Solar eclipses: Why they happen when they do

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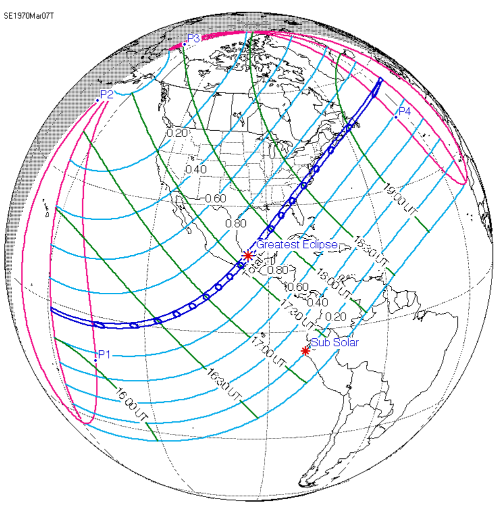
University of Rochester

March 22, 2024

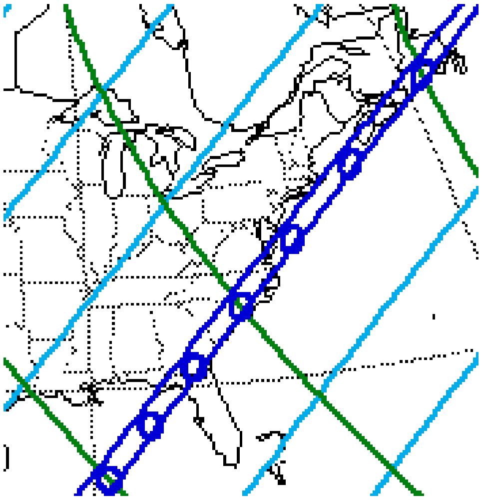
1 My first total solar eclipse

My first total solar eclipse



March 7, 1970

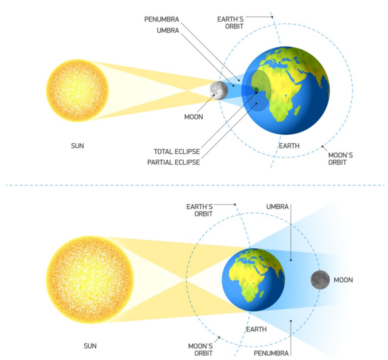
My first total solar eclipse (continued)



March 7, 1970

2 Basic facts about eclipses

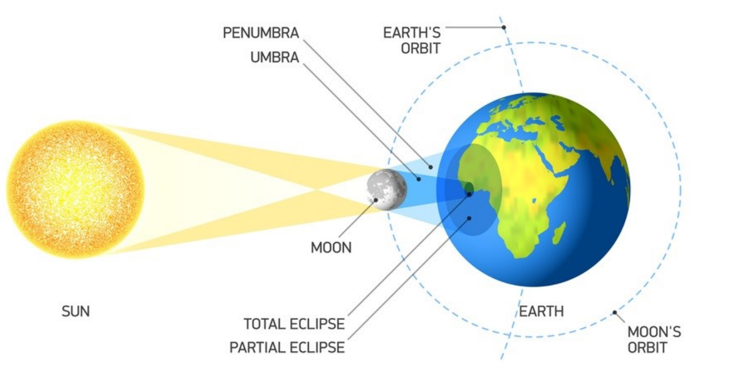
Basic facts about eclipses



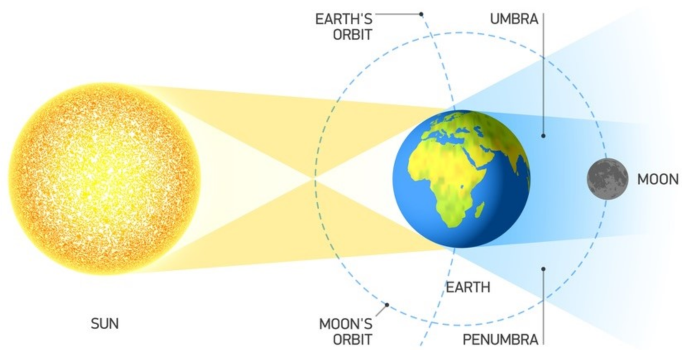
A solar eclipse occurs when the shadow of the moon falls on the earth. It can be up to 250 miles wide and moves eastward (relative to the surface of the eastwardly rotating earth) at varying speeds over 1000 MPH.

