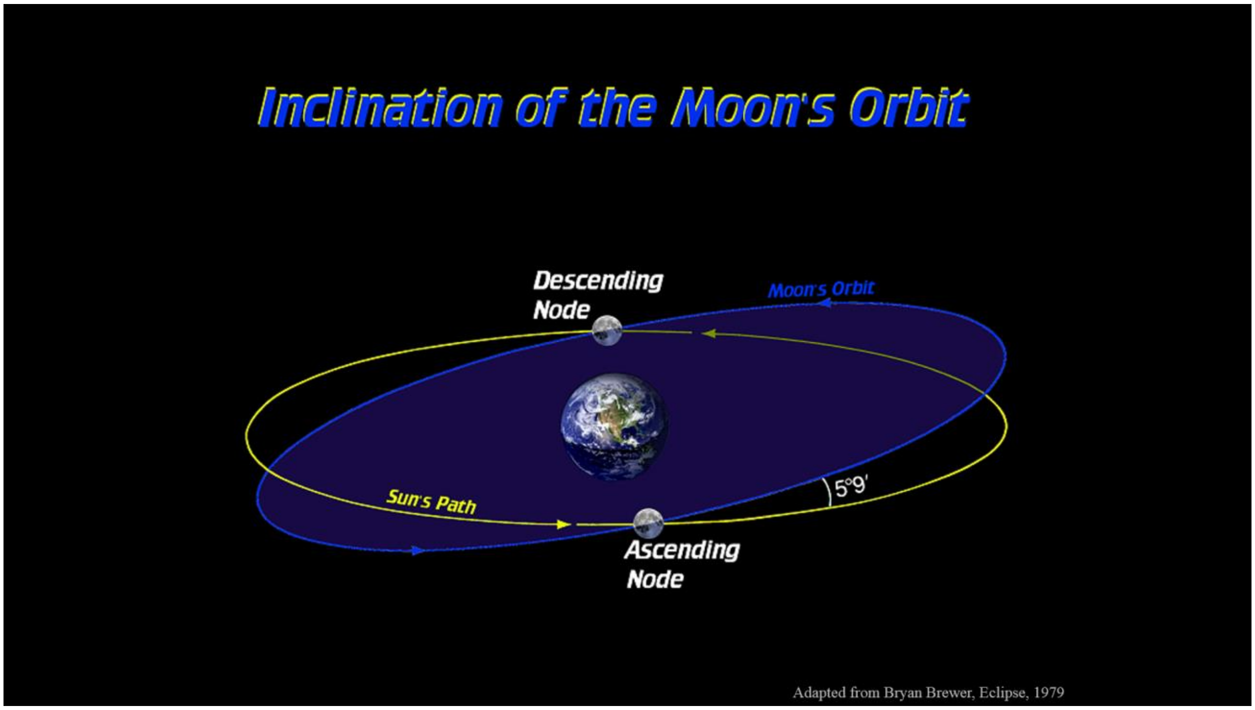


Turning to the sun, this slide documents the sun when Earth was at perihelion (left—closest to the sun) and at aphelion (right—farthest from Sol). Perihelion in 2013 was actually on January 2 for that year, but unfortunately it was cloudy on that day. We were at 91,330,000 miles. The aphelion image on the right was snapped on July 3, 2014, eighteen months later and within several hours of aphelion. Here we were at a distance of 94,490,000 miles from the sun. You have to look a little more critically, but a difference can be seen. Which sun appears larger?

Here are all four images for comparison, two of the sun and two of the moon when Sol and Luna were at their extreme distances. These are the same images that were seen in the previous slides, but reduced in size so they fit into the boxes which are the same size. The images were taken with the same telescope and with the same camera to create an exact scale.

Please understand that everything I say about solar eclipses applies to lunar eclipses. The reason I am hyping solar eclipses is because they are visually more spectacular. I also want you to see a total solar eclipse sometime during your life. You will never regret your choice, guaranteed.

Repetition of Eclipses



Here we have a slide which shows how the moon’s orbit (blue) is tilted to the Earth’s orbit (yellow). The blue represents the plane of the moon's orbit. The yellow represents the plane of the Earth’s orbit around the sun. Pretend that the sun is off to the right of the slide but in the plane of the ecliptic. The moon's orbit is tilted 5 degrees, 9 minutes to the ecliptic plane. I will be content if you remember 5 degrees. It is a small tilt, but since the moon and the sun are only a half a degree in diameter, a separation of even just one degree might not result in an eclipse occurring, let alone 5 degrees.