A lunar eclipse occurs when the moon passes through the earth's shadow, moving at roughly 2300 MPH.

Basic facts about eclipses (continued)



Basic facts about eclipses (continued)



Basic facts about eclipses (continued)


The eclipse of March 8-9, 2016 seen from space. The moon's shadow is over Indonesia.

More basic facts about eclipses

The diameter of the moon is 2,159 miles (3,474 km). The diameter of the sun is 864,938 miles (1.392 million km), about 400 times that of the moon.

The Moon is on average of 238,855 miles (384,400 km) away from Earth. The average distance between Earth and the Sun is about 93 million miles (150 million km) about 400 times that to the moon.

Why are these two ratios the same? Lucky coincidence!

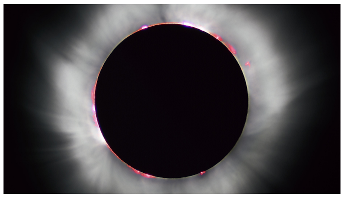
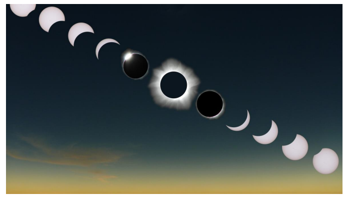
No other moon in the solar system has this property.

More basic facts about eclipses (continued)

The sun is both 400 times as wide and 400 times as far away as the moon. This means they appear to be the same size in the sky.

The diameter of each is about .9 percent of its distance. That makes its angular diameter about half a degree, or 30 minutes of arc, written as 30'.

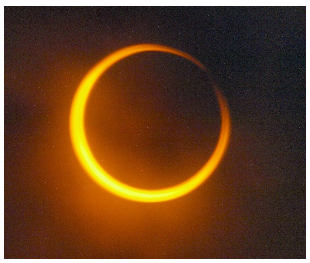
This means that when the moon passes directly in front of the sun, it is just big enough to cover it, but not big enough to cover the snowy corona around it.

More basic facts about eclipses (continued)

The distance to the moon varies from 225,700 miles (perigee) to 251,900 miles (apogee). This means its angular diameter varies by about 10 percent. If it passes in front of the sun when it is too far away, it is not big enough to cover the sun completely.

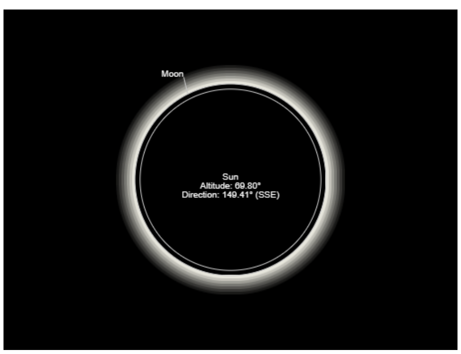
This results in an annular eclipse. The sun is still shining and too bright to look at even when the moon is dead center. You could miss it completely!



There was one in Rochester on May 10, 1994. We are lucky to live in a place with two solar eclipses in just 30 years! The image to the left was photographed through a filter.

More basic facts about eclipsesQ (continued)

On the other hand, if the moon is closer than average, it will appear to be slightly larger than the sun. This means that totality will last a little longer. This will be the case on April 8.



https://www.timeanddate.com/eclipse/solar/2024-april-8

3 Sidebar: Living on the moon

Sidebar: Living on the moon

Sidebar: Living on the moon (continued)

The earth would always be in the same spot in the sky. This is because the rotation of the moon is locked in by gravity to its orbital motion about the earth. The same side of it is always facing us. This is not a coincidence.

The earth would appear to be four times larger than the moon appears to be from earth, because it is! Its angular diameter would be 2 degrees instead of the moon and sun's half a degree as seen from earth. The sun's angular diameter would be the same as it is on earth.

The earth would never move but you could see it rotate once every 24 hours. (Seen from earth, the moon moves but does rotate.) The earth would have phases (new earth, full earth, crescent earth, etc) just like the moon does on earth. The sun would rise and set once a month.