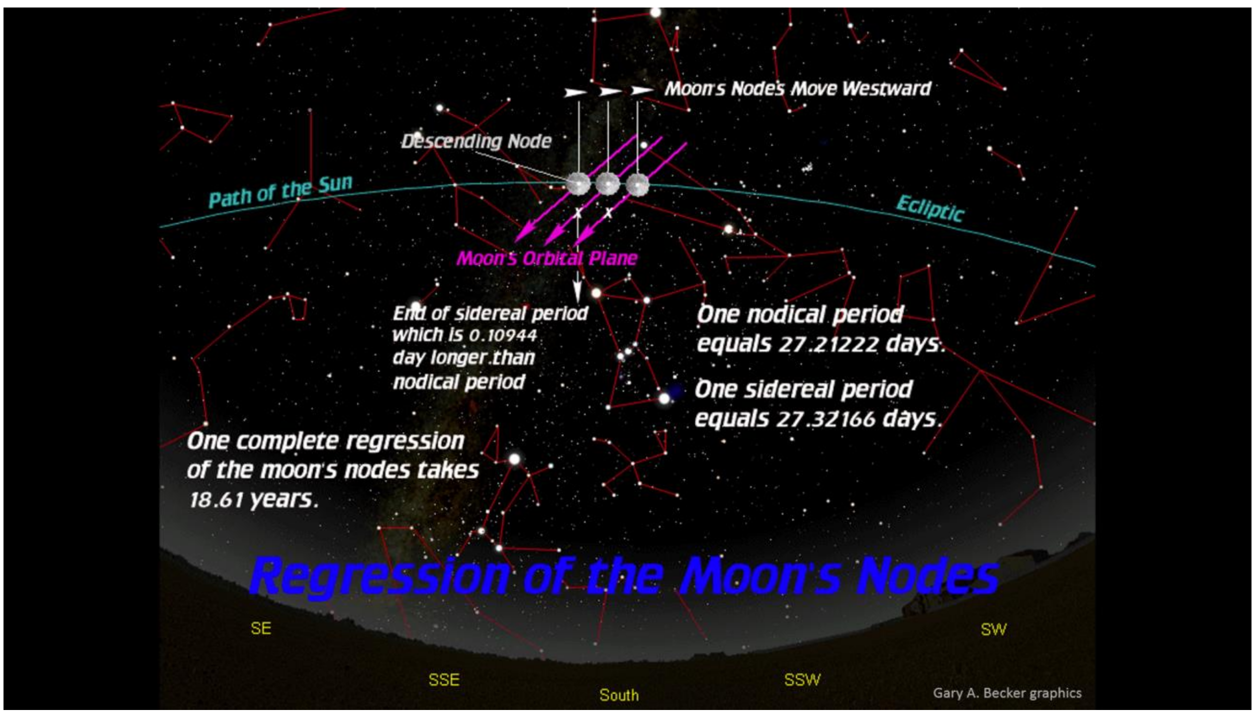
How large is a half degree? Just look at the moon when it is full in the sky. It is not very big. Keep in mind that from one horizon to the zenith to the opposite horizon is represented by180 degrees. Five degrees is not that big of an angle. If the moon is only a half-degree and the sun is only a half of a degree and somewhere, most of the time when the moon is either new or full, it will pass over or under the sun or Earth’s shadow and no eclipse will arise. But what happens if the moon is crossing the ecliptic, in other words if the moon is at or near a node (see next paragraph), and the moon is either full or new? Can you see that an eclipse must happen because the Earth and sun define the ecliptic? That is where the Earth and sun are always located.

Let’s reinforce the concept of a node which is simply an intersection point where two planes cross. In this case it is where the ecliptic plane crosses the orbital plane of the moon. At the position where the moon is traveling from above the ecliptic to below the ecliptic, is where the descending node is located. If the moon moves from below to above the ecliptic, that point of intersection is called the ascending node.

There are seasonal nodes, such as the vernal equinox which is located where the ecliptic plane crosses the plane of the celestial equator. The autumnal equinox is the intersection point where the sun traveling along the ecliptic plane moves from above to below the plane of the celestial equator.

If the moon is at or near a node and new, the moon's shadow must be on the ecliptic pointing directly towards the Earth. If the moon is full and at a node, it must intersect the Earth’s umbra, because Earth’s shadow must always lie on the ecliptic. If the moon is significantly above or below the ecliptic plane and in a new or full position, no eclipse can occur.   That is what happens on most months. The moon’s crossing position doesn't have to be exactly in the plane of the ecliptic. There is some wiggle room because the Earth presents a fairly large target for the moon's umbra and penumbra to strike as well as the Earth's shadows for the moon to enter. **The moon must be near or at a node and either full or new for an eclipse to transpire**.

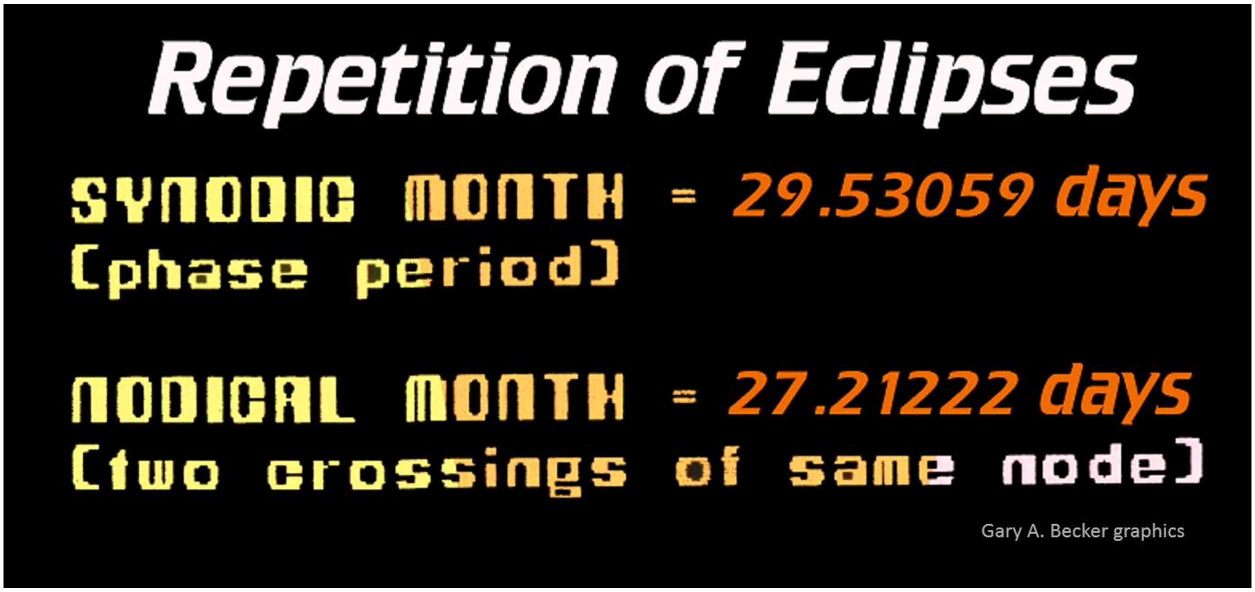
In a perfect world the time it would take for the moon to cross the same node twice should be the same as the sidereal period of the moon, 27.3 days. But this is not a perfect world. The time it takes the moon to cross the same node twice is called the nodical period and its interval is 27.3 days. Why is this?