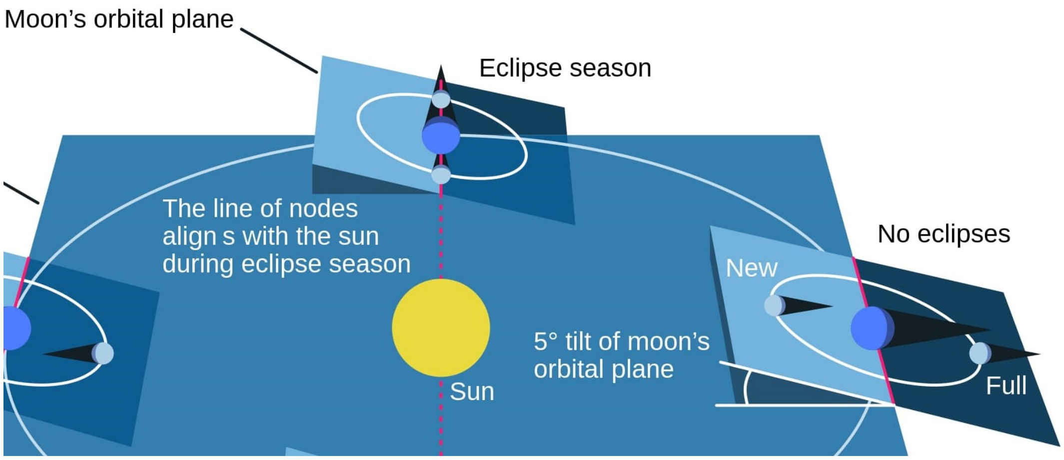
Sidebar: Living on the moon (continued)

Sometimes (when there is a lunar eclipse on earth) the sun would be eclipsed by the earth. Totality would last much longer (up to 4 hours) than a solar eclipse on earth, but you would only see a small portion of the corona and only at the start and end of totality. A solar eclipse on the moon would not be as cool as a solar eclipse on earth.

https://en.wikipedia.org/wiki/Solar_eclipses_on_the_Moon

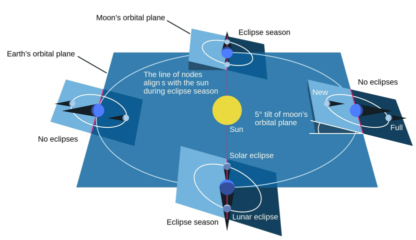
4 Why isn't there an eclipse every month?

Why isn't there an eclipse every month?



Back to eclipses on earth. The plane of the moon's orbit is inclined from that of the earth's orbit by 5.145 degrees. Usually the moon passes north or south of the sun at new moon, and north or south of earth's shadow at full moon. The points where the moon crosses the earth's orbital plane are the ascending node and descending node . Each red line in the picture is the line of nodes.

Why isn't there an eclipse every month? (continued)



Each red line in the picture is the line of nodes. Eclipses can occur only during the time of year when it is pointing toward the sun (within a few degrees), known as eclipse season. It occurs roughly twice each calendar year.

Meanwhile the line of nodes itself rotates clockwise roughly every 18.60 years. This means the time of the eclipse season changes gradually. It is April/October now but was August/February in 2017.

5 The Saros series

The Saros series

Over 2000 years ago Babylonian astronomers noticed that eclipses (both lunar and solar) occur in cycles of roughly 18 years. A Saros series is sequence of such related eclipses.

One Saros period (or one saros) is 6,585.321347 days, which is 18 years plus 10, 11 or 12 calendar days, depending on whether there are 5, 4 or 3 (!) leap years in the 18 year interval in question. Note that 18×365 days $= 6570$ days, 15.3 days short of a saros. The fraction of a day means that the next solar eclipse in a saros series is 8 times zones farther west.

A solar/lunar eclipse is almost always followed by a lunar/solar eclipse half a saros or sar (roughly 9 years) later.

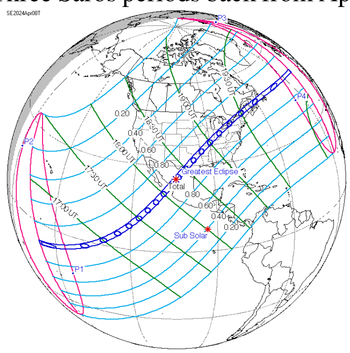
I will explain later why this happens. First we will look at three examples of solar eclipses in the same Saros series.

6 Examples of Saros series

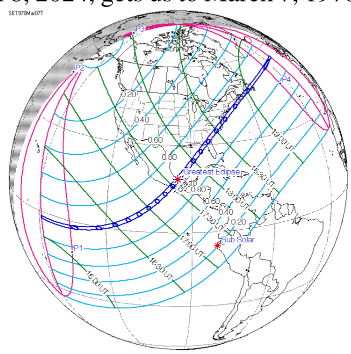
6.1 Example 1: Saros series 139

Example 1: Saros series 139

Three Saros periods back from April 8, 2024, gets us to March 7, 1970, the day of my first eclipse.



April 8, 2024

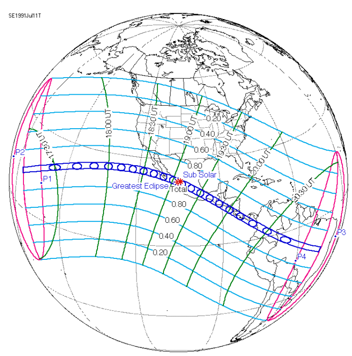


March 7, 1970

A nice thing about this Saros series is that the eclipses in it are getting longer. The one next month will last longer than the one I saw 54 years ago. The length of totality will peak in 2186 (9 cycles away) at 7 minutes 29 seconds, making it the longest one in 10,000 years!

6.2 Example 2: Saros series 136

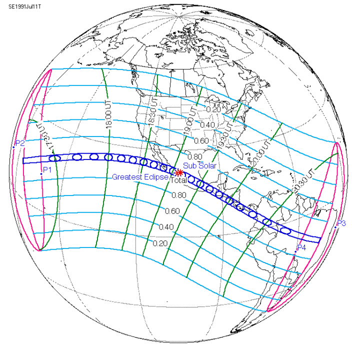
Example 2: Saros series 136



July 11, 1991

In 1991 there was a solar eclipse visible in Hawaii and Mexico. The Keck observatory atop Mauna Kea on the big island was in its path, and skies were clear there but some beaches on the island were clouded out.

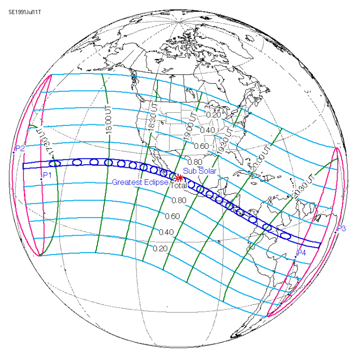
Example 2: Saros series 136 (continued)



July 11, 1991

There was an algebraic topology conference in Mexico organized around the eclipse at a site south of Mexico City. We had clear skies, after several days of clouds.

Example 2: Saros series 136 (continued)



July 11, 1991

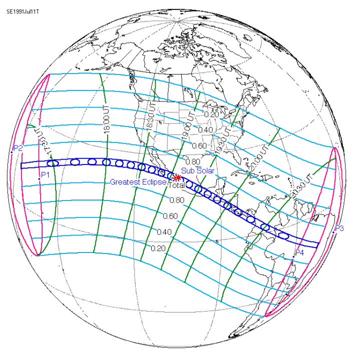
Teotihuacan is a spectacular archeaological site north of Mexico City. Ten thousand people gathered there to watch the eclipse.

Example 2: Saros series 136 (continued)

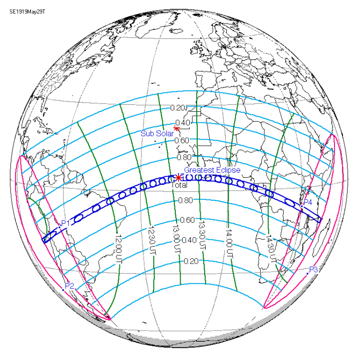



Those ten thousand tourists were not only clouded out, the eclipse made it rain on them! Totality causes a small temperature drop.

Example 2: Saros series 136 (continued)