Let us examine this concept in the next slide. Here the moon is on the ecliptic and at its descending node. The tilt of the moon's orbit is highly exaggerated. Keep in mind that it is just over 5 degrees. If we say go, the moon moves off to the left and comes around again ready to cross the ecliptic. However, its crossing position will be slightly to the right of where the moon intersected before. This call the regression of the moon's nodes. The node has moved to the right (west). When the moon crosses the ecliptic (the node) the next time, it will happen before it passes the position (now slightly lower) where its orbital motion ends the sidereal period. The sidereal period of the moon is 27.3 days while the nodical period of the moon, the time it takes to cross the same node twice is 1/10th of a day shorter or 27.2 days.

Please don't memorize these numbers beyond the first position to the right of the decimal.

We can now talk about an eclipse repetition cycle as can be seen in the next slide.



Our two drum beats are the synodic period, 27.5 days and the nodical period of 27.2 days. **If an eclipse occurs today, the next eclipse will happen when a whole number X, multiplied by the synodic period, equals the same number of whole**

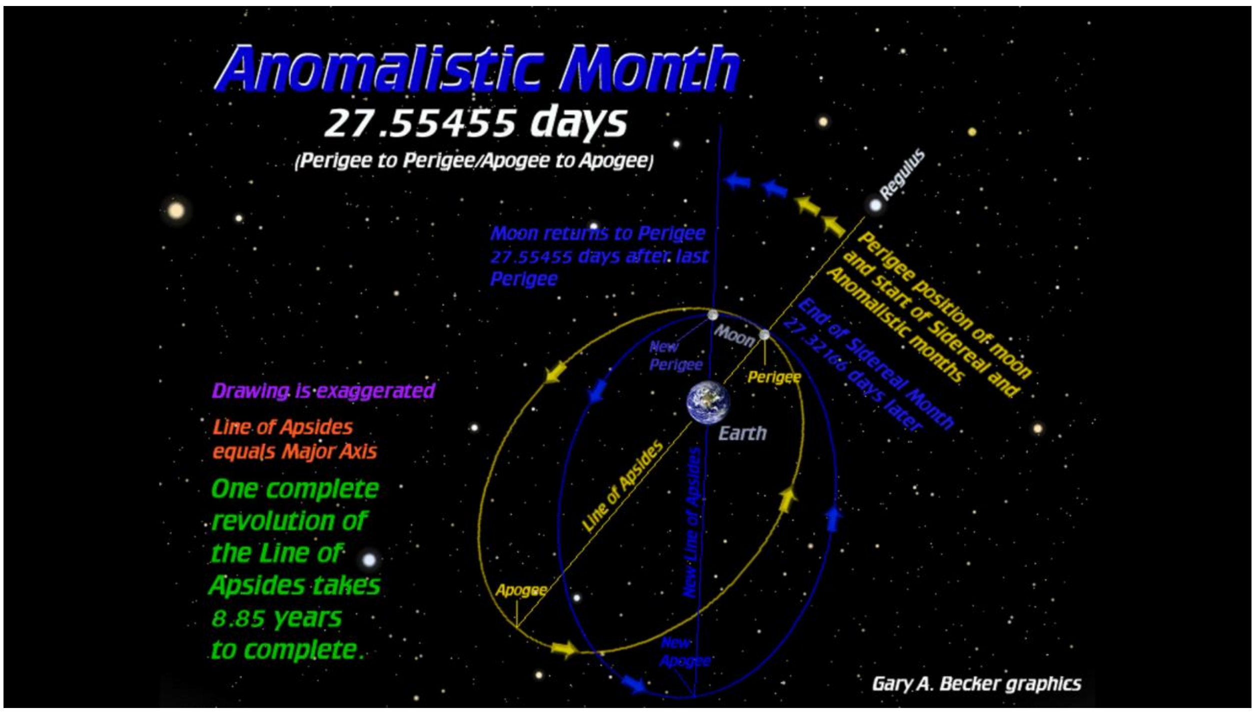
days as a different whole number Y multiplied by the nodical period. Those are our two drumbeats. When they both occur with the same number of whole days, we have an eclipse. When they become synchronized again another solar eclipse will occur. Forty-seven, 47 x 29.53059 days is equal to 51 x 27.21222 days. Both multiplications equal 1387 days.