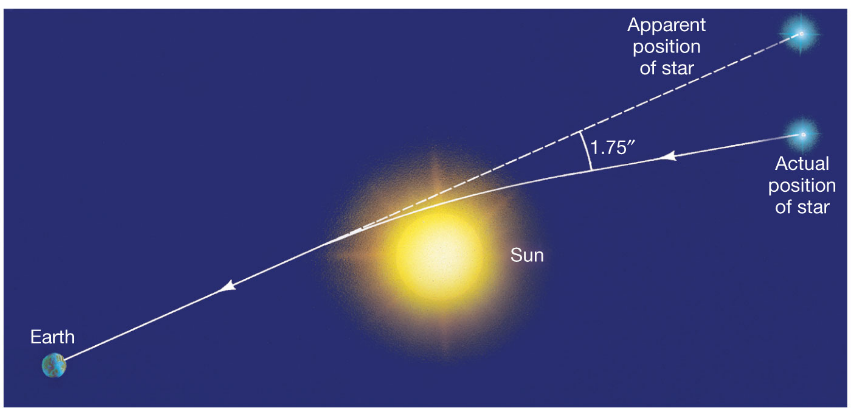
July 11, 1991



May 29, 1919

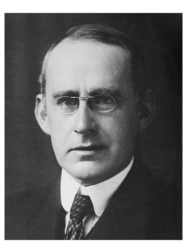
Four saros periods back from the 1991 eclipse gets us to May 29, 1919, the day of the Eddington-Einstein eclipse, possibly the most famous one in the history of science.

Example 2: Saros series 136 (continued)

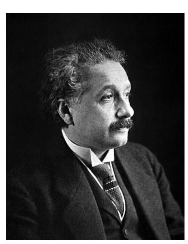


In his 1915 paper on general relativity, Einstein predicted that light from a distant star passing very near the sun would be bent by the sun's gravity. This change in direction would be very small, only 1.75 seconds or arc, or .000486 degrees. It would lead to an apparent change in the star's position. Because of the sun's brightness, this change could only be observed during a total solar eclipse.

Example 2: Saros series 136 (continued)



Arthur Eddington
1882-1944



Albert Einstein
1879-1955

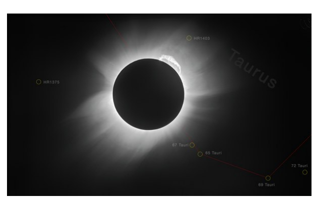
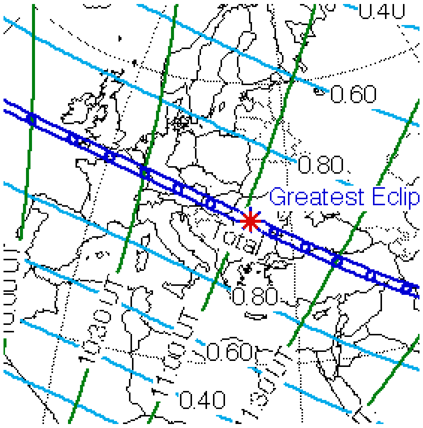


Photo by Eddington

The British physicist Arthur Eddington used the 1919 eclipse to make such an observation from the island of Principé off the west coast of Africa. Just six months after the end of World War I, a British scientist travelled to the ends of the earth to confirm the theory of a German one. The measurement was as Einstein had predicted. The ensuing headlines made him the most famous scientist in the world.

6.3 Example 3: Saros series 145

Example 3: Saros series 145



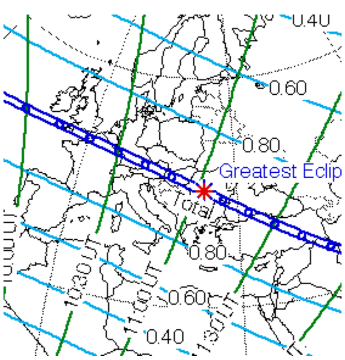
August 11, 1999

In 1999 there was an eclipse visible across Europe. I was hoping for a conference organized around it like the one in 1991. It did not happen, which was just as well. Most of western Europe was cloudy that day.

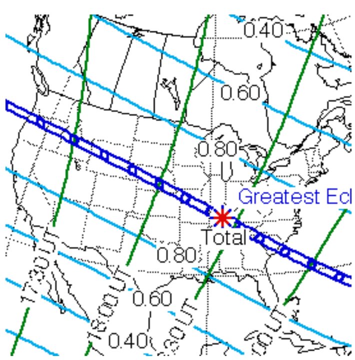
Example 3: Saros series 145 (continued)

Most of western Europe was cloudy that day. One exception was Bucharest, where the skies were clear.

Example 3: Saros series 145 (continued)



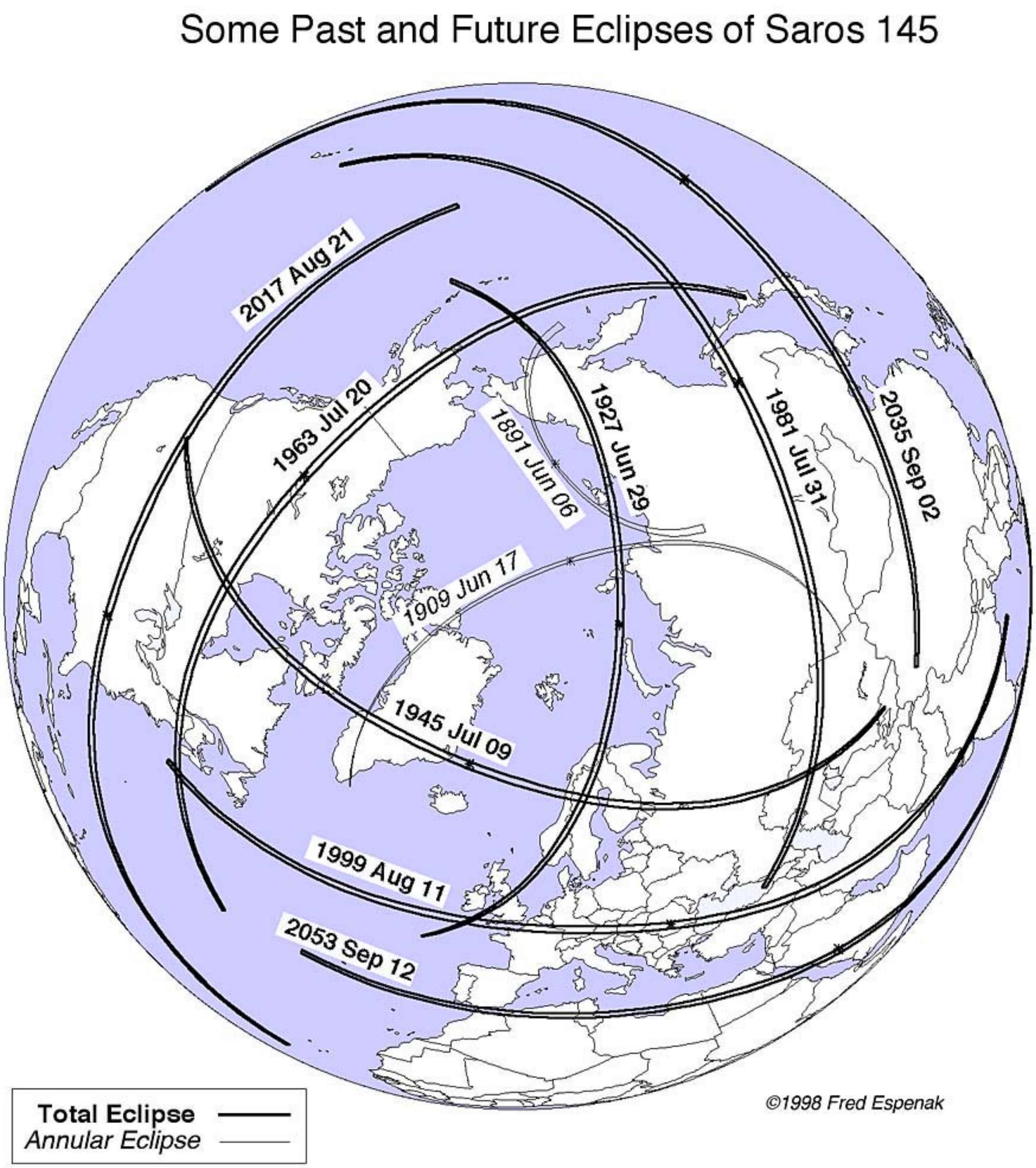
August 11, 1999



August 21, 2017

The next eclipse in the series was visible across the United States from Oregon to South Carolina. There was an another algebraic topology conference organized around it in Portland, and skies were clear.

Example 3: Saros series 145 (continued)



Courtesy of "Totality - Eclipses of the Sun" by Littmann, Willcox and Espenak

7 Why the Saros cycle?

Why the Saros cycle?