If a solar eclipse occurs today, those two beats hit. Then in subsequent time they will start getting out of phase. However, in 47 synodic months, which is equal to the same number of whole days as 51 nodical months, the moon will return to the same phase and the moon must be at or near a node. Another eclipse of the same type must ensue. The piece of information that I will not be able to predict is whether the solar eclipse will be total, annular, or partial.

Here is the rub. Ancient cultures were not really interested in partial or annular eclipse because they were essentially invisible to them. They were not as interested in lunar eclipses either, because the moon was not as important an object as the sun. Unless the moon has covered the sun to about 99.9 percent, the dark disk of the moon will not be visible against the sun. People were interested in total solar eclipses where the sun was "swallowed" by the moon. If the sun and moon were gods who were independent from human affairs, there was no reason to suspect that the sun would ever return if a total solar eclipse occurred. I am not trying to indicate that a deep partial or annular eclipse would not make the landscape look weird—weak shadows on the ground, the sky looking grey and bluish, but that would not be close to the visually spectacular effects of the moon totally eclipsing the sun.

There's one early story of two Chinese astronomers who were unable to predict a total solar eclipse. They were beheaded for their lack of knowledge.

We want to know when the next total solar eclipse is going to occur. Those are the really important eclipses.   I still need a new moon and I will still need the moon to be positioned in its orbit at or very near a node.   In addition, because I want to predict a total solar eclipse, I need the moon to be at a similar distance from the Earth, to create the same type of eclipse (total) as the last one that was viewed.



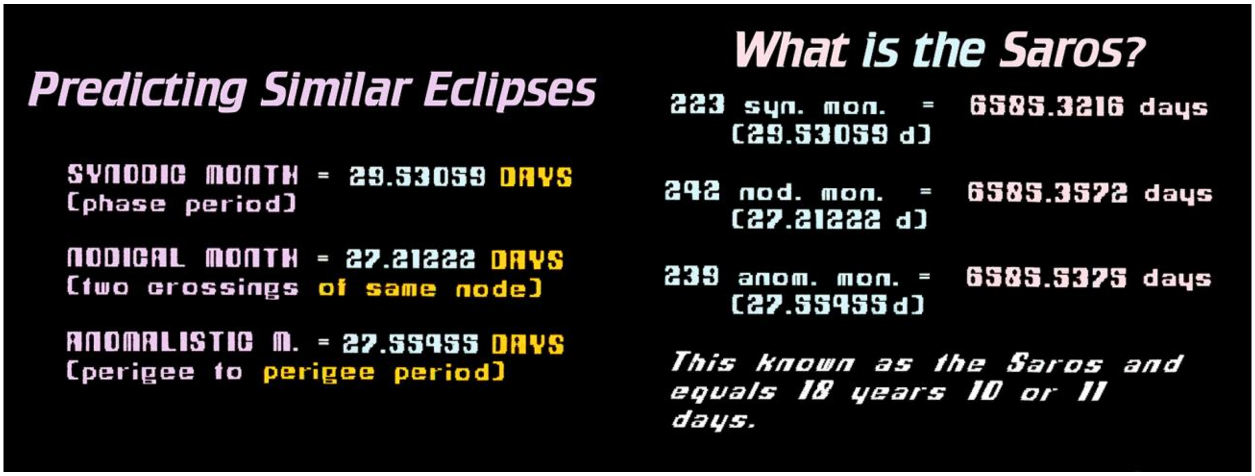
Here in this next slide we see an exaggerated view of the orbit of the moon. Its orbit is nowhere near this eccentric (oval) as the drawing. In fact, if you looked at the orbit of the moon, you would be hard pressed to tell that it was anything but a circle, especially if the Earth were covered. However, it is an ellipse and I need to express that very emphatically. Also, I don't want to be too simplistic, but on the other hand, I cannot really demonstrate this unless I greatly exaggerate what I am about to explain.

Let's start with the yellow orbit of the moon. We have the moon lined up with the star Regulus once again, but we also have the moon at perigee, its nearest position to the Earth. We want to know when the next perigee position of the moon is going to occur. I say go and everything swings into motion. The sidereal period has started, but I have also started the time period of another cycle which is called the anomalistic period—perigee to perigee, apogee to apogee. The moon starts revolving around the Earth. As it continues, I am going to change my position from the yellow orbit to the blue orbit. As the moon comes around, it is on the blue orbit. If you look closely, you can see the blue orbit is in front now of the original perigee position of the moon when it was on the yellow orbit. That is important, because when the moon passes Regulus for the second time ending the sidereal period, it has not yet reached it new perigee position. The moon is going to chug, chug along it orbit until it gets to its actual perigee location, which is the place along the line of apsides (major axis) to the left of its original position.

Here is the important part. The moon comes around, passes Regulus ending the sidereal period; but then the moon continues to chug along its orbital path until it reaches its next perigee location. The anomalistic period (perigee to perigee/apogee to apogee) is a longer interval of time than the sidereal period. The anomalistic period is 27.55455 days. Let's make it 27.6 days so that we don't go too crazy.

We have these three periods with which we have to consider. They are the synodic period of **29.5**3059 days, the nodical period of **27.2**1222 days and the anomalistic period of **27.5**5455 days. Those are the three beats that have to come together to produce a similar eclipse. When all three beats occur simultaneously, in other words, when they are multiplied by three different whole numbers to produce the same number of whole days, the moon will be new, the moon will be at or near a node, and the moon will be at a similar distance to the Earth as it was at the time of the first eclipse. Another solar eclipse must occur.