To understand the Saros cycle we need to know more about how the moon moves. There are four types of month we need to consider:

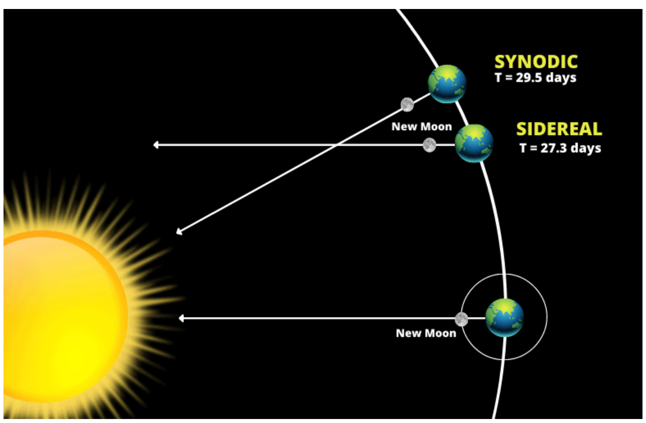
1. A sidereal month (27.32166 days or 27 days, 7 hours, 43 minutes, 11.6 seconds) is the time the moon takes to make one complete turn around the earth.

2. A synodic month (29.53059 days or 29 days, 12 hours, 44 minutes, 2.8 seconds) is the interval between two new (or full) moons.

WHY ARE THEY DIFFERENT?

Why the Saros cycle? (continued)

1. A sidereal month (27.32166 days or 27 days, 7 hours, 43 minutes, 11.6 seconds) is the time the moon takes to make one complete turn around the earth.
2. A synodic month (29.53059 days or 29 days, 12 hours, 44 minutes, 2.8 seconds) is the interval between two new (or full) moons.



One sidereal month after a new moon, the moon is not yet new again because the earth has advanced in its orbit around the sun. It needs 2 more days to reach the new earth-sun line.

Why the Saros cycle? (continued)

Four types of month:

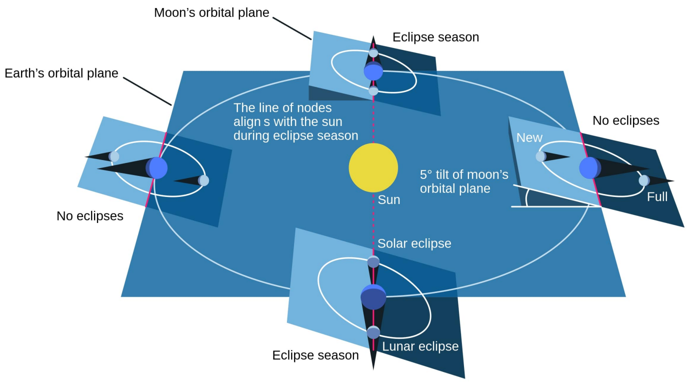
1. A sidereal month (27.32166 days) is the time the moon goes around the earth once in the stellar frame of reference.

3. A draconic month (27.21222 days) is the time between ascending (or descending) nodes, the point where the moon crosses the earth's orbital plane moving north (or south).

The draconic month is roughly 2.6 hours shorter than the sidereal month because the line of nodes is rotating slowly westward (clockwise), making a complete turn every 18.60 years. This motion is called nodal precession. It is a 3 body effect, caused by the sun's gravitational pull on the moon's orbit. The math here is very subtle.

Why the Saros cycle? (continued)

The draconic month is roughly 2.6 hours shorter than the sidereal month because the line perpendicular to the plane of the moon's orbit (and with it the line of nodes) is rotating clockwise roughly every 18.6 years.



Why the Saros cycle? (continued)

Four types of month:

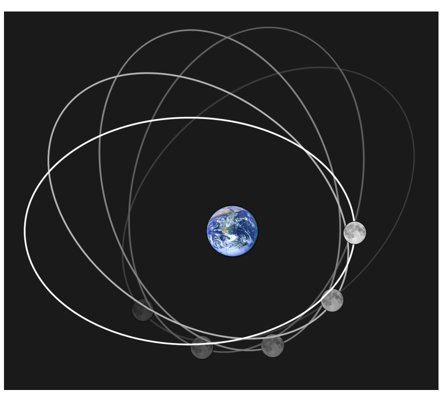
1. A sidereal month (27.32166 days) is the time the moon goes around the earth once in the stellar frame of reference.

4. An anomalistic month (27.55455 days) is the interval between two perigees, the times when the moon is closest to the earth.

The anomalistic month is roughly 5.6 hours longer than the sidereal month because the perigee/apogee line, called the line of apsides, is rotating slowly eastward (counterclockwise), making one turn roughly every 8.85 years. This is also a 3 body effect.