It is the same situation as the two-beat repetition of eclipses cycle, but it now involves three beats. What whole number X multiplied by the sidereal period; what whole number Y multiplied by the nodical period, and what whole number Z multiplied by the anomalistic period will result in the same number of days. The slide below shows those numbers which lead to an 18 year, 10 or 11-day period known as the saros.



Please do not memorize these numbers except to the first numeral to the right of the decimal. It is the understanding of the concept that is important.

If a total solar eclipse occurs today, I can say with confidence that in 6585 days the moon will be new, the moon will be at or near a node, and the moon will be at a similar distance in comparison to the last eclipse of that saros sequence. There must be another solar eclipse and that eclipse must be similar to the last eclipse of that saros cycle.   The length of that period is 18 years 10 or 11 days. Actually, it is 18 years, 9, 10, 11, or 12 days depending upon the number of leap year days that occur within that 18-year time span. You will have to know 18 years 10 or 11 days, but the 9 and 12 almost never occur.

All these eclipses which are similar (related) to each other, create a unique saros cycle which can last about 1200 years.

I need to step back and regale you with another piece of eclipse information. If a total solar eclipse occurs today, will the very next total solar eclipse happen in 18 years 10 or 11 days? The answer is no. There are well over two hundred saros cycles running simultaneously which gives someone who is interested in observing eclipses multiple opportunities to view solar and lunar eclipses each year if that person is willing to travel.

Because there are two nodes, a descending node where the moon is traveling from above the ecliptic to below the ecliptic, and an ascending node where the moon is moving from below the ecliptic to above the ecliptic, there must be at least two solar eclipses and two lunar eclipses occurring each year. However, there can be as many as seven eclipses, solar plus lunar, occurring in a year's time. There could be two lunar and three solar; five lunar and two solar; three lunar and three solar, etc. There must always be two lunar and two solar eclipses in a year's time, but there can be as many as five of one type of eclipse, seven eclipses total, during the course of a year

Below, I am showing you one complete saros cycle, a unique sequence of eclipses from the first partial eclipses that occurred at the South Pole to the last partial solar eclipse that will be occurring at the North Pole. Study it for a moment with respect to the evolution of the different types of eclipses that occur.

A Complete Saros Cycle

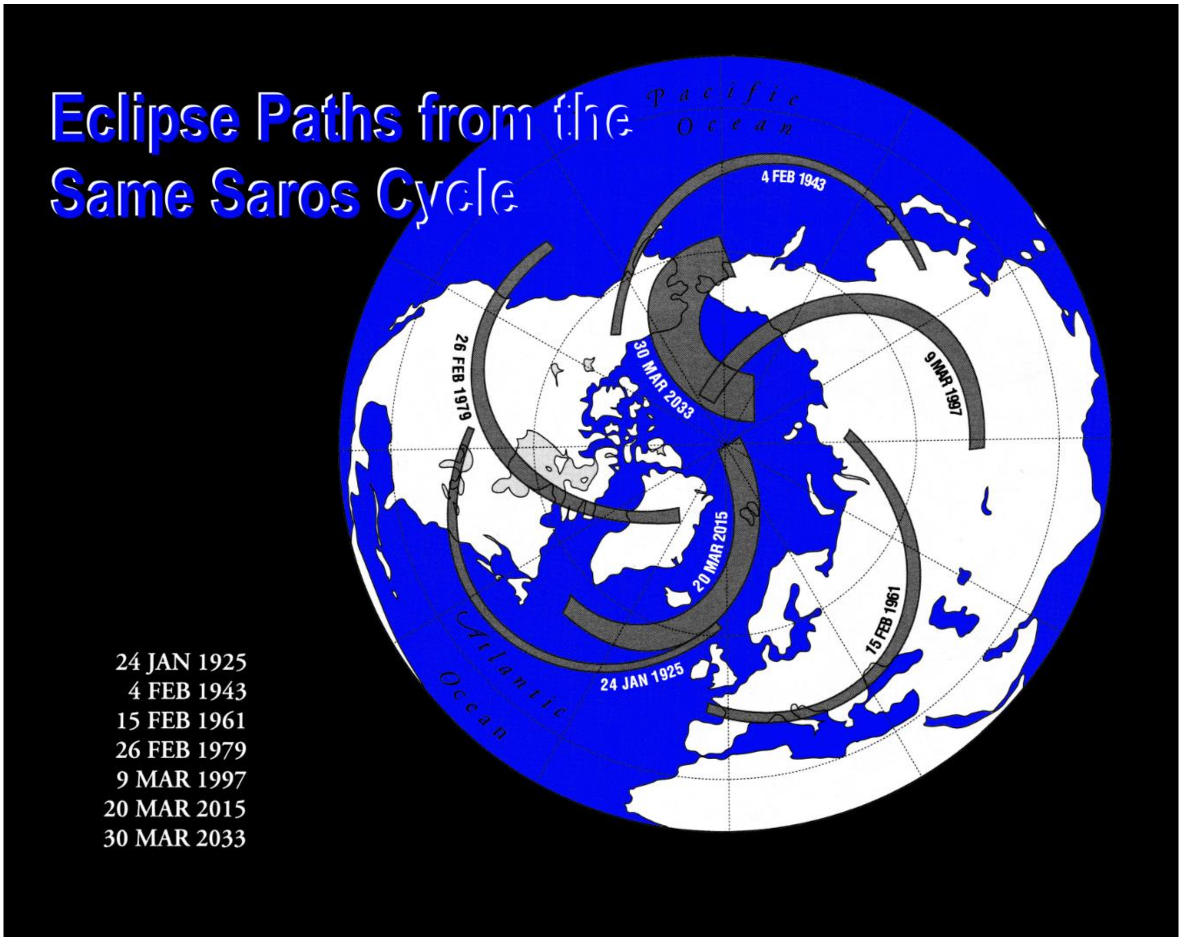
Date	Type	Date	Type
933 May 27	Partial	1582 June 20	Total
951 June 7	Partial	*1600 July 10	Total
969 June 17	Partial	1618 July 21	Total
987 June 28	Partial	1636 Aug. 1	Total
1005 July 9	Partial	1654 Aug. 12	Total
1023 July 20	Partial	1672 Aug. 22	Total
1041 July 30	Partial	1690 Sep. 3	Total
1059 Aug. 11	Annular	1708 Sep. 14	Total
1077 Aug. 21	Annular	1726 Sep. 25	Total
1095 Sep. 1	Annular	1744 Oct. 6	Total
1113 Sep. 11	Annular	1762 Oct. 17	Total
1131 Sep. 23	Annular	1780 Oct. 27	Total
1149 Oct. 3	Annular	1798 Nov. 8	Total
1167 Oct. 14	Annular	1816 Nov. 19	Total
1185 Oct. 25	Annular	1834 Nov. 30	Total
1203 Nov. 5	Annular	1852 Dec. 11	Total
1221 Nov. 15	Annular	1870 Dec. 22	Total
1239 Nov. 27	Annular	1889 Jan. 1	Total
1257 Dec. 7	Annular	1907 Jan. 14	Total
1275 Dec. 18	Annular	1925 Jan. 24	Total
1293 Dec. 29	Annular	1943 Feb. 2	Total
1312 Jan. 9	Annular	1961 Feb. 15	Total
1330 Jan. 19	Annular	1979 Feb. 26	Total
1348 Jan. 31	Annular	1997 Mar. 9	Total
1366 Feb. 10	Annular	2015 Mar. 20	Total
1384 Feb. 21	Annular	2033 Mar. 30	Total
1402 Mar. 4	Annular	2051 Apr. 11	Partial
1420 Mar. 14	Annular	2069 Apr. 21	Partial
1438 Mar. 25	Annular	2087 May 2	Partial
1456 Apr. 4	Annular	2105 May 14	Partial
1474 Apr. 16	Annular	2123 May 25	Partial
1492 Apr. 26	Annular	2141 June 4	Partial
1510 May 8	Annular-total	2159 June 16	Partial
1528 May 18	Annular-total	2177 June 26	Partial
1546 May 29	Annular-total	2195 July 7	Partial
1564 June 8	Total		

*Begin dates from Gregorian calendar

Why do the eclipses change their types when a saros cycle is supposed to predict similar eclipses? It is because each of these beats has a fraction included with that same number of whole days which gradually causes the saros cycle to become more in step and then to lose its synchronization which allows eclipses to be seen from the Earth.

Eclipse after eclipse in the same saros cycle is not quite the same. The synodic beat decimal of 0.3216 day indicates that the next eclipse in the sequence will be happening about 1/3 of a day later. This mean the path of totality will be about 8000 miles to the west of the previous total solar eclipse. If an eclipse is visible in Africa, the next eclipse of that same saros cycle, 18 years, 10 or 11 days later will occur over the Pacific Ocean.

Since the main beat for eclipses is the synodic period the difference in the decimal remainders between the synodic/nodical and the synodic/anomalistic periods show that the position of the moon's position with respect to the node and the distance of the moon from the Earth will also be changing slowly over time. A saros cycle starts coming into synch at either the north or south poles at the beginning of a cycle, improves with time to produce a long series of total solar eclipses, then gradually become out of phase to produce a series of partial solar eclipses at the opposite pole of the Earth.



This slide highlights a few of the paths of totality from the same saros cycle that you just viewed. We are looking at the eclipses of 1925, 1943, 1961, 1979, 1997, 2015, and 2033. The moon's shadow runs west to east across the surface of the Earth if you want to follow the paths in their correct directions. However, what I really want you to notice is how the paths of totality are winding their way up towards the North Pole as this saros cycle nears its end.

My father saw the January 24, 1925 total solar eclipse as a very deep partial eclipse from Allentown. It was 98 percent total. My grandfather took a barrel and filled it up with water. Then he took a piece of glass and smoked it with a candle. They held the glass in front of their eyes looking at the reflection of the sun in the water. This occurred when my dad was nearly six years old. My father remembered this eclipse quite vividly which may have influenced his desire to become a science/mathematics teacher in the public schools. Pretty cool regarding my grandfather's ability to create a safe view of this eclipse, however, never use a smoked glass to view directly the partial stages of a solar eclipse. That is still dangerous. This eclipse was total in Scranton, PA and went across Manhattan in New York City. Manhattan island, as you may well know runs north-south. The eclipse path was almost exactly west-east. In Manhattan, volunteers were stationed on the rooftops of buildings to determine the exact location where the eclipse became total. In other words, these people were trying to determine the southern limit of the eclipse. It turned out that the eclipse became total north of 86th Street and was partial south of that location. This eclipse became known as the 86th Street Eclipse.

Another interesting factoid about this eclipse was that the it occurred on a Saturday. The NYC Transit Authority did not take into consideration that there might be many interested folks wanting to go uptown that day to see the eclipse. The subways were on a light Saturday schedule, and there were literally tens of thousands of people caught below street level waiting for a subway train to transport them north, up town.