Why the Saros cycle? (continued)

4. An anomalistic month (27.55455 days) is the interval between two perigees, the times when the moon is closest to the earth.



The rotation is called apsidal precession.

Why the Saros cycle? (continued)

To summarize,

1. A sidereal month (27.32166 days) is the time the moon goes around the earth once in the stellar frame of reference.

2. A synodical month (29.53059 days) is the interval between two new (or full) moons.

3. A draconic month (27.21222 days) is the time between ascending (descending) nodes, the point where the moon crosses the earth's orbital plane moving north (south).

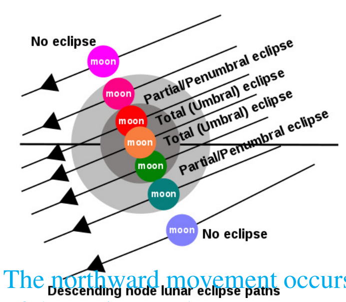
4. An anomalistic month (27.55455 days) is the interval between two perigees, the times when the moon is closest to the earth.

Why the Saros cycle? The punch line!

The saros period, 6,585.321347 days, which is 18 years plus 10, 11 or 12 calendar days, is precisely 223 synodic months, which is 241.999 (called this number δ) draconic months and 238.992 (call this number α) anomalistic months.

Why 223? It is the smallest number of synodic months that is this close to whole multiples of both the draconic and anomalistic months. This means that one saros period after an eclipse (either solar or lunar), the geometry of the earth-moon-sun system in nearly identical, leading to a nearly identical eclipse. The fact that α and δ are not exactly whole numbers means that this geometry varies slightly from one eclipse to the next in the series.

Why the Saros cycle? (continued)



In a series of lunar eclipses where the moon is near , the first one (which is only partial) occurs when the moon as passed and crosses the southern edge of the earth's shadow. The Moon's path is shifted slighly northward after each successive saros.

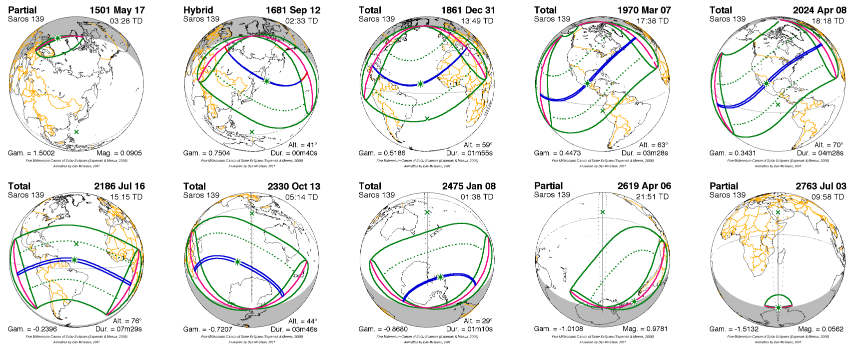
The northward movement occurs because each saros is slightly less (241.999) than a whole number of draconic months.

Conversely in the first solar eclipse of a Saros series near (such as the one for the coming eclipse), the shadow of the moon grazes the north limb (or edge) of the earth. It is shifted southward with each successive saros. Eventually it crosses the equator and then moves beyond the south limb of the earth to end the series.

A typical Saros series has 71 eclipses and lasts 1262 years.

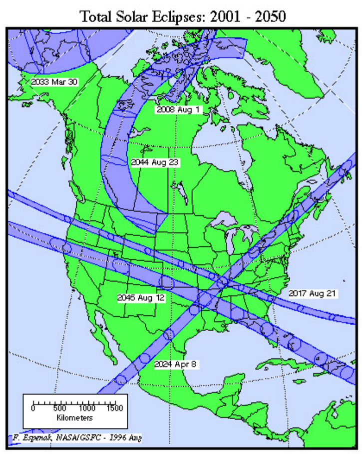
Why the Saros cycle? (continued)

Here are some eclipses in Saros series 139, which includes the ones of 1970 and 2024. It started in 1501 and will end in 2763.



8 Future eclipses

Future eclipses



The eclipses of 2024, 2045 and 2017 are in the same Saros series as those of 1970, 1991 and 1999 respectively.

9 The planets on April 8

What we might see on April 8

Planets and the comet during the coming eclipse. THINK BLUE SKIES!

THANK YOU!