Look at the March 20, 2015 path of totality. Can you see it ends just at the North Pole? March 20 is the vernal equinox. On the first day of spring the sun is just rising at the North Pole. I will have a question for you about this eclipse, dealing with Santa and how his toy production was affected.

You can see how this saros cycle is winding up towards the North Pole by just looking at the 1925 path of totality and the path of the moon's shadow in 2033. After 2033 the eclipses become partial and after 2195, even the penumbras will not touch the North Pole any more, thus ending this particular saros cycle as viewed from the Earth.

There has been no total solar eclipse that has gone through Allentown, Pennsylvania, or the Lehigh Valley for several hundred years. The next total solar eclipse that the Lehigh Valley gets to experience occurs on May 1, 2079.

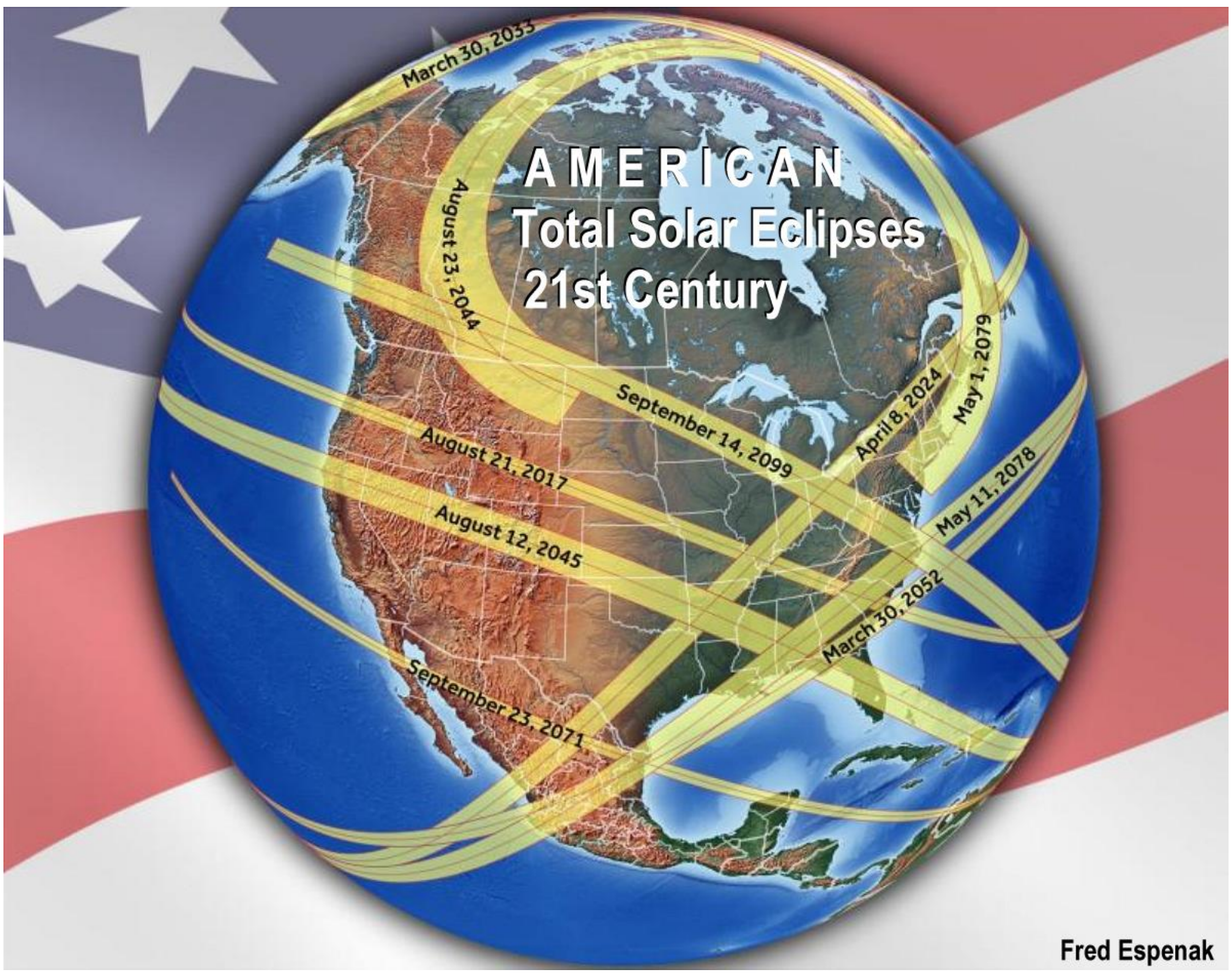
If you never plan to travel to see a total solar eclipse, chances are a total solar eclipse will not pass over the place where you are living.

Frequecy of Total Solar Eclipses at One Location

Location	Dates of Consecutive Total Eclipses	Years in Interval
London	Oct. 29, 878 A.D. — Apr. 22, 1715 A.D.	837
Jerusalem	Sep. 30, 1131 B.C. — July 4, 336 B.C.	795
Great Pyramid of Egypt	Apr. 1, 2471 B.C. — June 29, 2159 B.C.	312
Stonehenge	May 8, 1169 B.C. — May 7, 1066 B.C.	103
Yellowstone National Park	July 29, 1878 A.D. — Jan. 1, 1889 A.D.	11
Tomb of Tutankhamun	May 31, 957 B.C. — May 22, 948 B.C.	9
Lake Okechobee, Florida	Aug. 19, 2259 A.D. — Dec. 22, 2261 A.D.	2½
Southern New Guinea	June 11, 1983 A.D. — Nov. 22, 1984 A.D.	1½

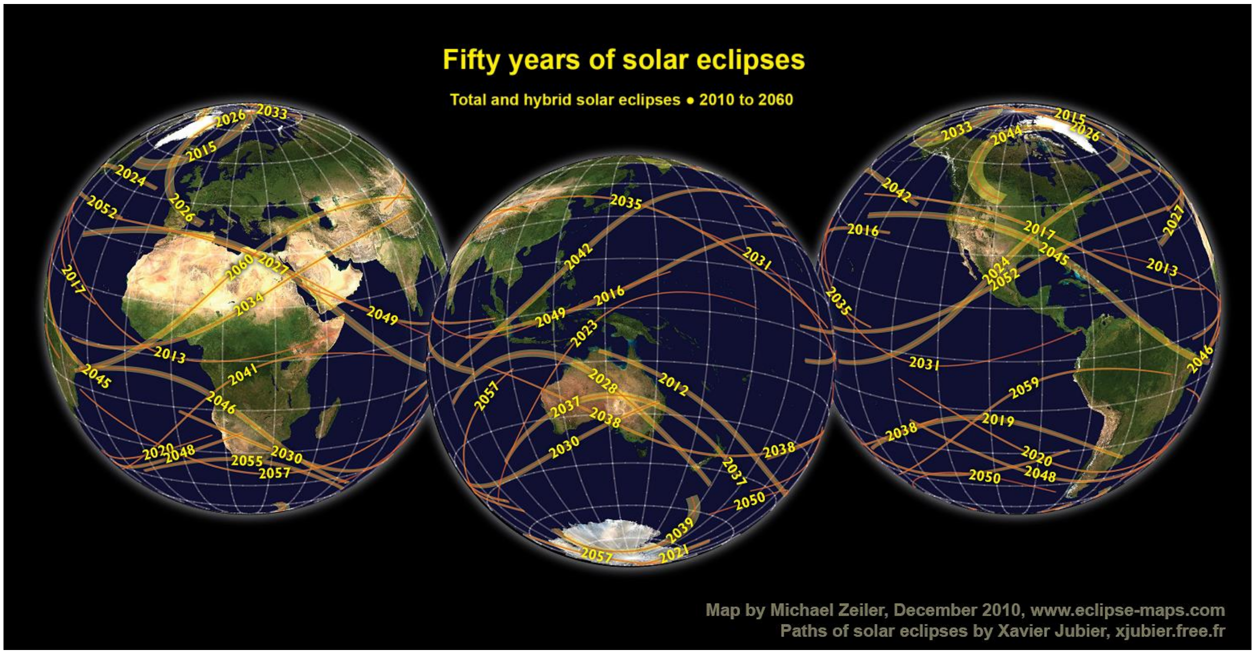
Bryan Brewer, Eclipse, 1979

In this slide we can see the intervals between total solar eclipses at specific locations. Keep in mind that the path of totality is relatively narrow, less than 100 miles wide on average. Notice London, England. That's a pretty good swath of time between two total solar eclipses, 878 AD to 1715 AD. However, you do not have to wonder why the "natives" in Southern New Guinea which is north of Australia, might have become a little restless. Only a year and a half went by between two total solar eclipses in that location. More likely your location is going to be similar to the 312-year or the 103-year interval between total solar eclipses.



The kids who are growing up in Carbondale, Illinois will think that eclipses are incredibly frequent, because an eclipse occurred there on August 21, 2017, and another total solar eclipse will happen on April 8, 2024. The 2024 eclipse is why I am hyping eclipses because that one is almost upon our doorstep. This is the one that you should be trying to see because it goes through Erie, PA; Cleveland, Ohio; and Carbondale, Illinois all within one day's travel. The path of totality also passes through Dallas-Ft. Worth, Texas. You can drive to warmer Texas in about two days of hard driving. This is where I hope to be. Erie and Cleveland are a very cold in April because of their nearness to the Great Lakes—lots of chilly breezes. After 2024, the US mainland will have to wait until the mid-2040s before witnessing another total solar eclipse. I guarantee that you will never regret seeing a total solar eclipse. In fact, most people who take the opportunity to see one, want to see more.

If you want to travel the world through 2060 to see a total solar eclipse, study this map below.



Look towards Australia for lots of eclipse fun. The 2023 total eclipse is really interesting. It is a very short, and it just clips the end of the very western tip of the state of Western Australia. But look at all of the others. It would be a great excuse to visit one of the friendliest places in the world. You may not want to leave. Just remember the season are reversed. However, since the paths of these eclipses all occur in the Southern Hemisphere they will happen during Australia's summertime.

Note the thickness of the path of totality of the August 21, 2017 eclipse. It was thin indicating that the duration of totality was short. I saw that eclipse in Guernsey State Park in SE Wyoming. Its duration was 2 minutes, 22 seconds where I observed it. Note the thicker path of totality for the April 8, 2024 total solar eclipse. The duration of totality during that eclipse will be just over four minutes in central Texas where I hope to see it. In equatorial regions and midlatitude locales, the duration of totality can be inferred by the thickness of the path of totality.

We'll talk more about those eclipses next time we meet.

March 10, 2021
March 9, 2021
March 8 2021
March 7, 2021
August 23, 2021